Blenbridge 1.15 Documentation

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Introduction

Here is an application that makes it possible to assemble a hexahedral 3D mesh in Blender, then turn it into a real finite element mesh for use in IA-FEMesh, Elmer, Calculix, or others. This is possible because Blender is tolerant of non-manifold meshes, and because its .ply export script respects quadrilaterals. Like other apps dealing with 3D matter, Blenbridge appreciates clean input:

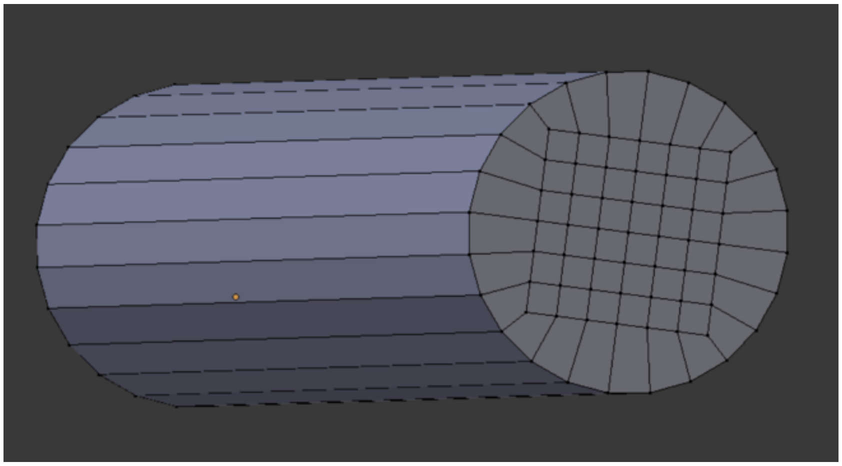
- no overlapping faces
- no errant vertices
- no unincorporated edges

In medium to large mesh models, the conversion time required can be a problem.

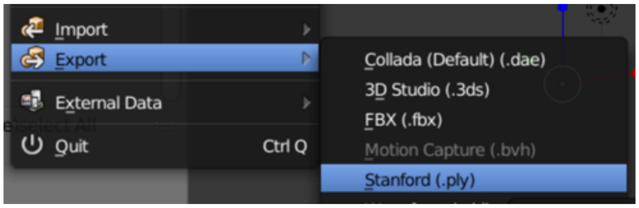
What follows is a loose description to familiarize the reader. The apps included in the basic tool chain include Blender 2.78a, Paraview 4.0.1, Gmsh 2.16, and IA-FEMesh 1.0. Blenbridge was written, compiled, and built in Lazarus 1.2.4 and 1.6.

Demo 1

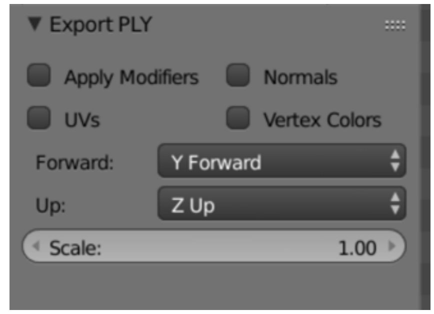
Below is shown the demo1 object as it looks when loaded into Blender. It consists of a mesh prism, constructed by hand from grid and circle.

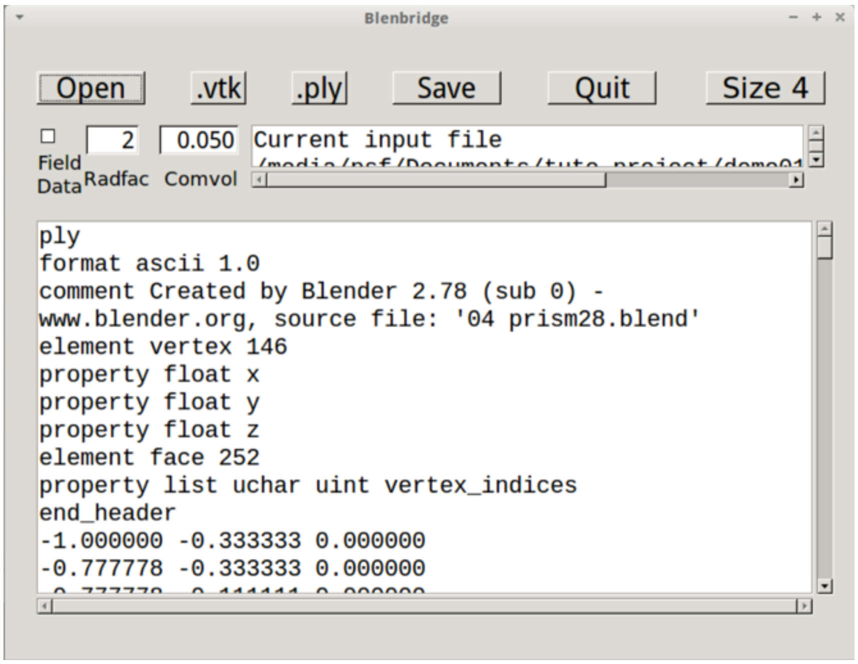


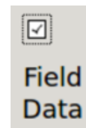
Right: the export menu in Blender. Stanford .ply is one of the standard export formats, and has the advantage that the numbering of the vertices matches the vtk system: both are zero-based.

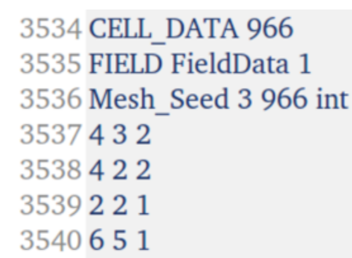


The options dialog for .ply export is shown on the right. All options are to be unchecked. The axis orientation is kept at default values so that the z-axis points up.







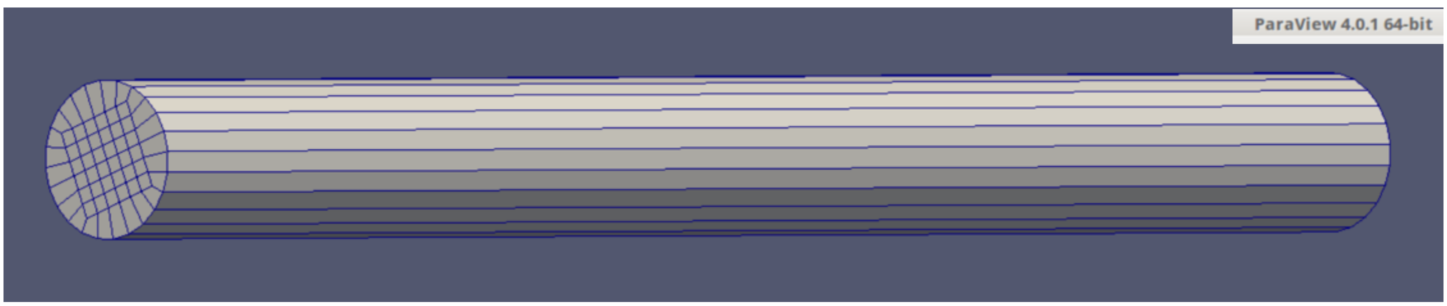


Above: the demo1 .ply file from Blender is loaded into Blenbridge and processed. The result file is given a .vtk extension (which must be added by hand) and saved. The flavor of Vtk that is produced is 'legacy'.

Note: The 'CELL DATA' block seen in the output file above is a Vtk field used by IA-FEMesh. Its presence does not bother either Paraview or Gmsh. However, if it is desired to import the .vtk file into Febio Preview, the Cell Data block must be removed first. (If the ‘Field Data’ checkbox remains unchecked, Blenbridge will finish slightly sooner.)

The conversion process consists basically of two steps: first, run Blenbridge on the desired file until no error messages appear, and second, open the resulting .vtk in Paraview until all the connected geometry is present.

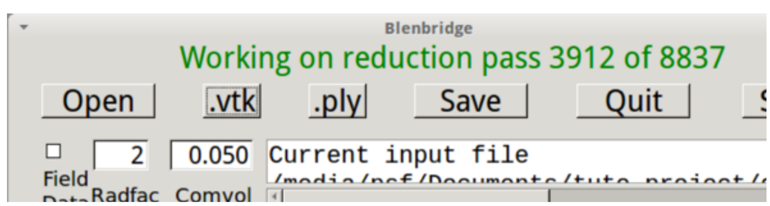
About ‘Radfac’. Blenbridge attempts to build a hexahedral element from each face in the model. To do this, it sequentially looks at small subsets consisting of possible connecting faces. The variable Radfac, or ‘radial factor’, determines the size of the working subset of faces, and is multiplied times the separation distance between centroids of candidate faces to decide whether to include them in the current search. The default Radfac value is 2, and is effective on well-proportioned geometry, (and on some not so well-proportioned). For example, the long prism elements of the mesh depicted below, converted by a Radfac of 2, are all present. If an element or group of elements is not converted by Blenbridge, we may decide to increase the Radfac level and try again. However, it should be noted that in the majority of cases, it is the presence of a geometric defect, or multiple ones, which cause the conversion of a mesh to be incomplete.



The .vtk output from demo1 is shown in Paraview. Paraview acknowledges the volumetric nature of the object, by using and saving volumetric connectivity, for example.

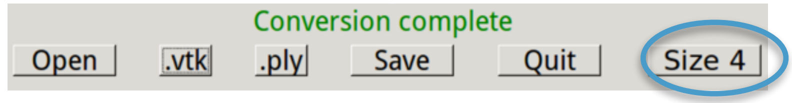
(Aside: Paraview 4 is 52 percent lighter than version 5, and though missing many enhancements, especially concerning rendering, it does fine for the purpose of showing geometry and mesh.)

As shown right, a dynamic label serves as a progress indicator. The ‘Conversion Complete’ message signals the end of the process.



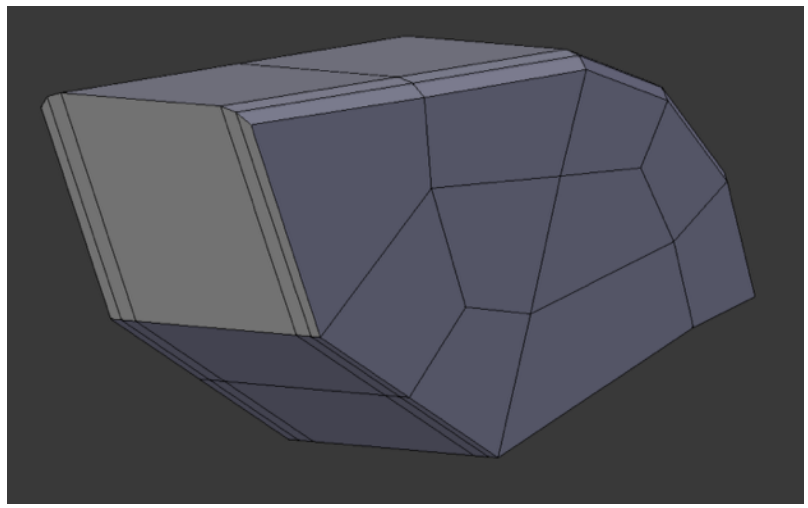
To convert .ply to .vtk, press the .vtk button. To go the other way, press the .ply button.

Blenbridge's main form is resizable. By clicking on the size button (shown circled), we are taken successively through five sizes. Blenbridge remembers the last size shown and will start the next session at that size.

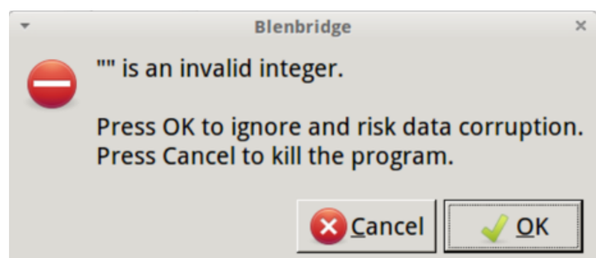


Demo 2

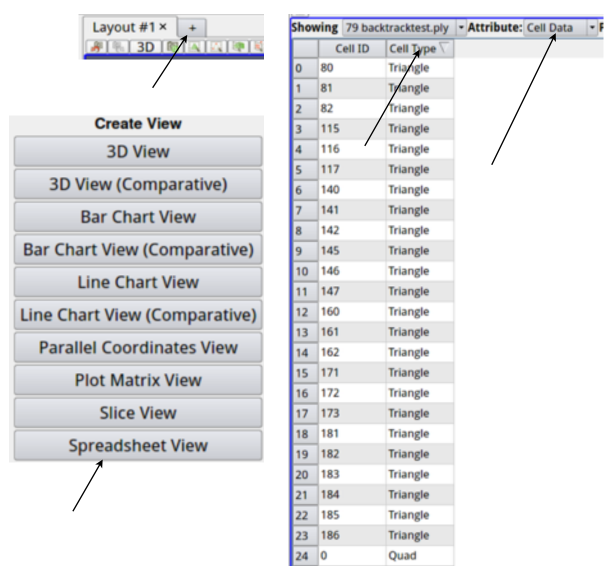
To the right is a pod corner object, shown in Blender. It has a couple of small defects.



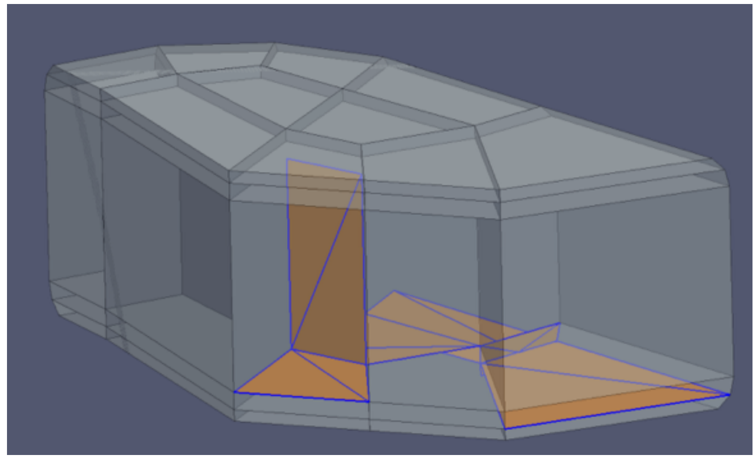
The error msg shown right meets us when we attempt to convert the .ply file into a .vtk in Blenbridge. The 'invalid integer' consists in a null character the program encounters when it reaches the end of a text line. In other words, an unexpected triangle. It is very helpful that most defects are interpreted as triangles by Blender's .ply conversion script.



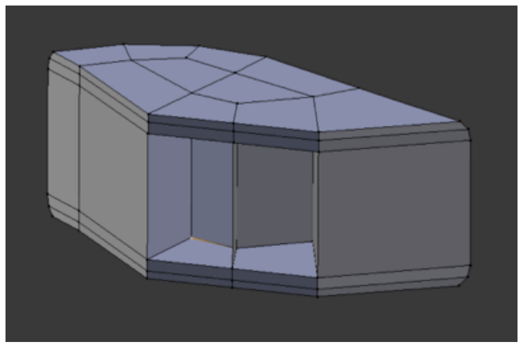
In Paraview, after the .ply file is opened, we open a new Layout, a Spreadsheet View. Toggling the Cell Type column, we see that the triangles are clearly listed. We select them, then apply the ExtractSelection filter to capture them.

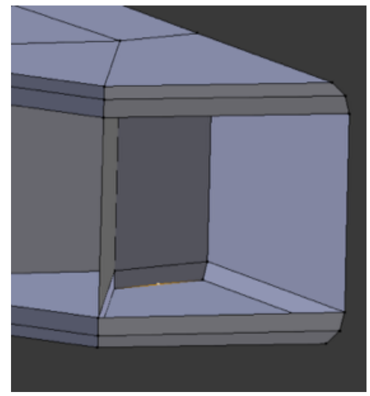


By showing both the main representation and the ExtractSelection at the same time, and reducing the opacity of the former, we can see where the triangles are.



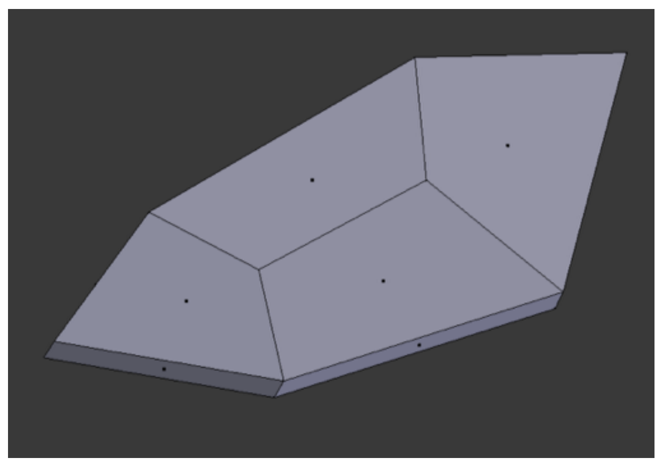
Two defects are easily hunted down (and shown selected at right): An extra vertex close to a corner, just out of reach of Blender's RemoveDoubles command. And another vertex in the middle of an edge where RemoveDoubles would not reach it. After these problems are corrected, we can convert the file without further difficulty.



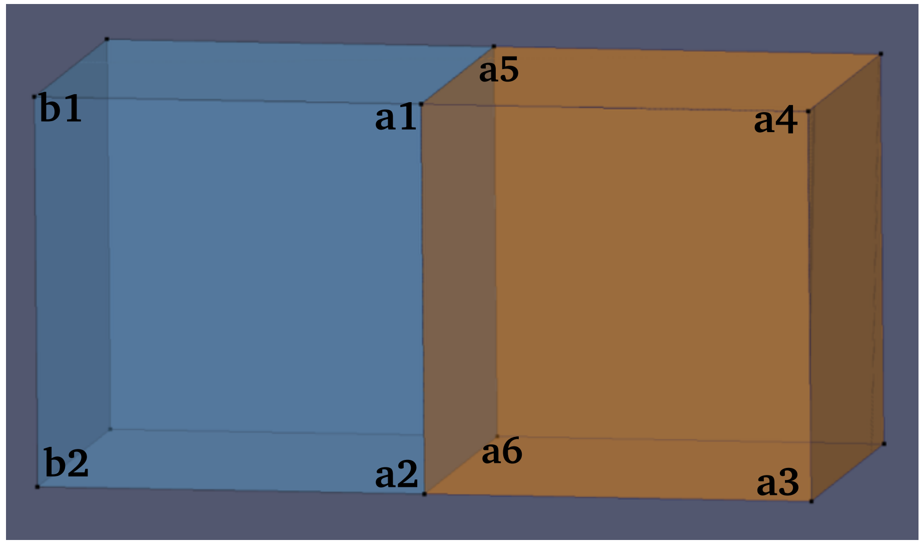


<u>Demo 3</u>

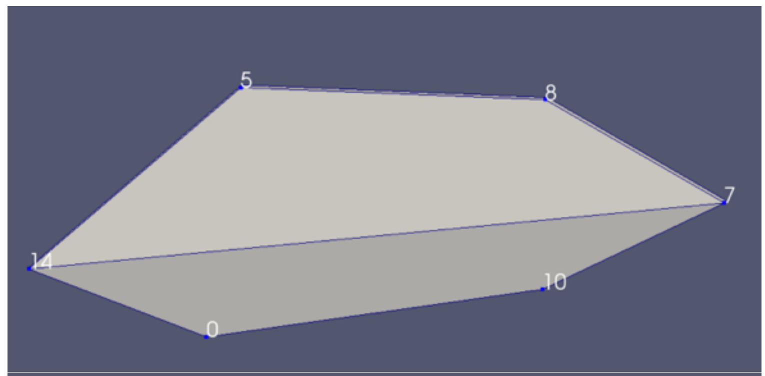
Here is a small segment of a larger curved surface. Its lack of flatness can make a problem for Blenbridge, which the variable Comvol deals with.

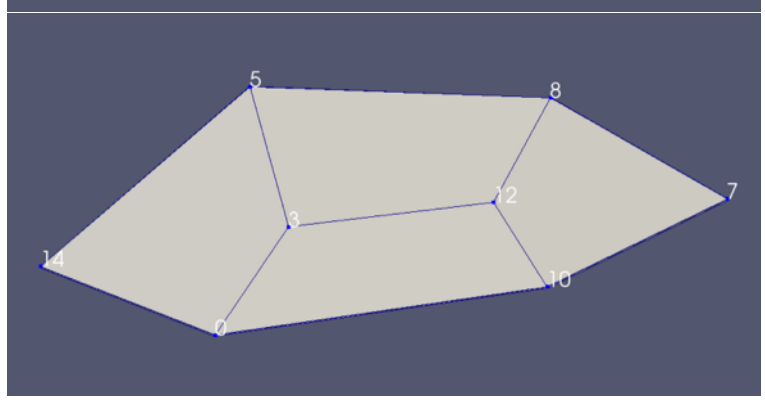


Referring to the two cube shapes shown below, suppose we are attempting to create an element from the six orange faces, starting with the front face and concentrating on the edge a1-a2. This edge is shared by the face a1-a2-a6-a5 and by the face b1-b2-a2-a1. Operating blind, Blenbridge would see no particular difference between the attached faces, and might choose the wrong one. But consider the tets a1-a2-a4-a5 and b1-a1-a2-a4. The first has a significant volume, but the second does not. Therefore if the volumes of a tetrahedron containing a prospective face's points (plus base face points) is compared with a characteristic bounding volume, or a proxy of it, the correct components can be chosen. This 'comparative volume' attribute is governed by the value of Comvol.



If a Comvol value of less than 0.016 is used, the erroneous conversion shown right, above, is produced. If a Comvol value of 0.016 or greater is used, the correctly depicted mesh conversion shown right, below, is produced. The default value of 0.050 for Comvol is satisfactory for all the demos in this document except one. For a case where an exception causes a different value of Comvol to be used, see p. 92.

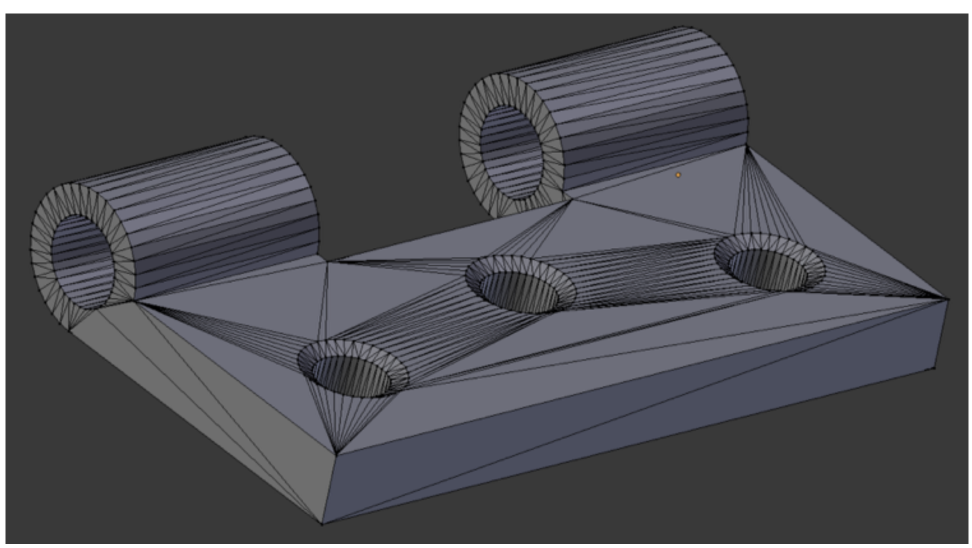




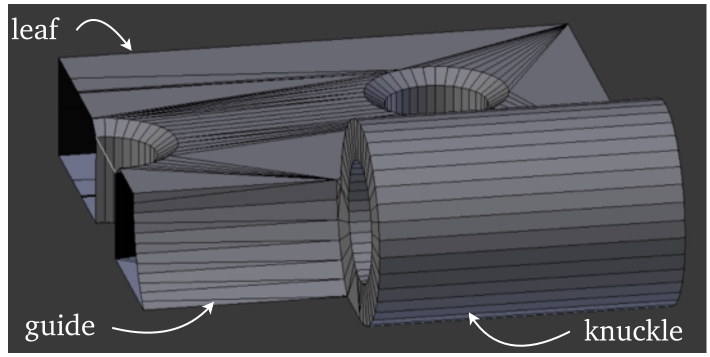
<u>Demo 4</u>

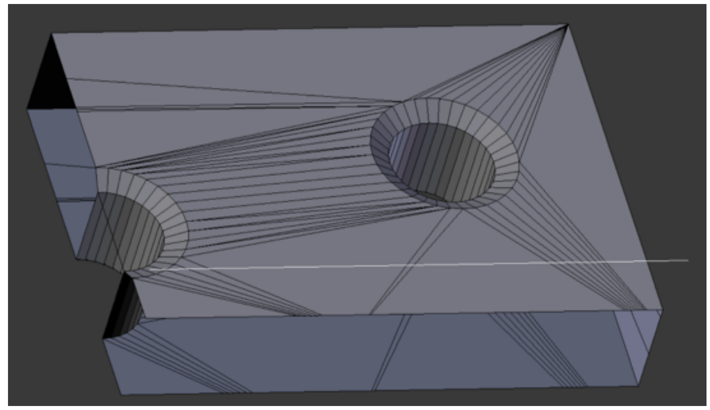
This object is a hinge.
The .stl file of this object is obtained from the Elmer GUI samples folder (see References), and imported into Blender.

This demo has more step-by-step comments than the others in this document.



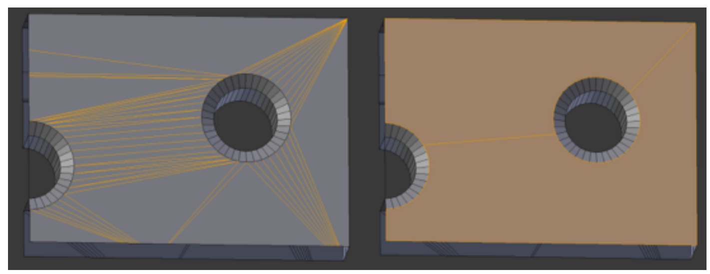
We first select a vertical edge, press Shift + ‘d’ (Duplicate), then ‘p’ (Separate) the edge into a separate object. We use the Knife Project command by selecting a random edge in Edit mode which will be used for cutting and modifying it so that from a chosen viewpoint it cuts as we wish. Then in Object mode we select first the cutter then the mesh. Then back in Edit mode we cut the model exactly in half vertically. We apply the Alt + ‘j’ command to turn some of the triangles into quads.



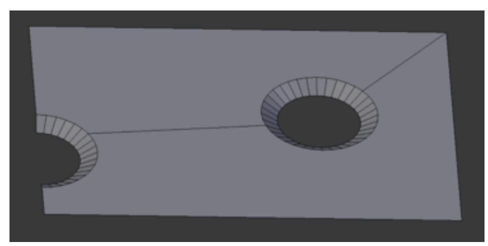


We cut horizontally at a convenient place to isolate the leaf section from the knuckle section, using a randomly selected and modified horizontal edge as cutter. The knuckle section we place on a separate layer temporarily.

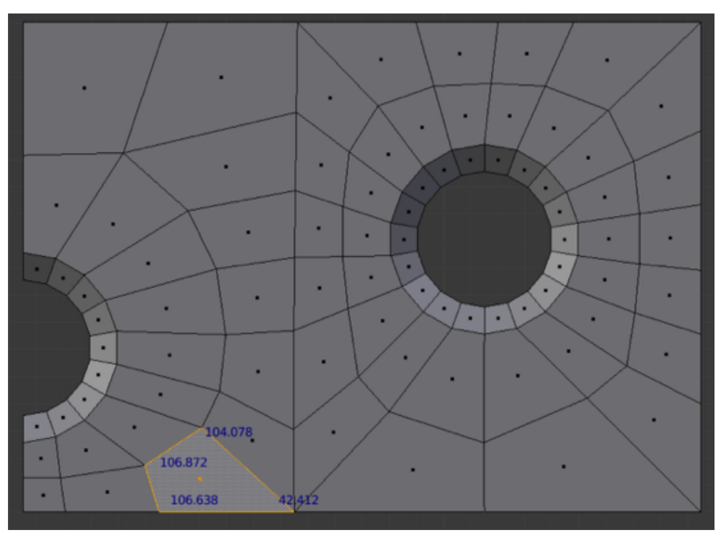
We select the surface edges and use the Mesh → Clean Up → Limited Dissolve command at default strength to eliminate the selected edges, leaving only a couple left after the command has finished.



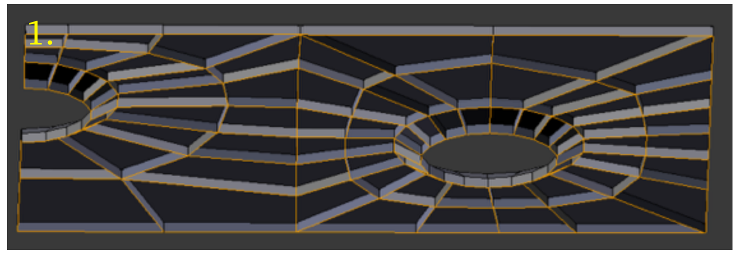
We note down the z-axis thickness of the leaf (5.0) and then delete all but the top layer of faces (plus hole bevels).

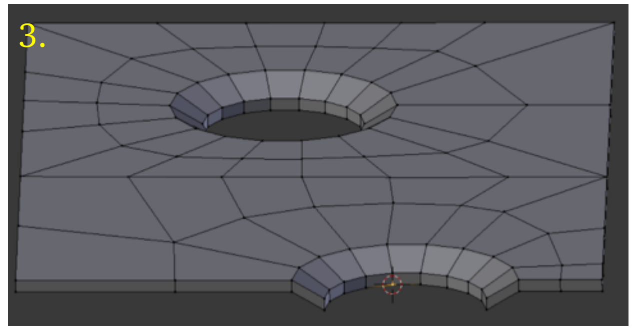


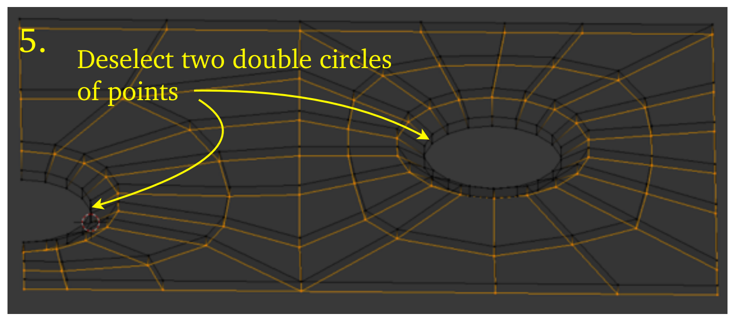
We reduce the hole divisions from 36 to 18 by merging points. We then use the Knife command by pressing ‘k’. We divide up the surface into faces with reasonably sized angles. We review the angle sizes using the Angle checkbox under the Mesh Display section of the ‘n’ properties panel. For mesh quality purposes we generally try to keep all angles less than 130 degrees and greater than 40 degrees, with no two angles in a face differing by more than 75 degrees.

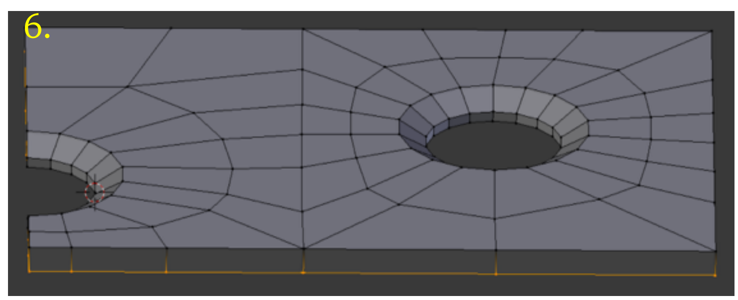


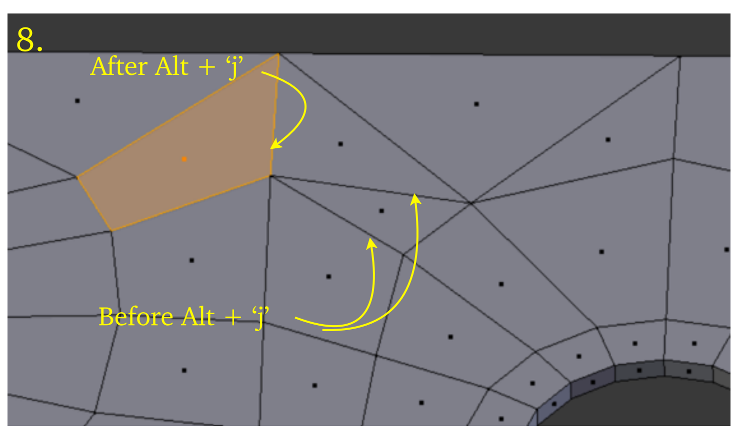
Now we do our first extrusion. We select all the faces with the boundary selection command. We then change the mode to edge select, the selected edges showing selection glow. Then we press Alt + ‘e’, followed by selection of ‘Edges Only.’ Then we enter ‘-.37983 z’ and press Return. The edges extrude downward by .37983 units, as shown in picture 1, an underside view. Next we select the 3D cursor as pivot point, picture 2. Now we switch to point select mode and select one of the lower inside hole points, as in picture 3, and then we press Shift + ‘s’, followed by ‘u’ to send the 3D cursor to the selected point. We then take a front view by pressing ‘1’. We go into wire frame mode by pressing ‘z’. We boundary select all the points below the top surface, as in picture 4. We now use the circle select command, ‘c’, along with the Shift key, to deselect the innermost points in the holes, as in picture 5. Next we press ‘s’ (Scale) + ‘z’ + ‘0’, and then press Return. All the points except those which were not selected jump to the 3D cursor z-position, which is .37983 units below the top surface, as seen in picture 6. Our next task is to cover the newly extruded edges with faces. We take a front view, ‘1’, and go into wire frame mode, ‘z’, and into edge select mode. Then we carefully select the lower edges, as in picture 7, the thin orange line showing we have selected only the bottom-most layer. Now we can exit wire frame mode and press Alt + ‘f’, (Face), making faces on the edges. We follow this immediately by Alt + ‘j’, to convert some of the triangles into quads. However, some have to be done by hand, as picture 8 illustrates. Alt + ‘j’, with two selected triangles, converts them into quads. If the triangles chosen are not compatible, Blender will not complete the command.



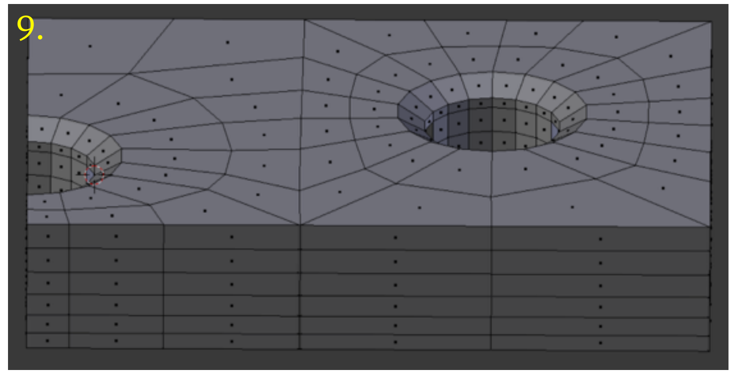


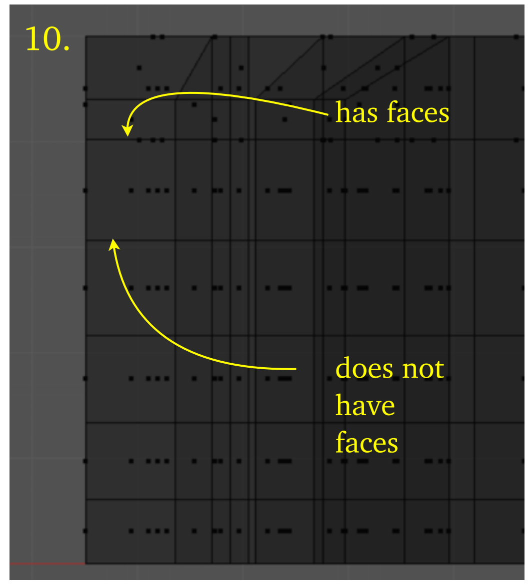


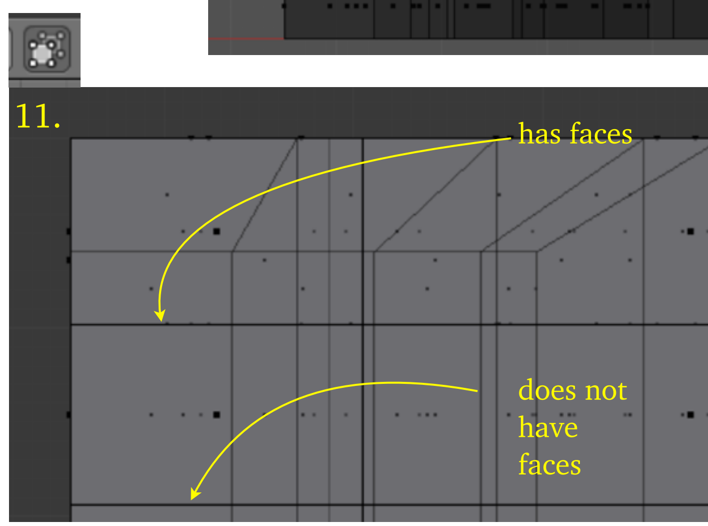




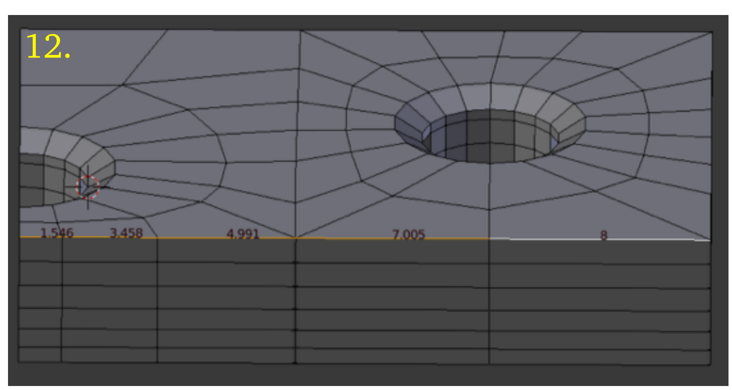
We have extruded the first level of the leaf section. To create the other five levels is similar and simpler. We put the mesh into front view with ‘1’, go into wire frame mode with ‘z’, go into face select mode, and carefully select the bottom layer of faces. Then we fall back to edge select mode and repeat the routine: 1. press Alt + ‘e’, 2. selection of option ‘Edges Only’, 3. enter ‘-.next-z + z’ and 4. press Return, where ‘-.next-z’ represents the next value in the sequence: -.95431, -.90227, -.82596, -.72743, and -.60934. This results in something like picture 9, which is a skirt of faces with only the first two horizontal levels populated with faces. The next task then is to put in the horizontal layers. We do this with a slight variation on the routine just used. We select the bottom layer of faces, as in picture 10, (or picture 11, using ‘Limit Selection’ button) with the face dots confirming which layer has the faces. Then we use the command Shift + ‘d’ (Duplicate) to duplicate the face layer. We immediately enter the distance of movement and the axis, and press Return. For example, the first is ‘-.95431 z’. If we make a numerical mistake, we will see too many layers of horizontal edges when we come out of wire frame mode. When we have finished, we select everything and Remove Doubles, finding that 535 doubles are removed. The degree of Verdict quality does not appear to be a potential issue with the leaf section, so we will not bother with doing that check.



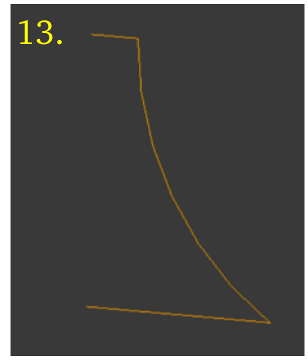


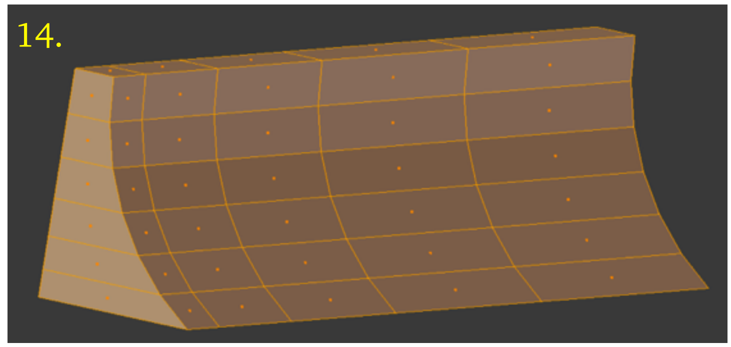


Before moving on to the construction of the guide, there are five edge lengths we need to capture, as shown in picture 12. They turn out to be: 1.546, 3.458, 4.991, 7.005, and 8, as revealed by Edge info: Length, under Mesh Display in the ‘n’ properties panel.

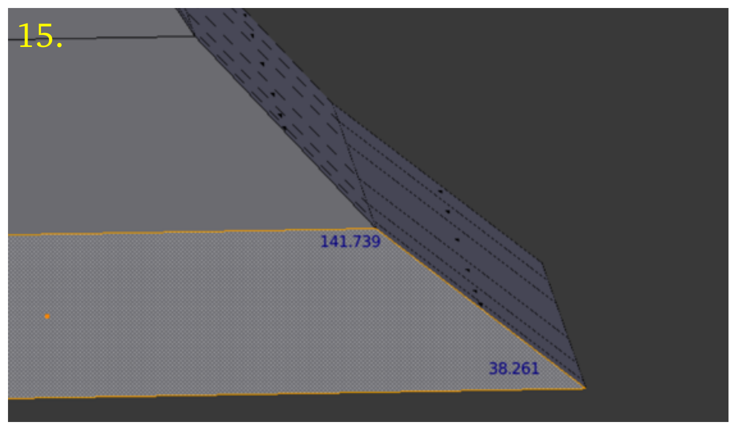


We start with the edge outline of the guide that was cut with the dividing knife, seen in picture 13. We first make an n-gon, using ‘f’ (Face), then use the knife tool to cut it into horizontal faces. These we extrude horizontally along the x-axis using the edge lengths found above, as shown in picture 14, so that they will match the edges of the leaf. We add vertical layers of faces exactly as we added the horizontal layers before, by duplication. When we remove doubles, Blender reports the removal of 70 doubles.


13.

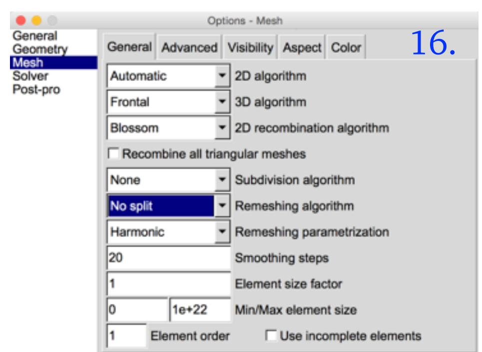

14.

There is one serious concern about the guide, which is the extreme angles on its lowest faces, as seen in picture 15. Two angles violate all three of the rules we mentioned before about angle quality. So we have to take time to check out the quality of the guide.



15.

The guide is the only object on its layer in Blender, so it is easy to export it to .ply. We remember to uncheck all export options. We do the conversion in Blenbridge, using defaults. We remember to rename it using the extension .vtk after conversion. We open the .vtk in Gmsh, create a 3D mesh, and save it as a .vtk. Picture 16 shows the Gmsh mesh options to create a mesh with no increase in element density. Picture 17 show the Gmsh mesh dialog settings to create a mesh with one level of refinement. Picture 18 shows the mesh creation selector, arrowed, on the Gmsh main GUI.



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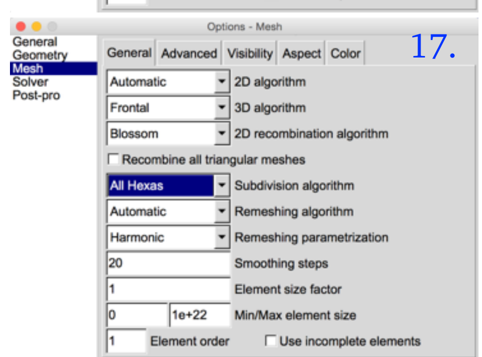
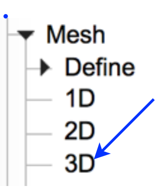
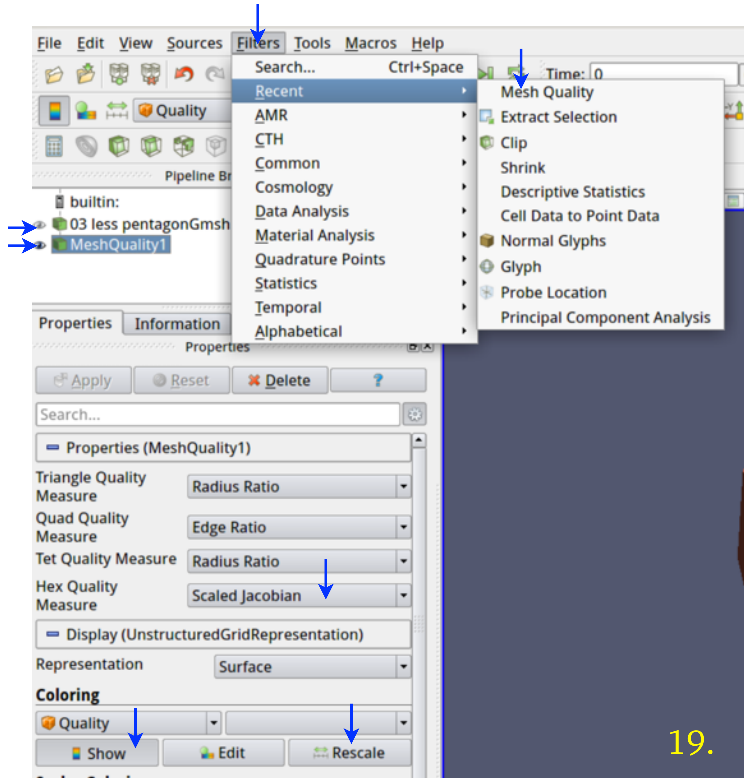


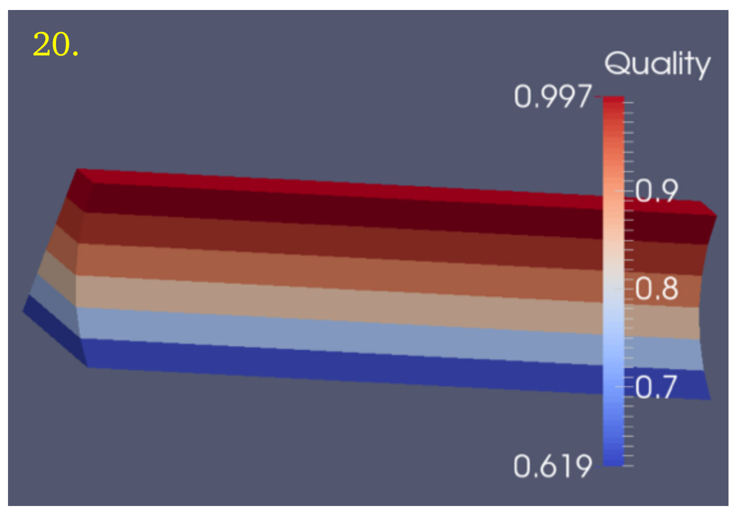
17.

18.


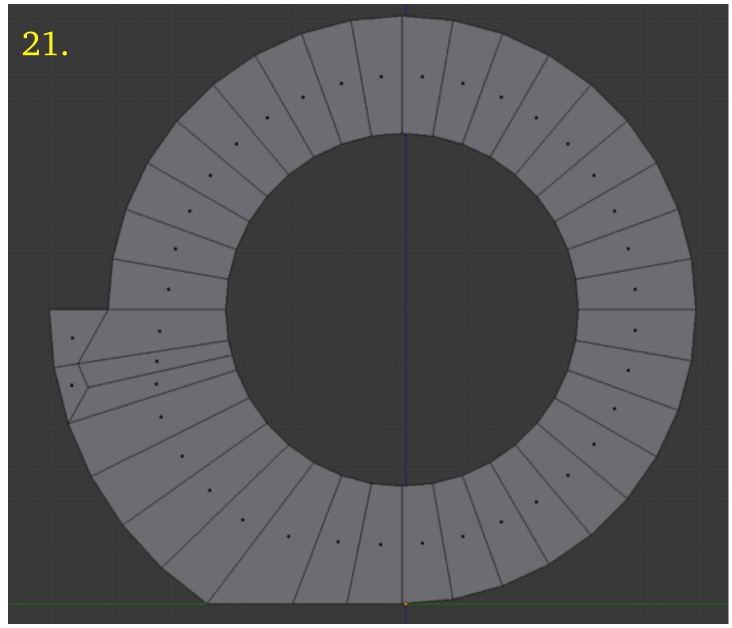
We open the resulting .vtk in Paraview, the GUI of which is shown in picture 19, with arrows at labels of interest. We apply the Mesh Quality filter, dial the Hex Quality Measure spinner button down to Scaled Jacobian, click the Show and Rescale buttons under Coloring, and find the circumstance shown in picture 20.

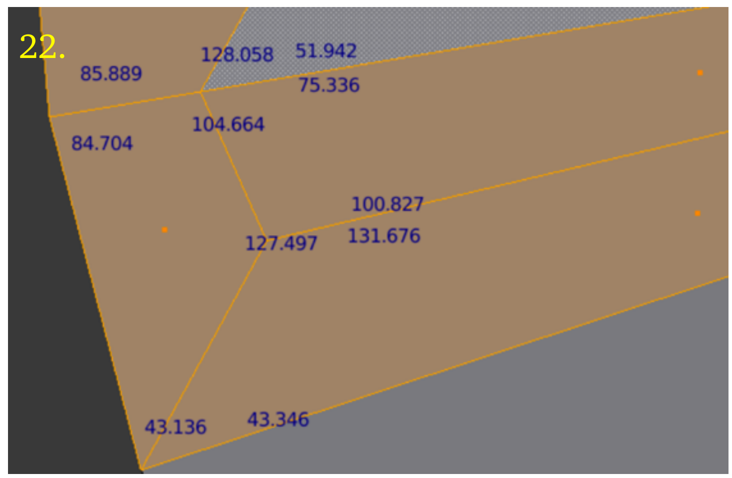


According to the Verdict quality assessment system embodied in the Paraview Mesh Quality filter, elements with a Scaled Jacobian score between 0.5 and 1.0 are acceptable.The guide has surprisingly good quality for its poor angles, and shows a minimum quality level of 0.619. We speculate that the nice flat sides compensate for the poor angles.

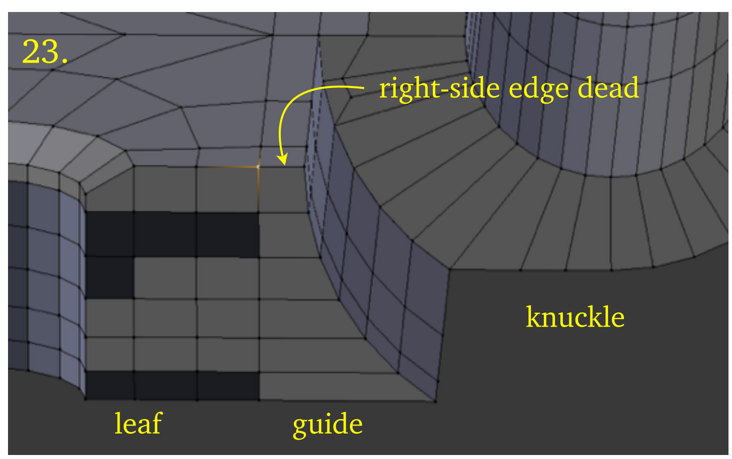


It is time to move on to the knuckle. The knuckle end plate which is adjacent to the guide we now duplicate and put on a new layer. We eliminate triangles by hand, making angles as favorable as possible. As picture 21 shows, the outline is in no way extreme and the angles do not give difficulty. Picture 22 shows the worst angles. The x-value of the end we are working on is 34.5, which means there are two horizontal extrusions to be accomplished. We do these just as we did for the guide.

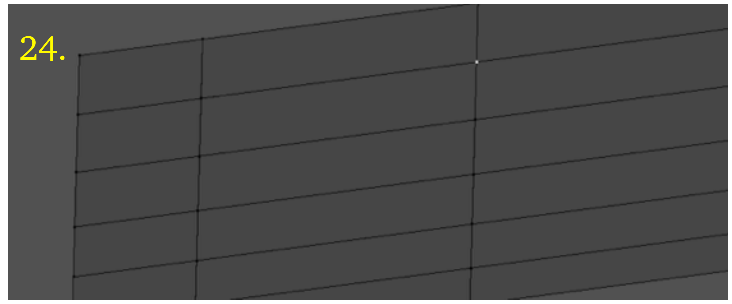


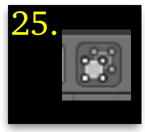


It remains to assemble the hinge. We put the three subassemblies on the same layer and join them. After joining, it is necessary to check the points involved to make sure they are sound. Picture 23 shows an unsound one immediately. We can see that for this selected point, the selected point ‘edge glow’ does not extend from the leaf side to the guide side, as it should.



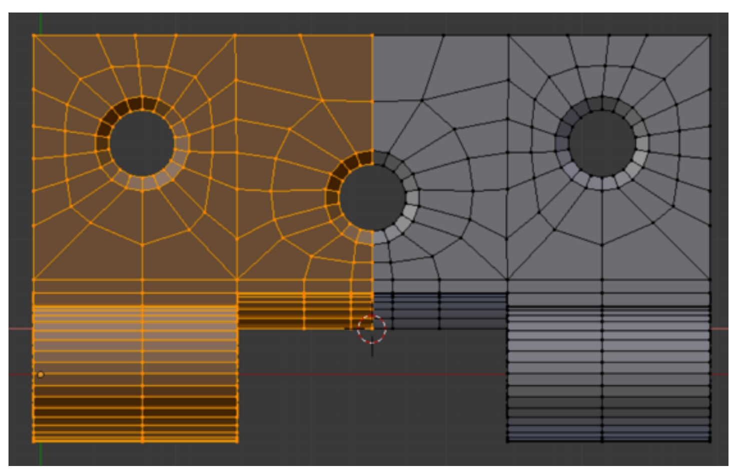
We take a top view, ‘7’, and in point select mode we boundary select and hide all points which are not on the join boundary between leaf and guide. We go into wire frame mode and take any convenient perspective. Then we select each point, clicking on it at least twice. The first time it may glow in all directions, but on the second click it may go dead, as shown for the point in picture 24. Indeed, it would be surprising if they were not all half dead. For each one so found, we ‘c’, circle select around it and merge the points. Note that is only works in wire frame mode, or in the mode governed by the button with Tooltip, “Limit selection to visible”, shown in picture 25. At the boundary plane between guide and knuckle, we repeat the process of verifying soundness of points, though this boundary does have a curve.

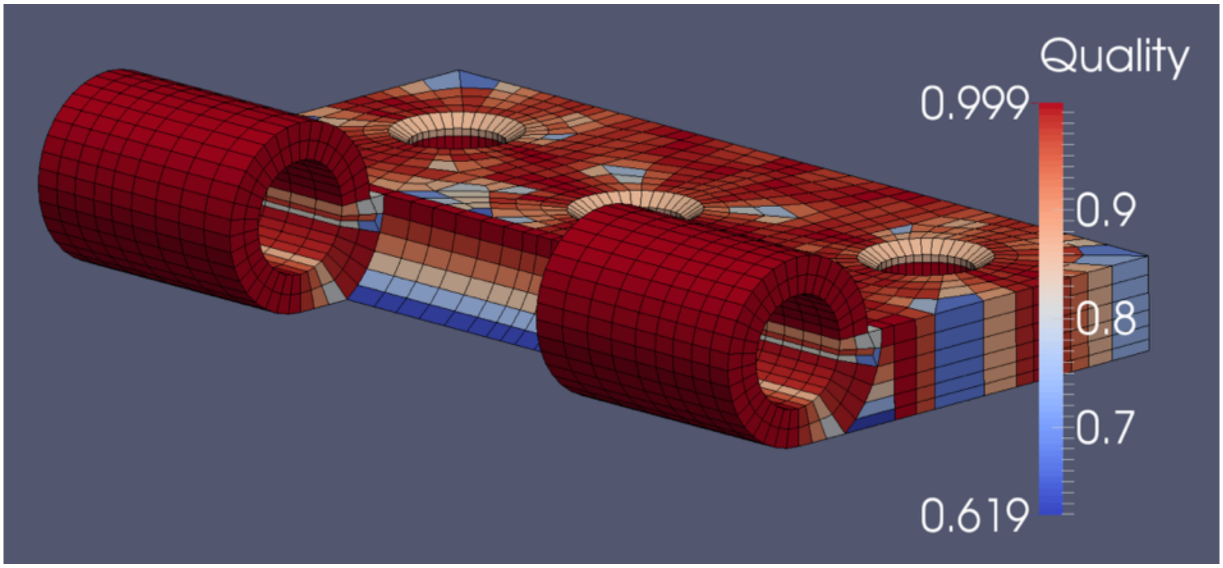




Our next task is to check the quality of the assembly, using the same steps as when we checked the guide quality. We find that Verdict calculations give the subassembly a score of 0.619, the same as the guide achieved earlier. With this value determined, we can go on to the mirroring.

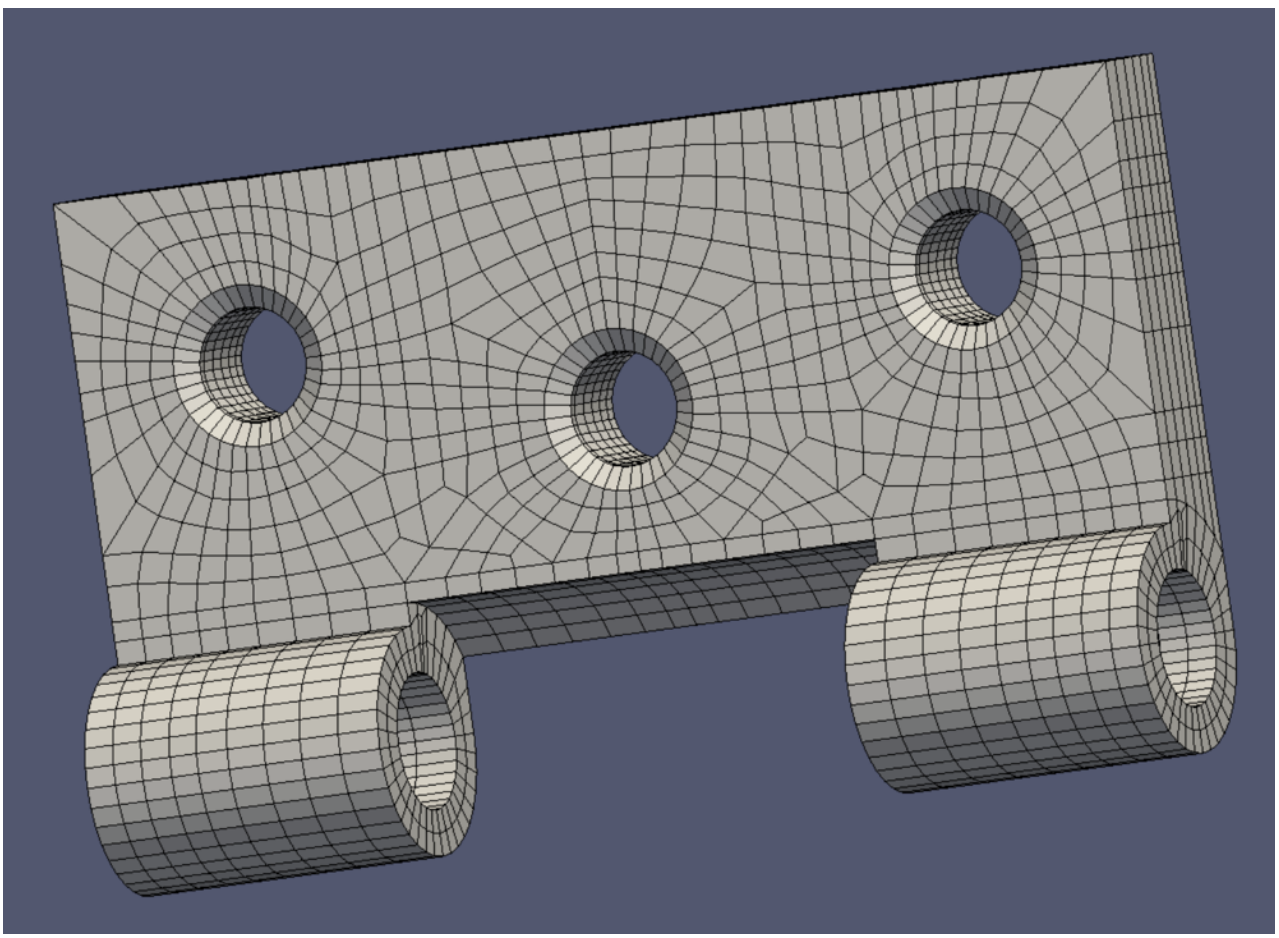
The division cut runs along the y-axis, but we want to mirror around global x. Before mirroring, we select a base point on the mesh and send the 3D cursor there to anchor the action. Then we Shift + ‘d’ (Duplicate) the mesh and perform the mirroring on the still-selected duplicate. After the mirroring, we select everything and Remove doubles. Blender reports the removal of 147 doubles.





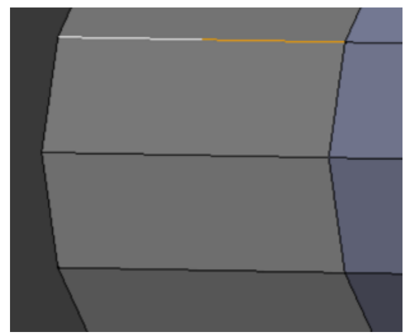
Using the process described in the last seven pages, we create a mesh with a slightly different face pattern. The 18,676 faces of this final mesh require 65 seconds for Blenbridge to convert to .vtk. The final totals are 5556 elements and 7888 nodes.

Shown above is the Mesh Quality filter view in Paraview, which evaluates the mesh. With a minimum of 0.619 for all the elements, the mesh scores well.

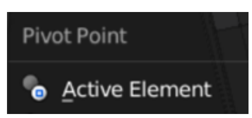


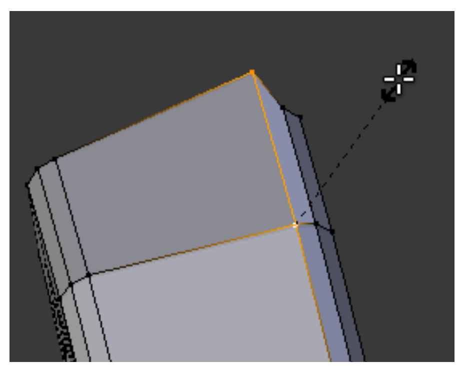
If the mesh is saved in Gmsh as a .msh file, it can be loaded into Elmer. Elmer will not attempt to remesh it. Saved in Gmsh as a .inp file, it can be used in Calculix or Febio.

Here we offer a few edge tricks.

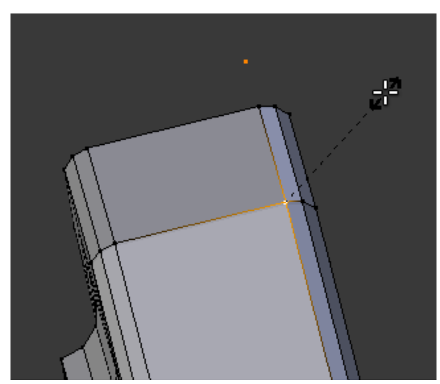


1. A fundamental geometry-creation step in Blender is splitting an edge. The keyboard steps for the selected edge are Ctrl+ ‘e’, followed by ’s’. Both halves remain selected, and if in this state the command is repeated, both edges will be split, allowing quick division into 2, 4, 8, or 16 pieces, as required.





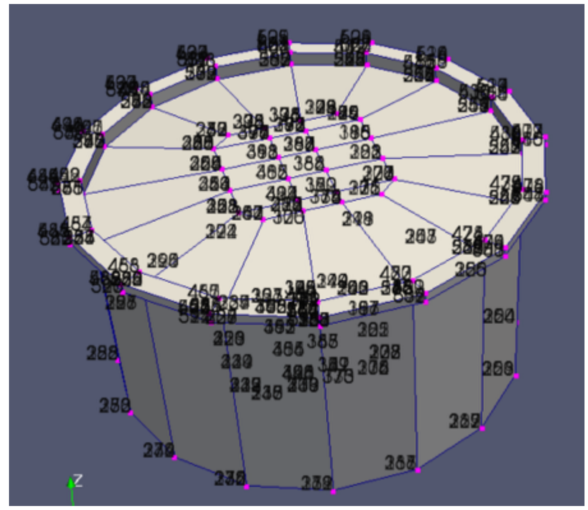
2. Sliding a selected point along an edge is Shift + ‘v’. But to extend the end point of an edge, make sure that the pivot point is ‘Active Element’. Then first select the point to be stretched, then its base point, then ‘s’ (Scale).



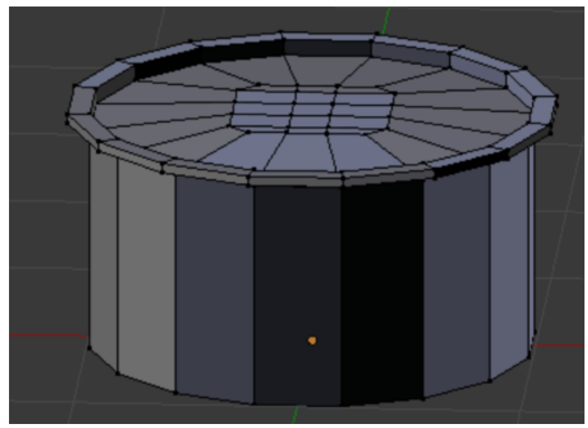
3. Using the same pivot point as 2, but creating a new edge with the same direction as the original. After selecting the first point, press Shift + ‘d’ (Duplicate). Then press Escape to keep the new point from wandering. Then select the base point, press ‘s’ (Scale), and position the new point with its **inherited directionality**. Now the point can be connected with the last end point with the ‘f’ (Face) command to create new geometry.

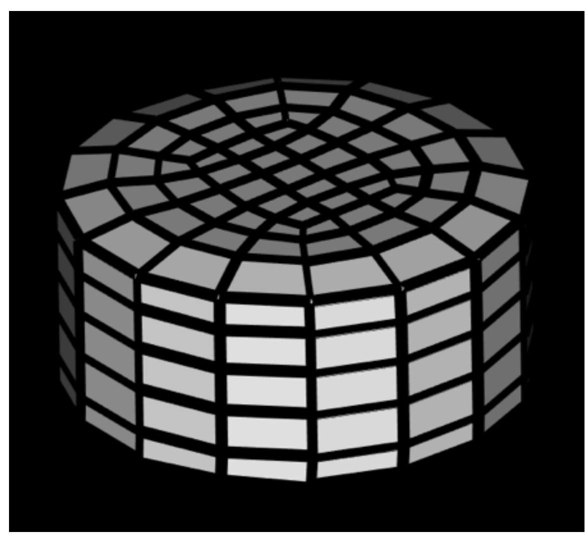
Demo 5

After demo5.ply fails to convert, the .ply is opened in Paraview. All the points have multiple superimposed labels, indicating that the operator forgot to uncheck the export options check boxes in Blender's export dialog.

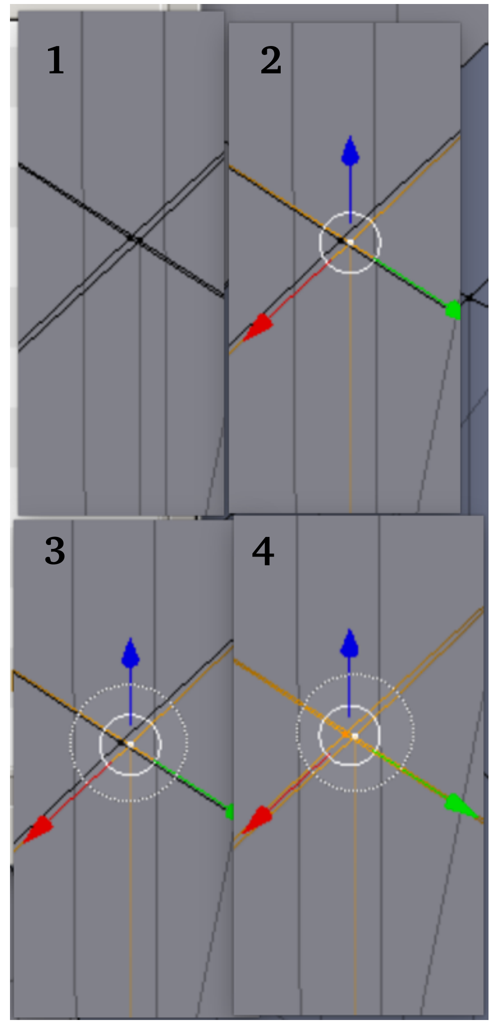


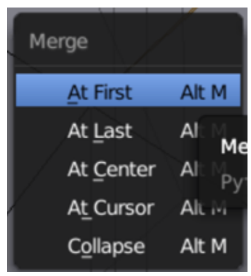
At right top is shown a proto-block, and at bottom a test mesh, from IA-FEMesh. The wrangling of lattice blocks for the generation of non-organic shapes in IA-FEMesh is apparently an arcane science. A starting shape is supplied in the demo files under the name 'demo5'. The user of IA-FEMesh must exercise extreme care in positioning the lattice block precisely if regular-looking edges and corners are to be obtained.



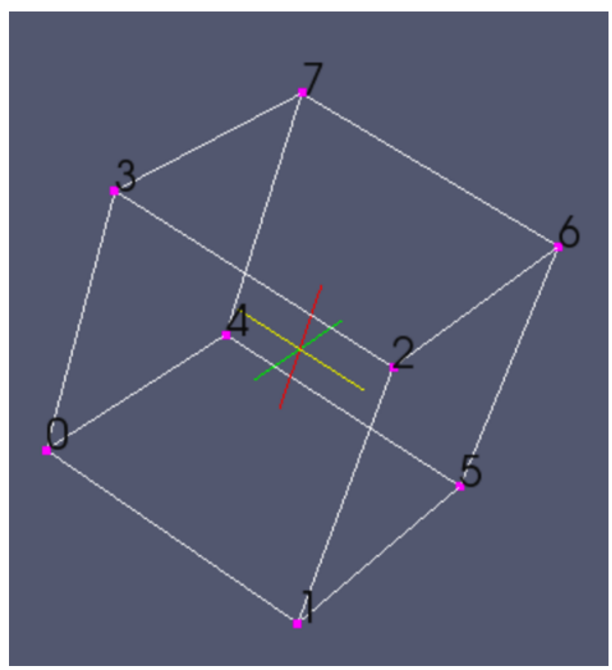


The basic Blender Merge procedure has better control than 'Remove Doubles'. Pic 1: in inspecting a zoomed view, an undesirable doubles situation is seen. Pic 2: The desired base locus is selected. Pic 3: 'c' key invokes a selection circle, which is scrolled to the desired size and positioned to target a cylindrical volume for the merge. Pic 4: after the selection click the points all light up. This is followed by the dismissal click, releasing the selection circle. Below left: then Alt+'m' brings up the merge menu, and the 'a' key does the merge. In this procedure, it is not necessary to know the number of points involved or their exact location.





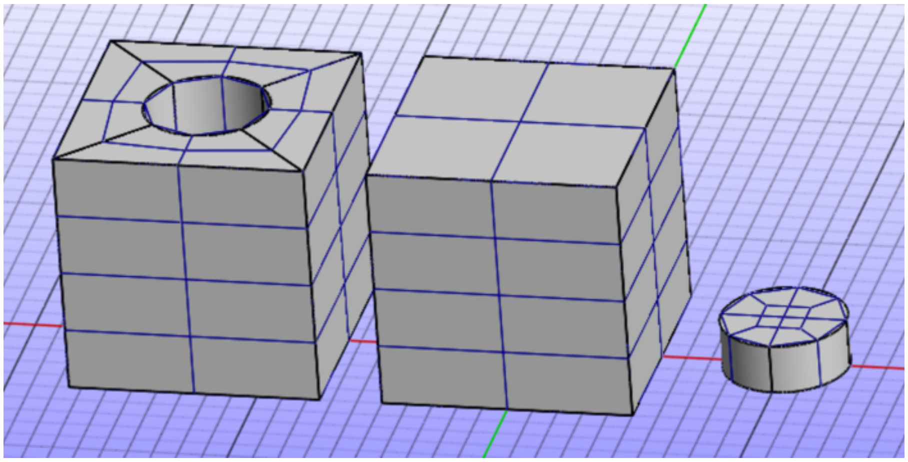
It might be of interest to look at Vtk winding order. As shown, we may have 0-1-2-3 on one face, then slide back along the edge where we started to pick up the opposite face, 4-5-6-7. Since, looking at the outside surface of the faces, one face is wound clockwise and its opposite wound counter-clockwise, it doesn't matter for a given face whether the external numbering is ccw or cw, so long as it follows the assignment system just described.



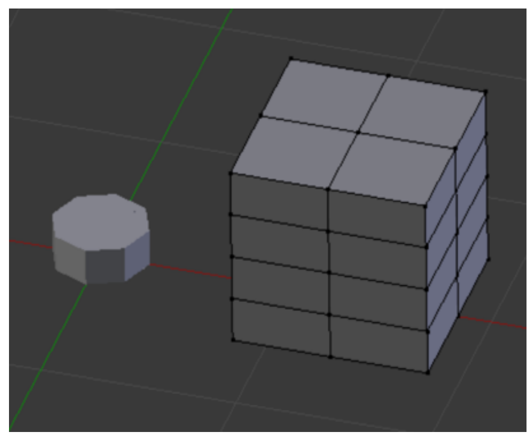
Thus, the element might appear in the .vtk files as 8 0 1 2 3 4 5 6 7
or 8 2 6 5 1 3 7 4 0
or any one of 46 other possibilities.

Demo 6

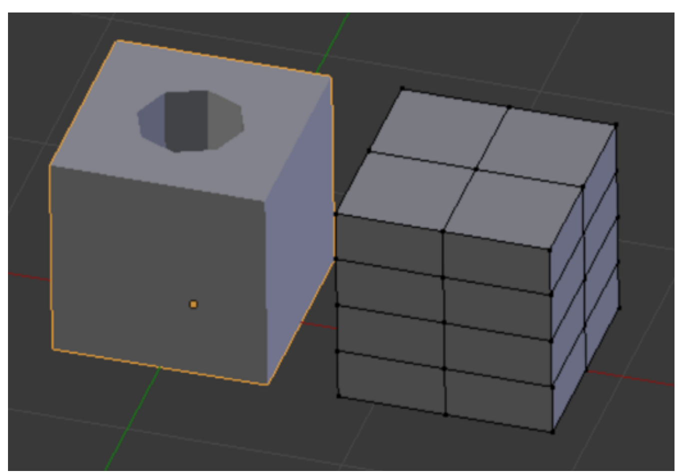
Blenbridge can convert .vtk files to .ply format. In this way a mesh can be updated or overhauled, then reconverted and reused. However, there are some other paths for use of .vtk as input. Below are some objects created in Febio Preview, then exported in .vtk format. The idea is to put these together in Blender.



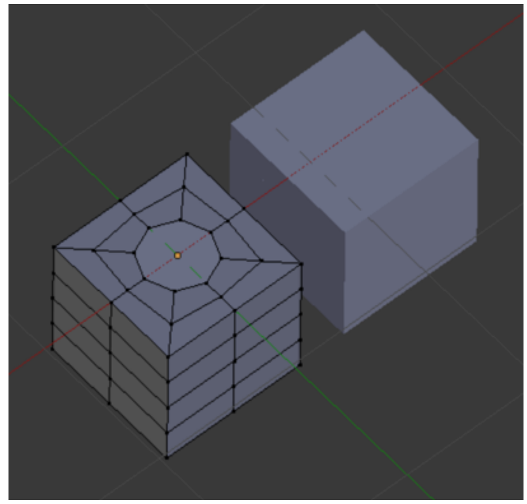
Two of the three objects are shown in Edit mode in Blender after having been converted by Blenbridge. They have been imported separately, so only one of them can be selected at a time. We will call them the ‘plug’ and the ‘block’.



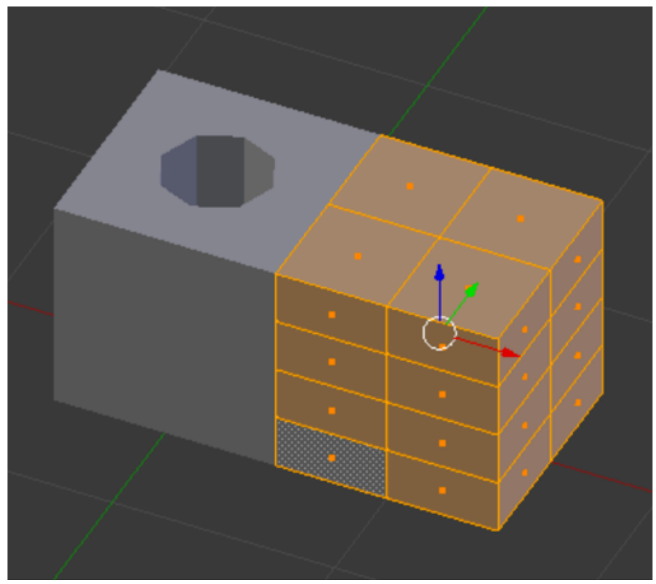
The ‘tube’ is imported and takes its place beside the ‘block’. When it comes in, it nails the ‘plug’. There is no need to adjust the position of either. The intention is to make an object with a blind hole.



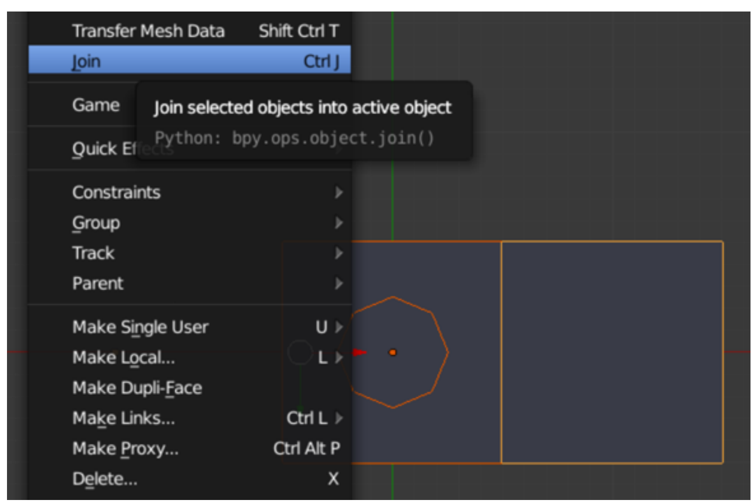
Here is a bottom view. The ‘block’ will be grabbed and moved along the x-axis with 5-place accuracy, after which the group will be joined.



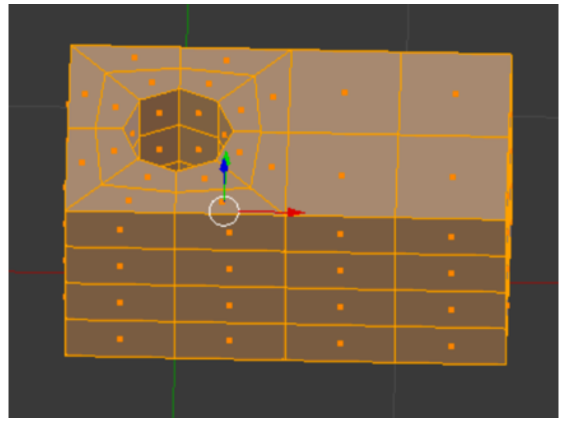
As described.

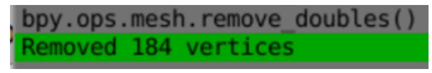


In Object mode the three are joined.

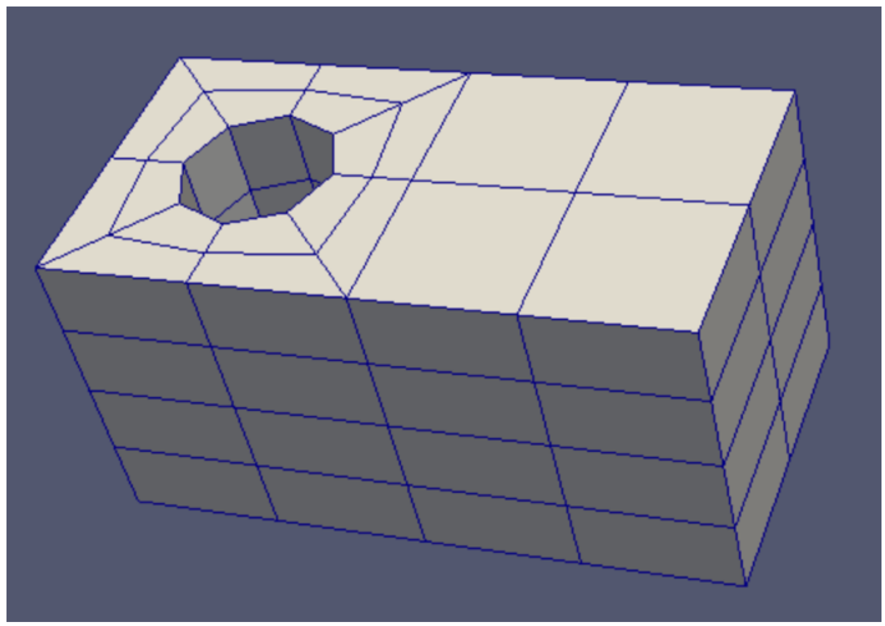


Joining unifies the object. Then the ‘Remove Doubles’ command cleans up the interface.



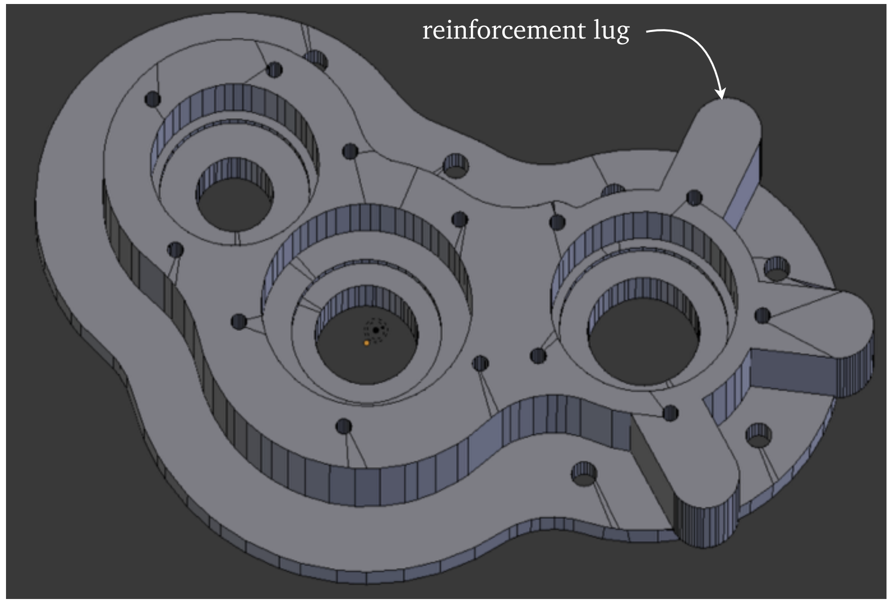


The product can be used as mesh in any finite element environment, and, as far as we know, cannot be assembled this way in Febio Preview.

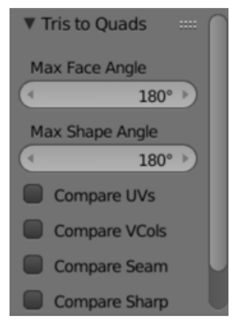


Demo 7

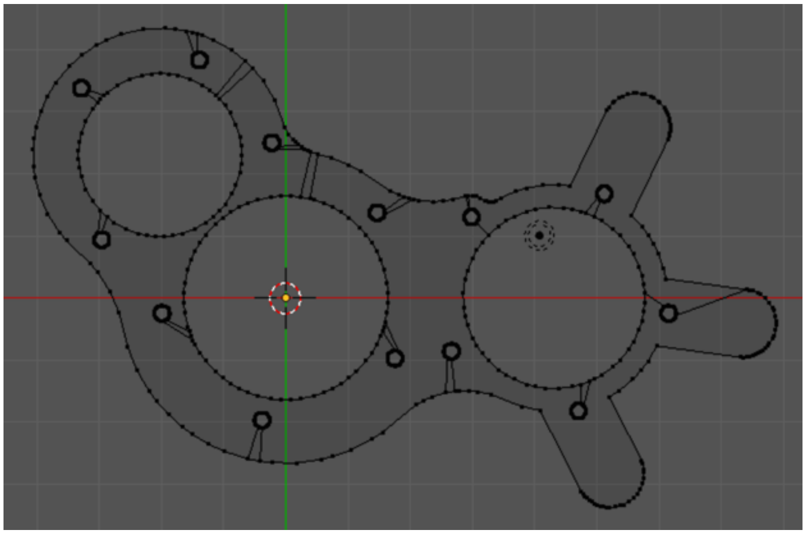
This object is a pump casing. It belongs to the INRIA model repository (see References). Hosted as a .stp file in the Elmer GUI samples folder, it is converted to an .obj by FreeCAD, and then imported by Blender. (The model can also be accessed in .stp and .stl format from the Aim Shape model repository.)



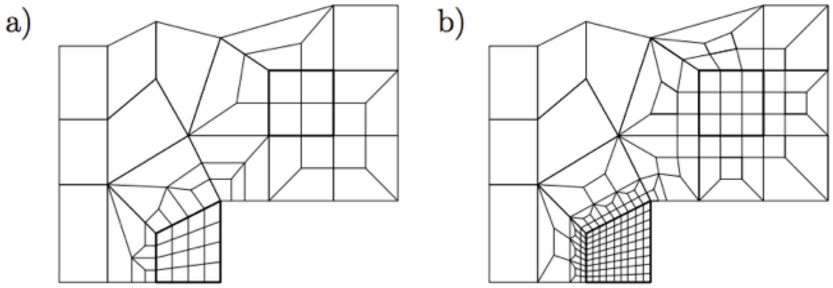
The commands ‘Mesh → Faces → Tris to quads’, and ‘Mesh → Cleanup → Limited Dissolve’ remove all traces of triangles and get the model ready to edit. The settings used in this case are pictured at right. The reason the flat surfaces of the mesh show very few edges is that they are just single big n-gons.



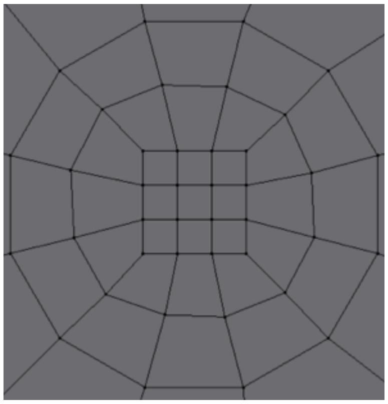
We hide everything except the top n-gon. The wireframe view in Blender's Edit mode is the most convenient setting for doing the work. The tools to be employed are the knife tool, edge extrusion, and duplicate-and-move. When open gaps occur in the working plane of faces, and there is no n-gon surface to operate on, ordinary face making will take the place of the knife tool.



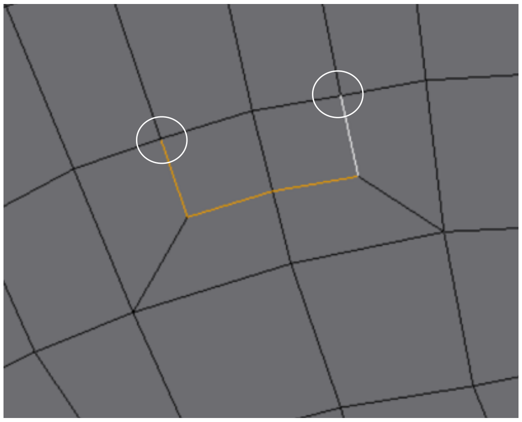
Two illustrations concerning transition zones, between different levels of detail, in quadrilateral mesh. For this and other useful illustrations, see Schneiders in References.

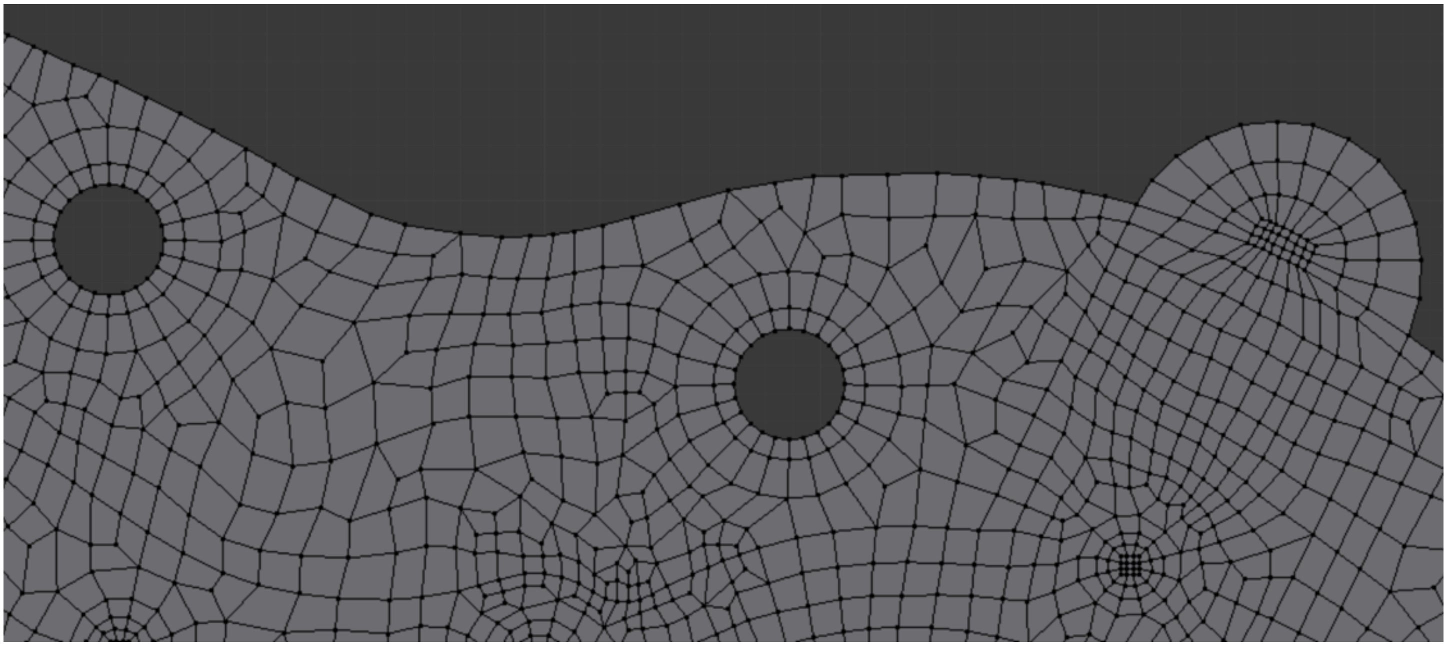


We elect to use 12-division hole bottoms and use Blenbridge to translate the appropriate pattern from Febio Preview, then import the resulting .ply into Blender.

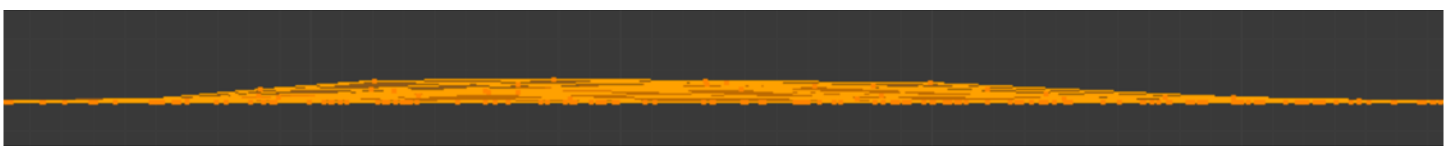


The tension of two loose-ended points (circled) can be balanced by creating a loop. However, if a match cannot be found for a surplus point, an exterior boundary point must be created or destroyed to maintain the balance.

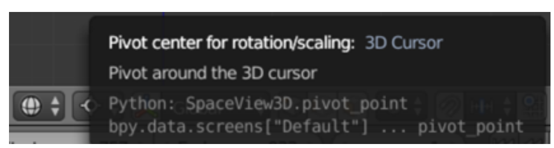


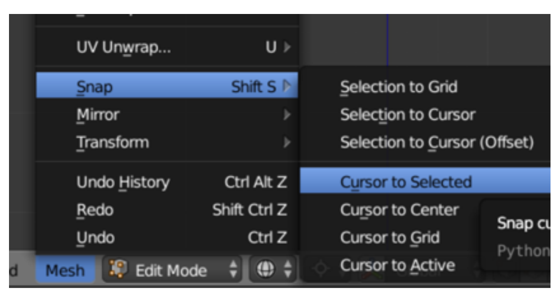


Being careful to always remain in top view, we make the mesh. Because the view is perpendicular to a main axis, moving with ‘g’ (grab) does not disturb the flatness (much). This is the mainstay of smoothing operations on the mesh. When it is necessary to slide a vertex along an outside edge, we use Shift+‘v’ to do it.



The zoomed mountainous region seen from a front view is only 0.007 Blender units high, but perfect flatness can be achieved easily. We first make sure the 3D cursor is the Pivot Center. Then we use Shift + ‘s’, followed by ‘u’, to snap the 3D cursor to a selected point with a z-value that we want all the points to have. Then we select all points and press ‘s’ (scale), then ‘z’ (axis), then 0, then Enter.





Blender's mesh tools are designed to prevent non-manifold extrusions, the very thing we want. Accidentally producing a considerable quantity of inconvenient duplicate edges or faces is not difficult. Here we offer a procedure to avoid this outcome. As an example, assume a repeated extrusion height of 0.12 along the z-axis:
1. In front or side view, wire frame, border select the plane to be extruded.
2. Keyboard choose Alt+'e', then 'Edges Only'.
3. Keyboard enter '-.12 z'.
4. Press Enter.
5. Repeat steps 2 through 4 to create as many stacks as desired, then press 'a' to clear the selection.

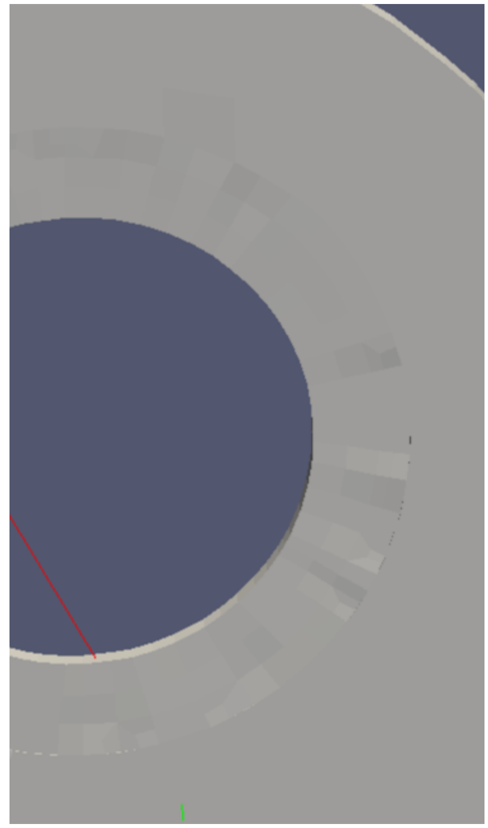
To fill in the horizontal planes (still in front view, wireframe):
1. Border select the initial plane in points select mode, (thus avoiding all created vertical faces).

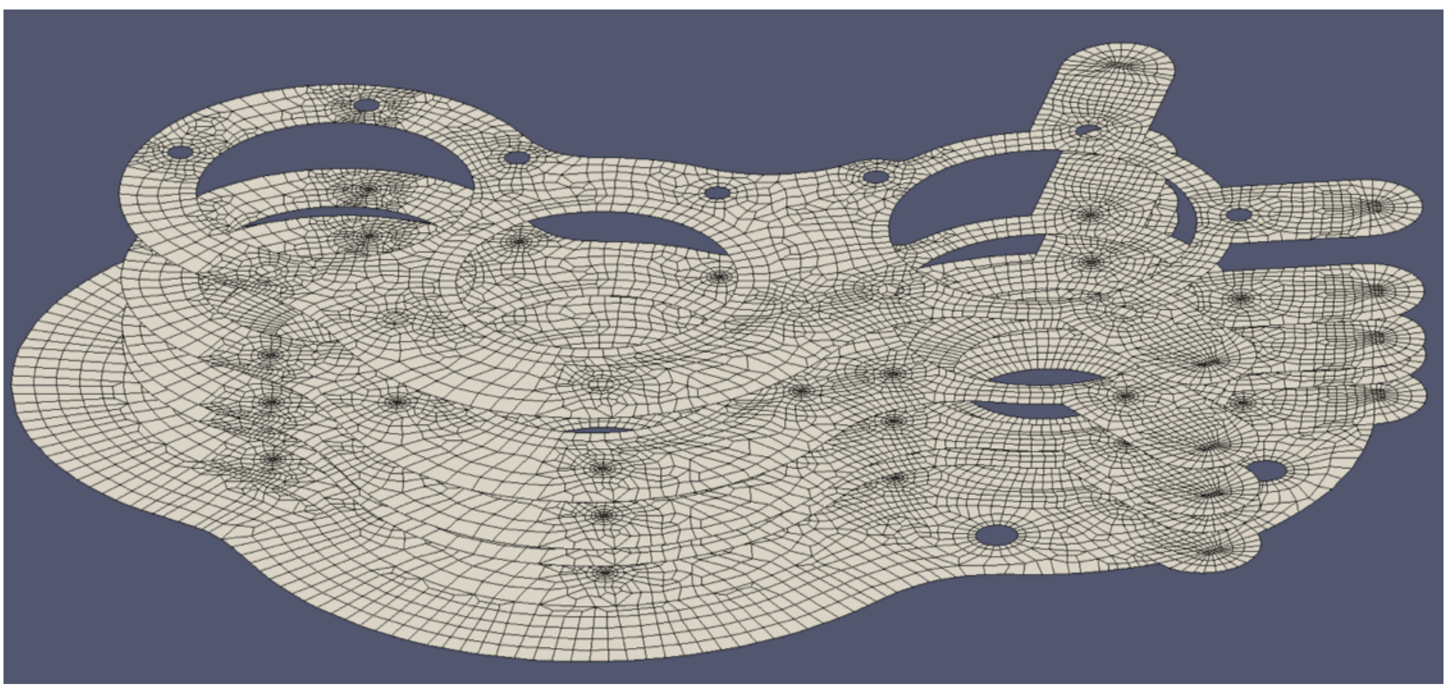
2. Upgrade the selection to face mode.

3. Press Shift+'d' (duplicate).
4. Keyboard enter '-.12 z'.
5. Press Enter.
6. Repeat steps 3 through 5 until the duplication reaches the bottom edges.

Final step: Select all vertices and press 'Remove Duplicates' to remove the swarm of duplicated points which will have accumulated.

At right is an area of relative unflatness. It is easy to see where the tip given on p. 25 still has influence, and where new work has ruined the effect. Best practice would be to always re-flatten the working plane before a cycle of extrusions starts.

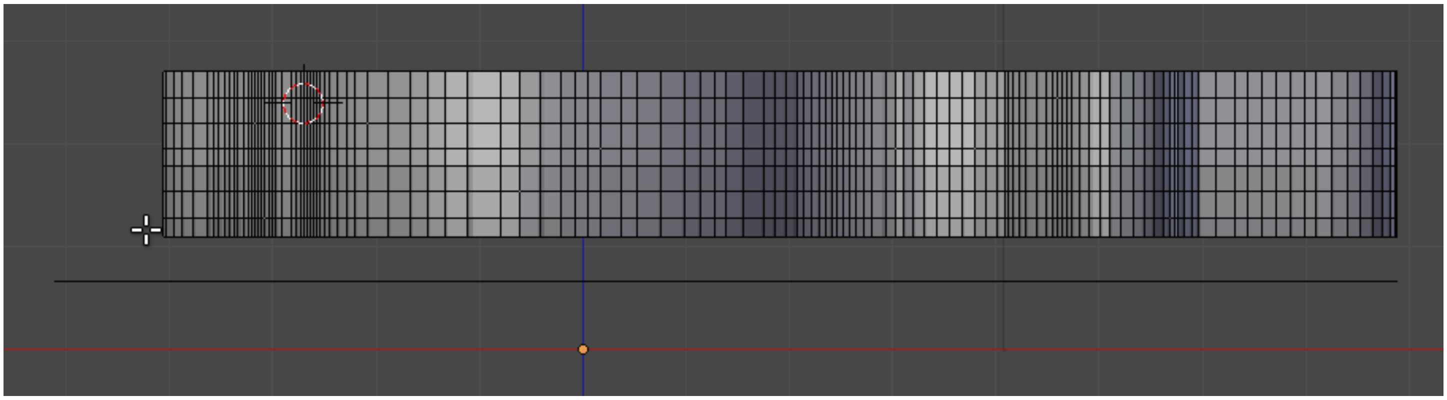




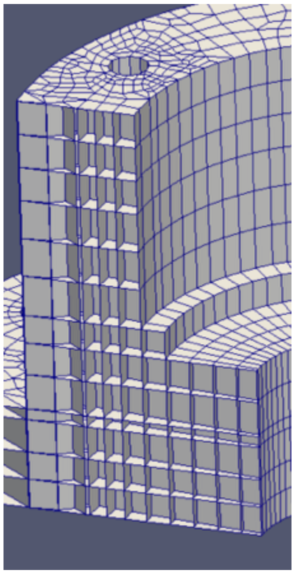
We stage the five working plates that will play parts in the vertical extrusion process. Each plate differs from the one above and below because of its characteristic features.

Plane	Initial Position	Move	Direction	Landmark	Comment
plate #1	2.69902	0.22	down	intermed	extrude edges
		0.22	down	intermed	extrude edges
		0.22	down	intermed	extrude edges
		0.25144	down	hole bottoms	extrude edges
		3 times	down		**duplicate and move** using heights of first 3 extrusions
plate #2	1.78758	0.25	down	intermed	extrude edges
		0.2608	down	1st shoulder	extrude edges
		1 time	down		**duplicate and move** using height of first extrusion
plate #3	1.27678	0.18239	down	2nd shoulder	extrude edges
		0 times			no duplication for this part; plate #4 will supply its floor
plate #4	1.09439	0.21	down	intermed	extrude edges
		0.22776	down	top of flange	
		1 time	down		**duplicate and move** using height of first extrusion
plate #5	0.65663	0.07296	down	cone start	extrude edges
		0.21482	down	cone end	extrude edges
		0.18	down	intermed	extrude edges
		0.18885	down	bottom base	extrude edges
		4 times	down		**duplicate and move** using heights of all 4 extrusions

With a somewhat complicated generation course, we note down the various extrusion steps. Accuracy is a relative concept, but our goal here is to get the horizontal and vertical parts's positions to match within the 0.0001 unit default separation of Blender's 'Remove Doubles' function.

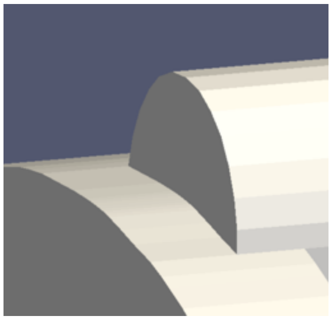


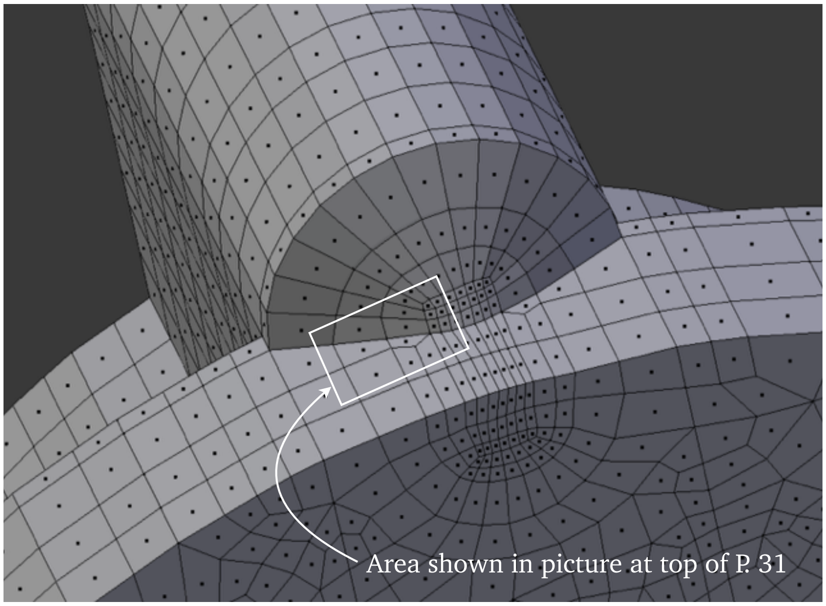
The construction process in progress. If necessary, we can switch out of wire frame for a moment to verify the 3D cursor location for a duplication, then go back into wireframe, press the ‘b’ key, and make the selection. In the above picture, the final as-yet unused plane is shown as the black line at the bottom. After the steps are completed, Blender reports the removal of 54,946 duplicate vertices.



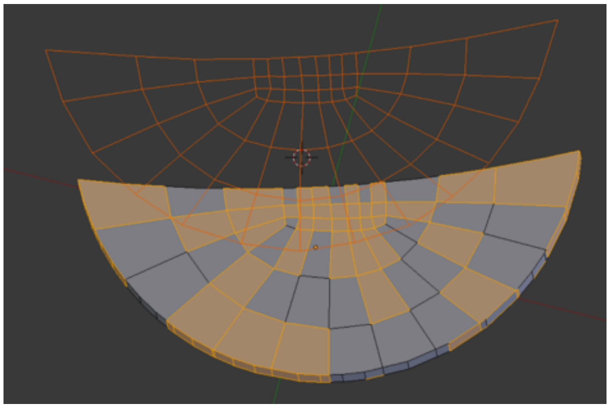
One task which is needed after construction is to verify that the horizontal floors of the mesh all made it into the model. We can do this in Blender, or we can open the mesh in Paraview and apply a Clip filter to the .ply file to have a look inside.

On a first attempt we choose to “de-feature” the conical treatment of the bottoms of the reinforcement lugs and make them flat, as shown below, due to their negative mesh quality impact. However, after consideration, the look of greater authenticity contained in the picture right tempts us to look further into the problem.

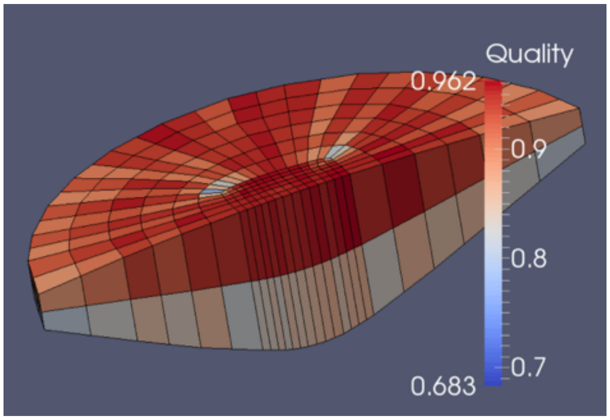




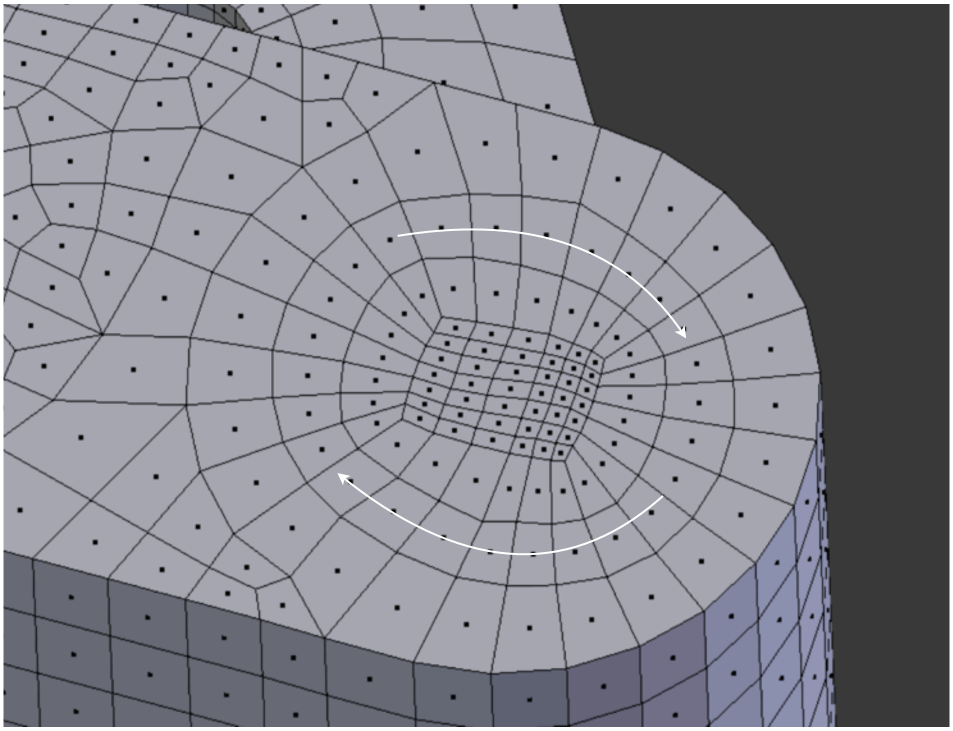
The original model contains the surfaces making up the cones. We desire these surfaces. We use the lug pattern incorporated in our mesh to knife project at full scale down through the original structure, then merge the original into ours, thus capturing the surface contours.



After the Scaled Jacobian quality turns out well, we are encouraged to seek a way to incorporate the cones into our mesh.

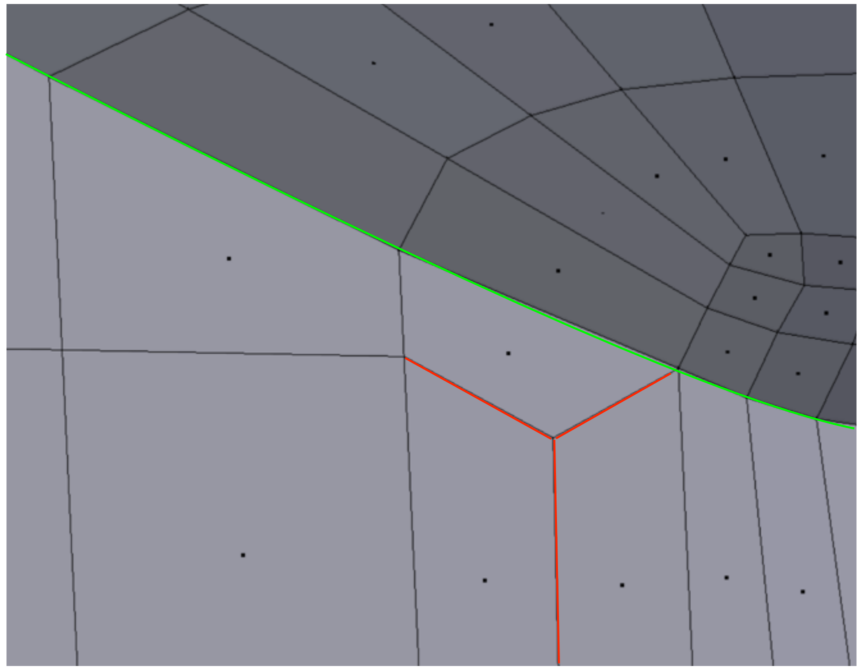


The key concept is reflection. Any nonconforming edge structure is given a reflection path, so that it does not carry back into the main mesh. This strategy prevents excessive proliferation of elements in the main structure.

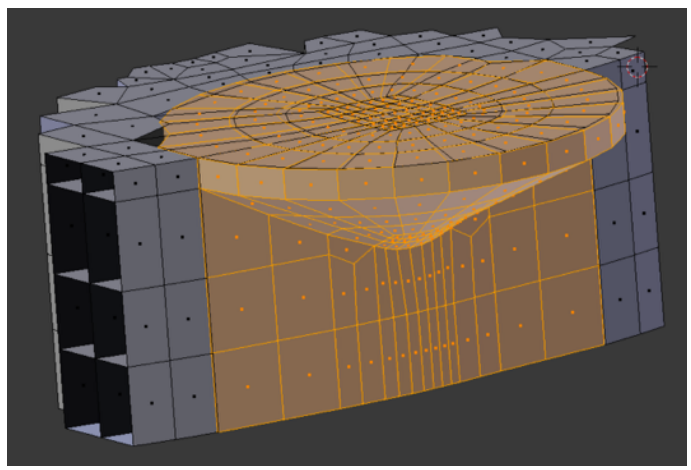


The edges outlined in green are handled by conforming the existing edge network in way of the cone. The edges outlined in red are reflected.

We will see this approach again, in Demo 22.



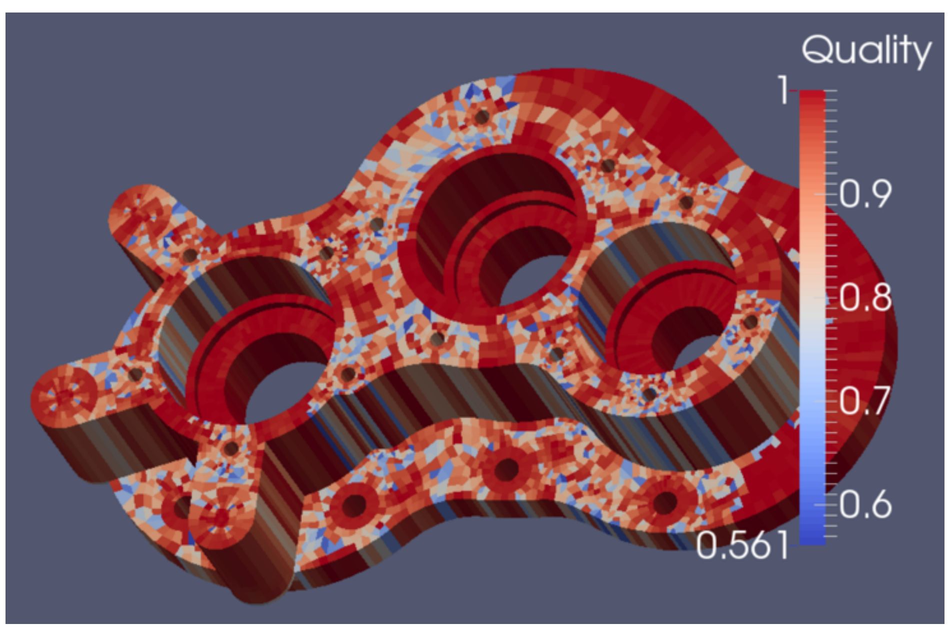
After the fashioning of a successful cone subassembly for one reinforcement lug, the basic pattern is adapted and reused on the other two. Slight accommodations are necessary to suit individual sites.

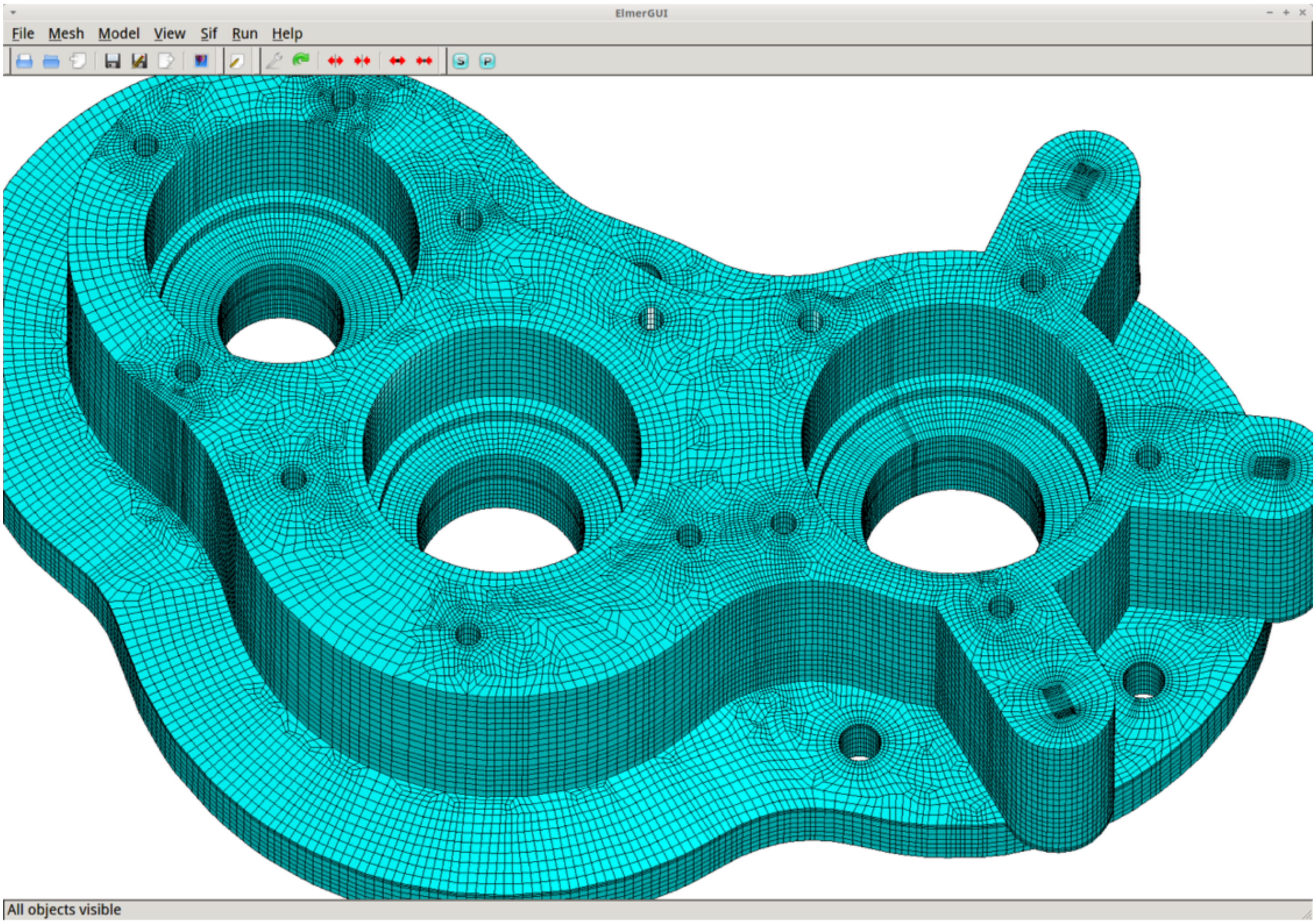


The final mesh quality check is favorable, showing a minimum Scaled Jacobian score of 0.561.

For the final mesh, we allow Gmsh to refine and split it. This results in 404,480 elements and 444,215 nodes.

For Blenbridge to convert the .ply file to .vtk format for this rather large model requires 44 minutes 44 seconds on a recent Macbook.



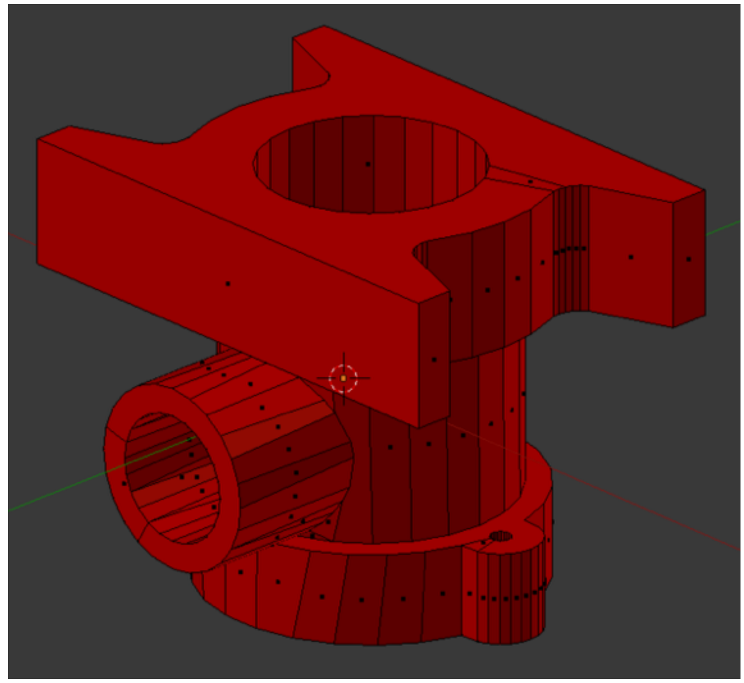


The final mesh is shown in Elmer GUI. With 16GB of ram, we could possibly carry out either a heat transfer calculation or tackle a structural mechanical problem, assuming we are using an iterative solver, the type which Elmer has.

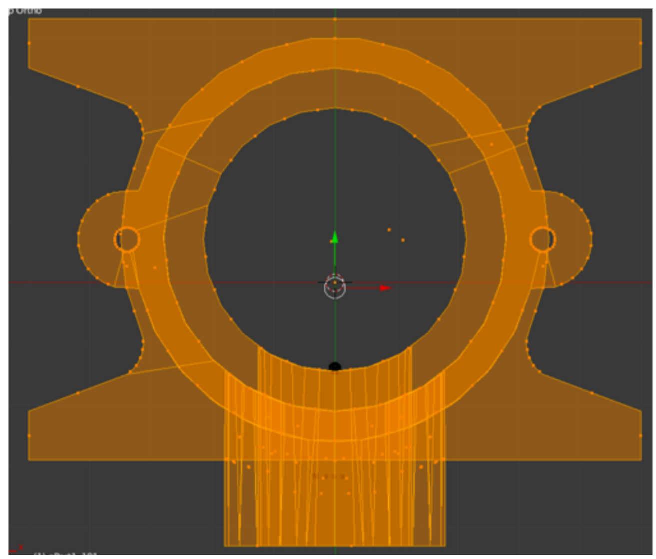
If a smaller model is needed, the version before Gmsh refinement has the same quality level, but only 50,560 elements and 60,590 nodes.

Demo 8

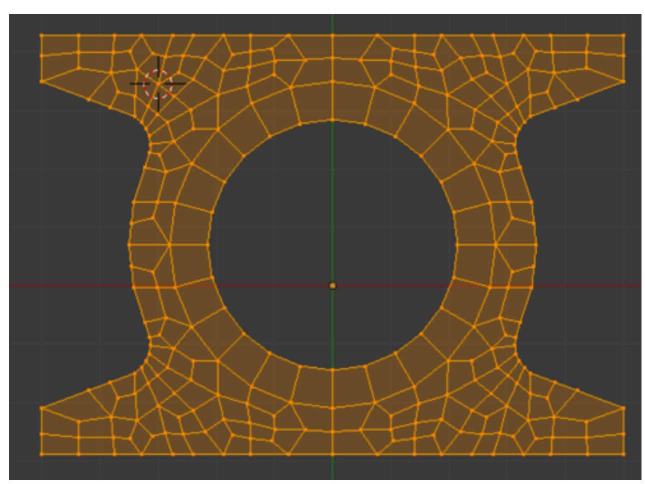
This object is a specialized pipe fitting. It resides in the INRIA model repository as a .3ds file, and is imported into Blender with Blender's .3ds import script. Its title is "DEMO10" (See References). We apply the mesh command Tris to Quads and then Limited Dissolve at a level of 8 degrees.



In a top wireframe view we get an 'x-ray' look at the model. The perpendicularity of the geometry checks out good, but the quad angles of the faces making up the horizontal pipe are irregular and the horizontal pipe will be rebuilt. Notice that in the model as shown both ID and OD of the horizontal tube penetrate. However, for finite element mesh purposes it is not necessary for the OD to do so.

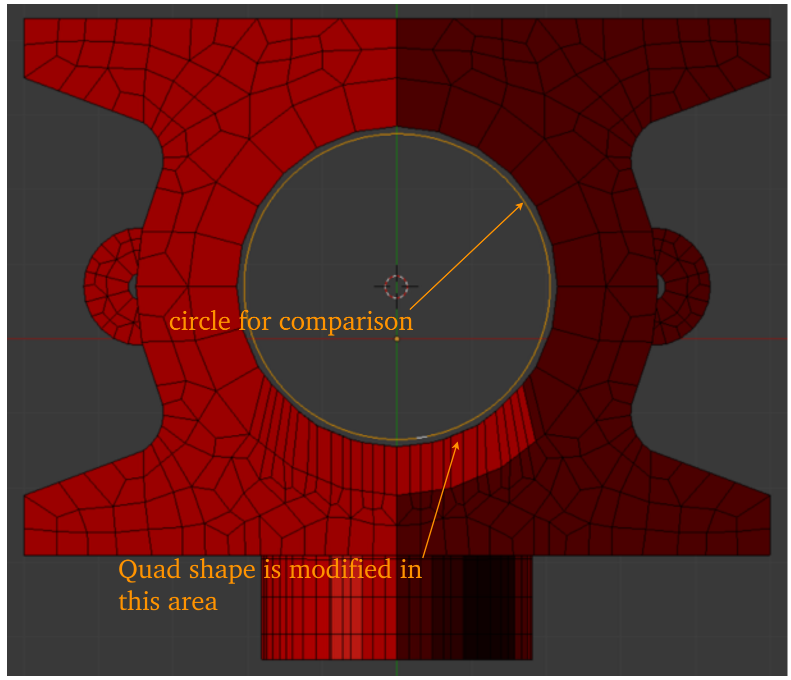


An early version of the 'hat' plate is shown. Where symmetry exists, mirroring saves work.

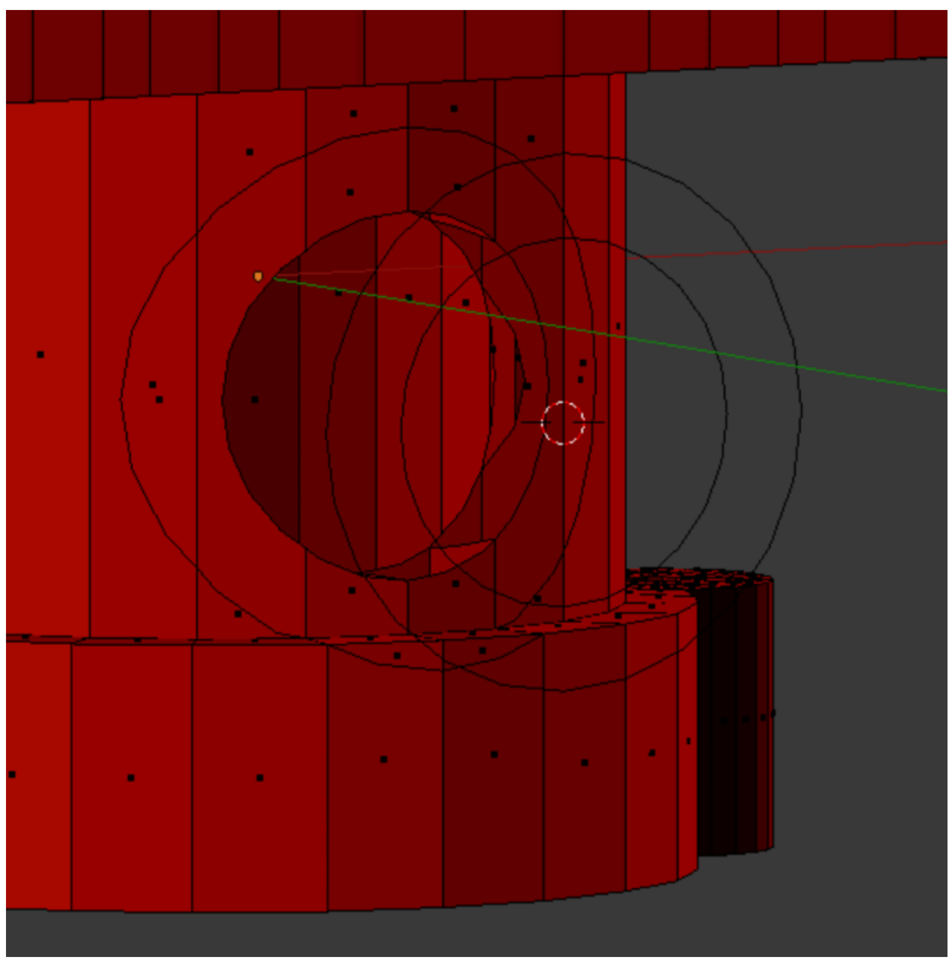


Our main challenge will be building the mesh in the area of the horizontal penetration. Of the 24 divisions in the horizontal pipe section, some will be incorporated vertically, and some horizontally. The elements in the vertical tube wall are modified to ease the area of vertical integration.

Also, to meet the minimum element quality level for Verdict's Scaled Jacobian, we found it necessary to fudge the circularity of the ID slightly, as can be easily seen in the area indicated by the lower arrow.

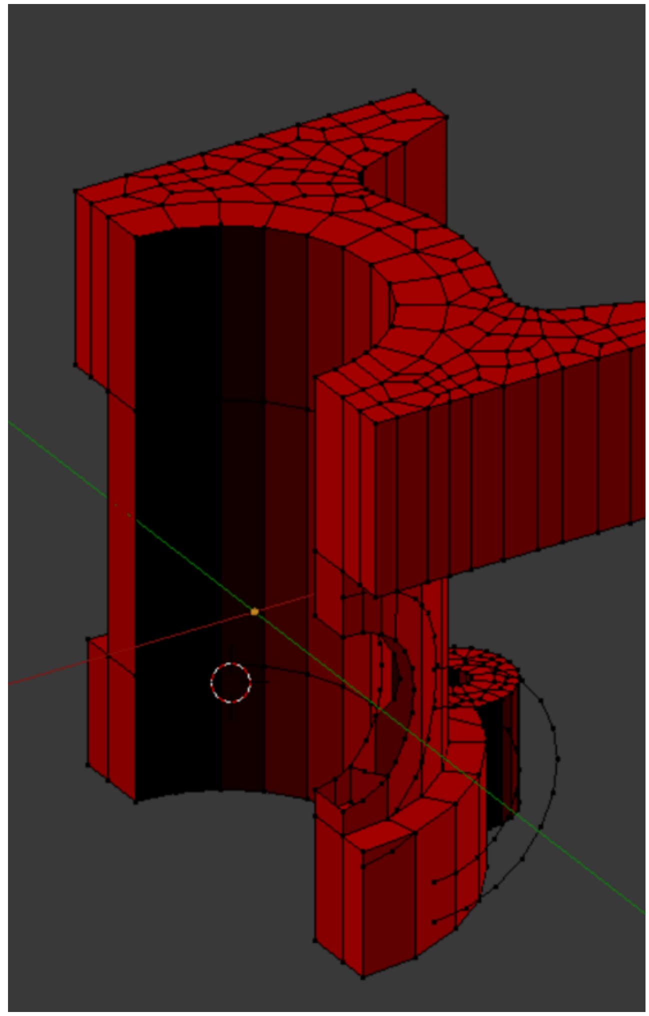


New circles are made and saved separately. It is necessary for the circles to be separate objects in order to use the Knife Project tool. Also, before cutting the inner surfaces, it may be necessary to hide the new faces created by the OD cutting circle in order to give the ID cutting circle "room to work". The floating set of circles will be joined and eventually form the boundary end of the horizontal pipe. Before that happens, they make useful reference shapes, frequently referred to by pressing the '1' key to see the front view.



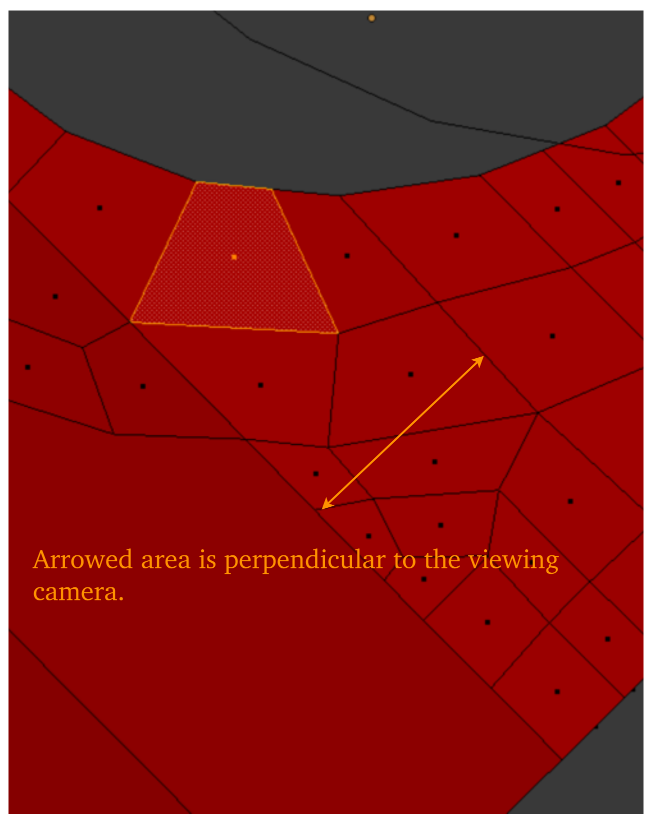
The cutting circles are brought in from their own .blend file using the Append command, while in Object mode. The line in the Append packing list that contains the desired item is the Objects line.

An important characteristic to remember about the Knife Project command is that the cut which it makes copies the camera view exactly at the instant the cut is made. Therefore Shift + ‘1’ is pressed prior to the cut.



The Knife Project tool is located in the Add section of the ‘t’ (Tools) sidebar.

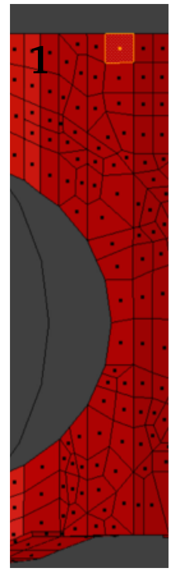
To move a vertex along an edge is not difficult, we just use the Shift + ‘v’ command like always. However, in order to ‘g’ (grab) a vertex without disturbing the flatness of the working area, the view needs to be perpendicular to the camera. This is accomplished by selecting a face on the hex flat being worked on, and pressing Shift + ‘7’.

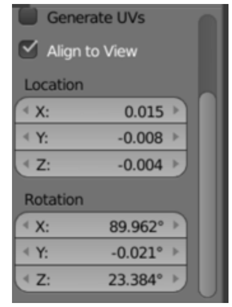


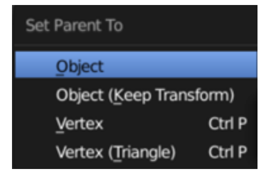
The Shift + ‘7’ command for perpendicular viewing covers normal situations, but sometimes it is necessary to flatten a patch of faces whose plane has an arbitrary spatial orientation. A procedure for this somewhat involved and rarely needed task is as follows:

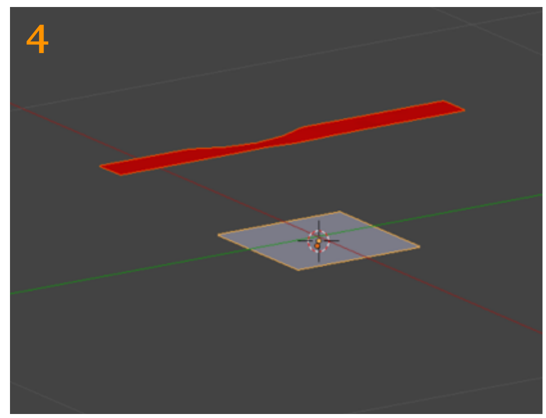
1. Use Shift + ‘7’ , + ‘1’, or + ‘3’ to bring one single, selected face of the patch into the most convenient face-on viewing perspective. (Pic 1.)
2. Select the remaining faces of the patch.
3. Press ‘p’ , then ‘Selection’ to make a separate object from the patch.
4. Tab into Object mode. Deselect all.
5. Select and hide all except the patch object.
6. Add a mesh plane. Check-mark the box in the Tools panel labeled ‘Align to View’. (Pic 2.)
7. If necessary, scale the newly added plane so that the plane and the patch can be seen side by side.
8. Deselect all, then select first the patch, then the plane.
9. Press Ctl + ‘p’, (parent), then ‘Object’. (Pic 3.)
10. Zero out the x- y- z-settings of the plane in the rotation section of the Properties panel. (The patch will follow the plane.) The patch is now aligned to the global axes. (Pic 4.)
11. With the patch selected, Tab into Edit mode. (No harm if the parent plane remains visible.)
12. Perform the flattening operation along the z-axis, as described on p. 25, to make the patch completely flat. (Pic 5.)
13. Tab back to Object mode.
14. With both patch and plane selected, press Alt + ‘p’, then, ‘Clear Parent’. (Pic 6. The patch snaps back to its original position.) Delete the plane.
16. Unhide the hidden parts of the model.
17. Join the patch back into the model.
18. Tab back to Edit mode to resume work.

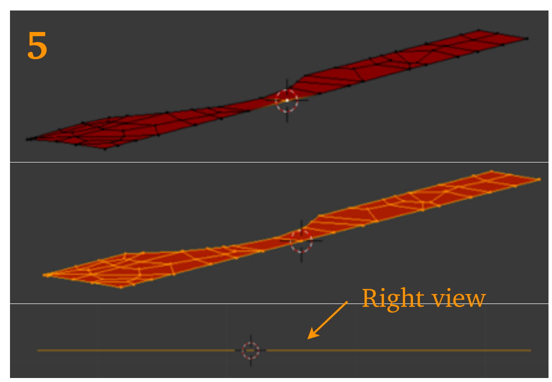
If this does not work the first time, watch the short YouTube video NEUa1IA7NBQ, “How to Straighten Inclined Objects in Blender.” (See References.) This video shares some of the steps outlined above. It should be noted that this method of flattening only works if the unflatness to be removed is small in scale.

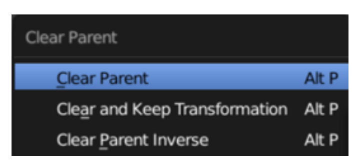


2


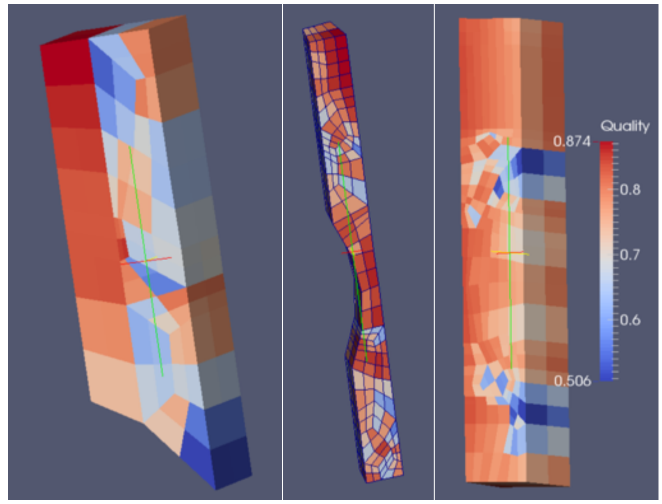
3




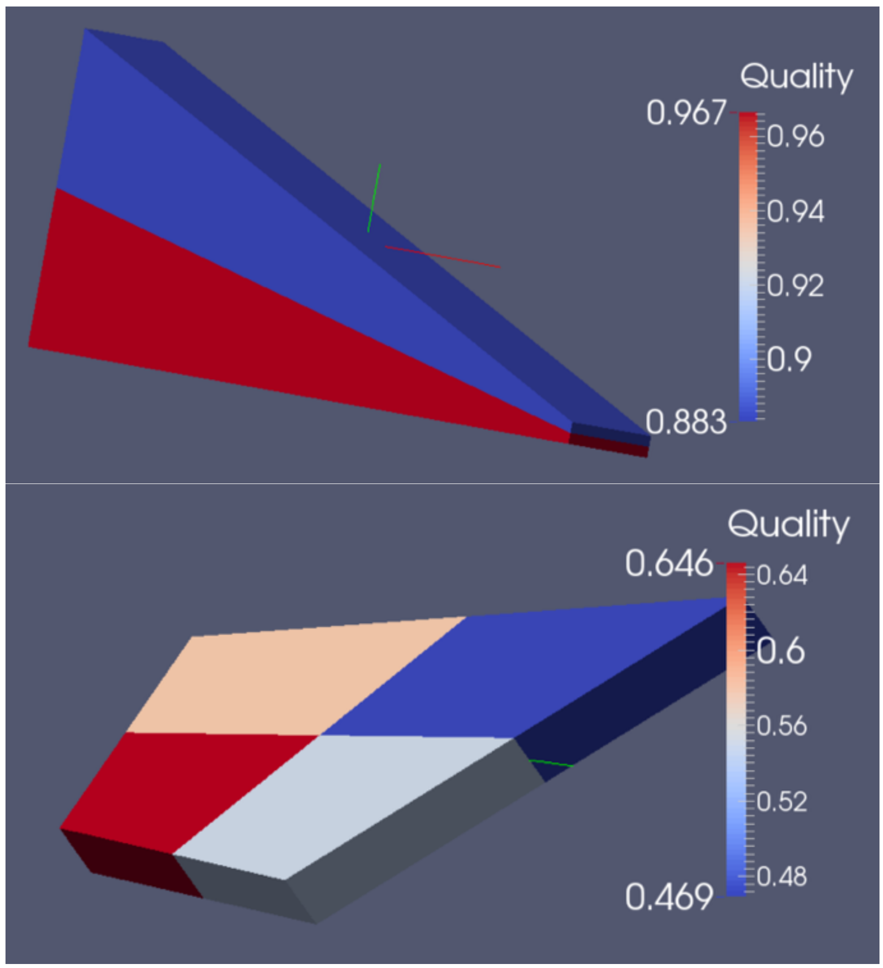


6


As we progress in the process of building up the detail in the penetration area, we occasionally break off chunks comprised of elements, convert them to .vtk, run them through Gmsh, and then examine them in Paraview. It is remarkable how greatly the quality improves after remeshing in Gmsh.



As an experiment, we make two single elements in Blender with the same general body taper of 28 degrees. One element is a wedge with a nose, and the other a diamond. Gmsh splits them into four. Then we view their Scaled Jacobian values in Paraview. Notice the disparity of scores. The option of installing a nose is worth remembering for those situations in which it will work.



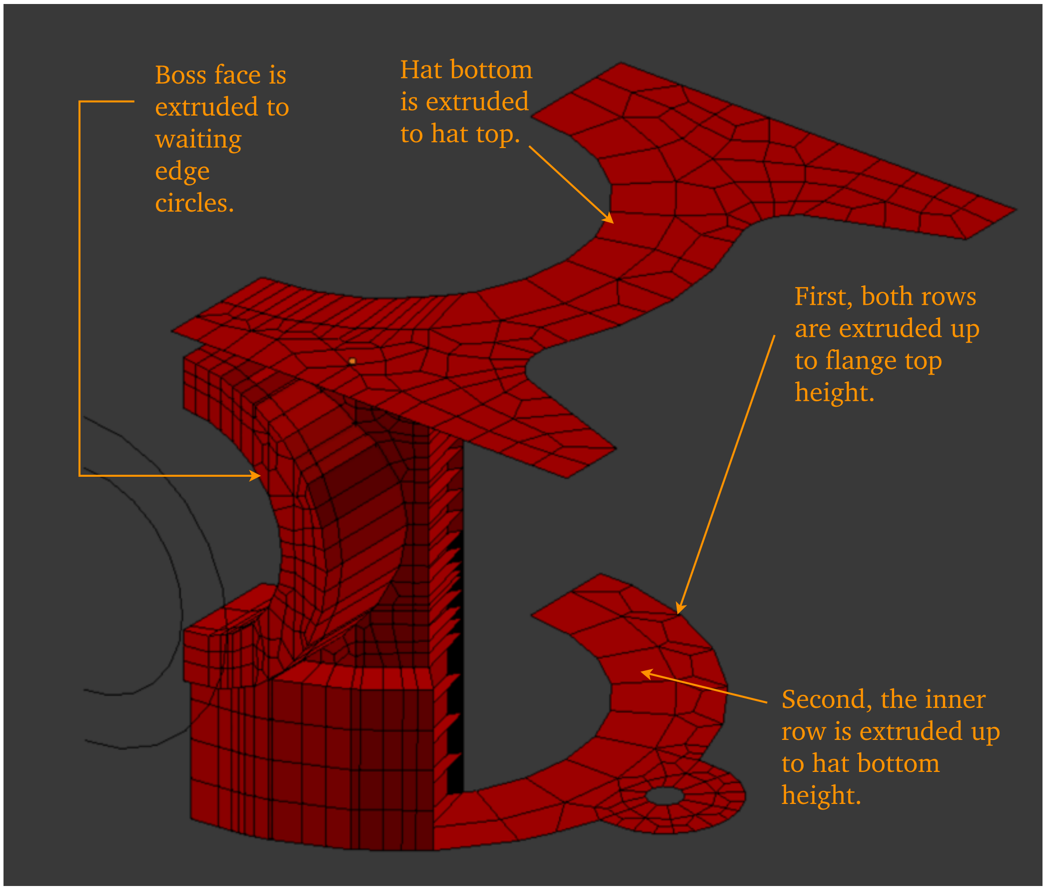
Plane	Initial Position	Move	Direction	Landmark	Comment
floor base	-0.04048	0.00448	up	intermed	extrude edges
		0.00448	up	intermed	extrude edges
		0.00448	up	intermed	extrude edges
		0.00456	up	flange top	extrude edges
		4 times	up		**duplicate and move** using heights of all 4 extrusions
vertical wall	-0.02248	(see list of 22 moves below)	up	base is flange top; final extrusion is hat bottom	extrude edges
	1: .00161, ***2:*** .00134, ***3:*** .00184, ***4:*** .00154, ***5:*** .00068, ***6:*** .00098, ***7:*** .00155, ***8:*** .00185, ***9:*** .00234, ***10:*** .00235, ***11:*** .00235, ***12:*** .00235, ***13:*** .00146, ***14:*** .00132, ***15:*** .00159, ***16:*** .00085, ***17:*** .00137, ***18:*** .00154, ***19:*** .00288, ***20:*** .00174, ***21:*** .00227, ***22:*** .00218				
		21 times	up		**duplicate and move** using height of first 21 extrusions
hat	0.0155	0.00625	up	intermed	extrude edges
		0.00625	up	intermed	extrude edges
		0.00625	up	intermed	extrude edges
		0.00625	up	hat top	extrude edges
		4 times			**duplicate and move** using heights of all 4 extrusions
horizontal pipe	-0.02708	0.005	negative Y	boss surface	extrude edges
		0.005	negative Y	intermed	extrude edges
		0.005	negative Y	intermed	extrude edges
		0.00092	negative Y	end-of-pipe surface	extrude edges
		4 times	negative Y		**duplicate and move** using lengths of all 4 extrusions

The various extrusion steps are summarized. In comparison to the work associated with meshing the penetration area, the extrusions are negligible in terms of the time they require. Note that the coordinate numbers are all extremely small. Blender can work comfortably on a very small scale, if the model happens to be so constructed. However, it can have undesirable repercussions, for example when removing doubles.

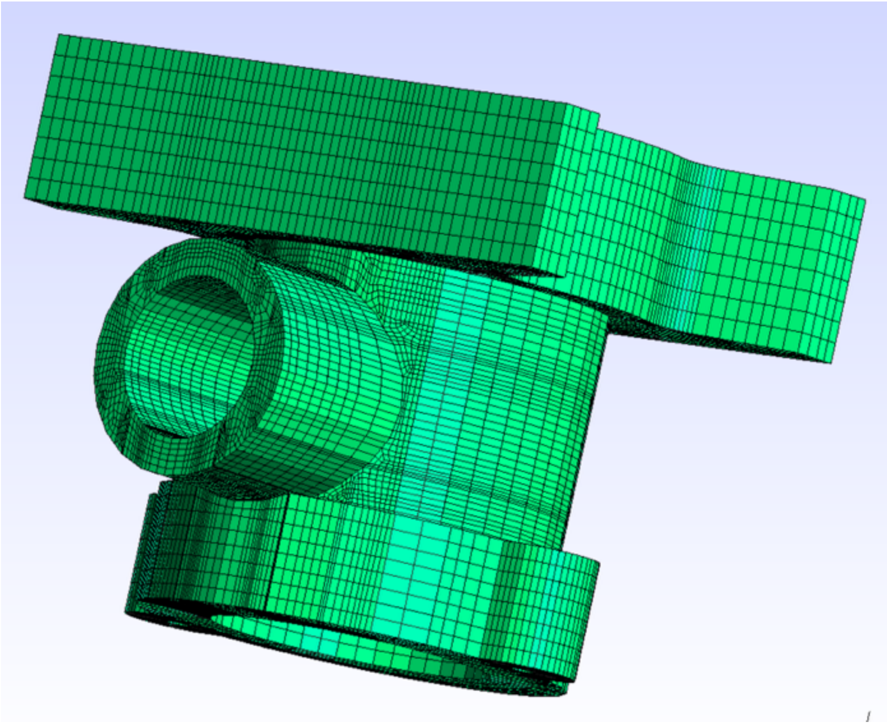
The model at the time of the start of the extrusion steps is shown.

The double arc of quads which forms the base will serve for two extrusion steps, the outer elements becoming deselected when the upper extrusion is performed.

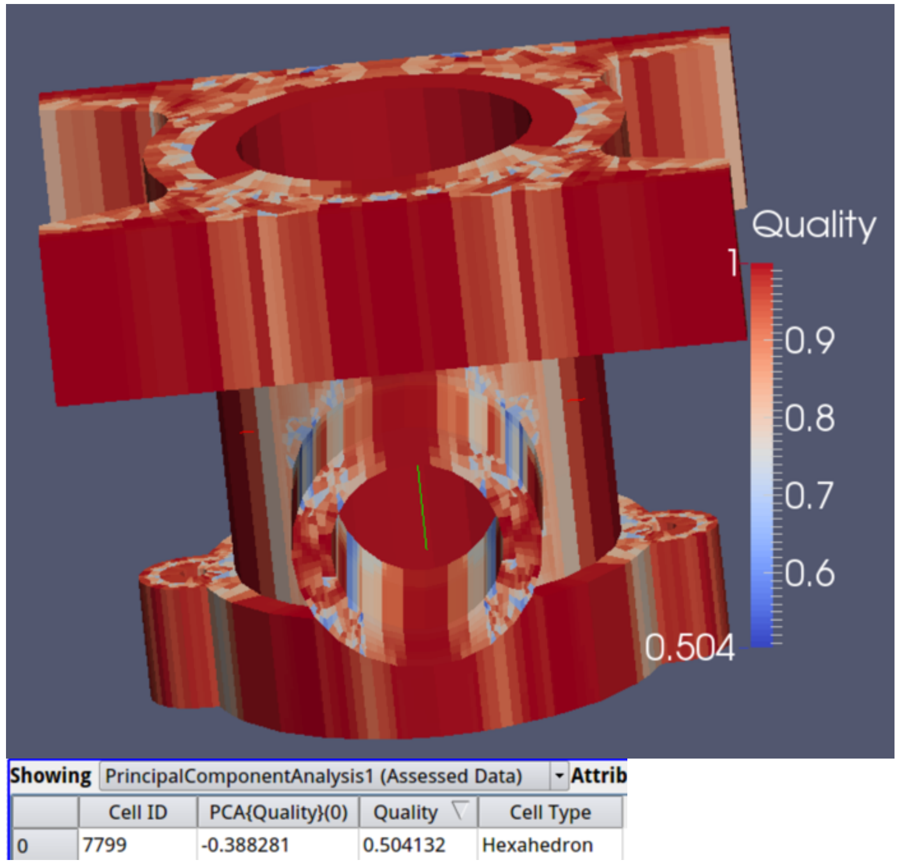
Note that we choose to save final mirroring until last. However, it is not necessary to do it this way.



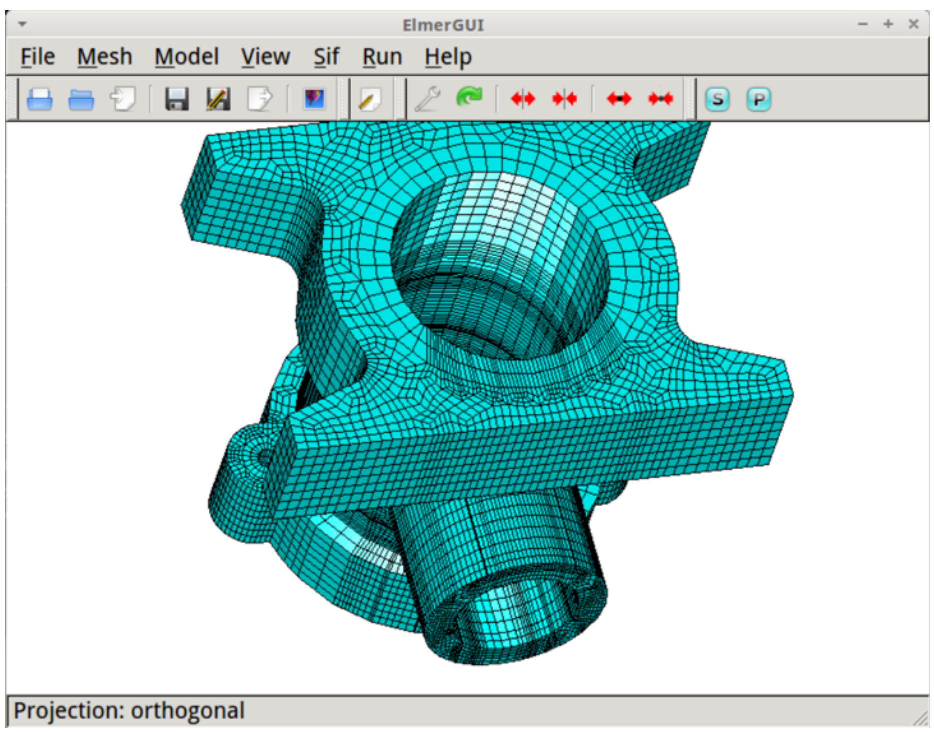
The final model is shown as it emerges from the Gmsh remesh. It has 32,744 elements, and 42,005 nodes.



The final quality for the indicator Scaled Jacobian is shown, along with the worst element value. All elements are in the acceptable range.

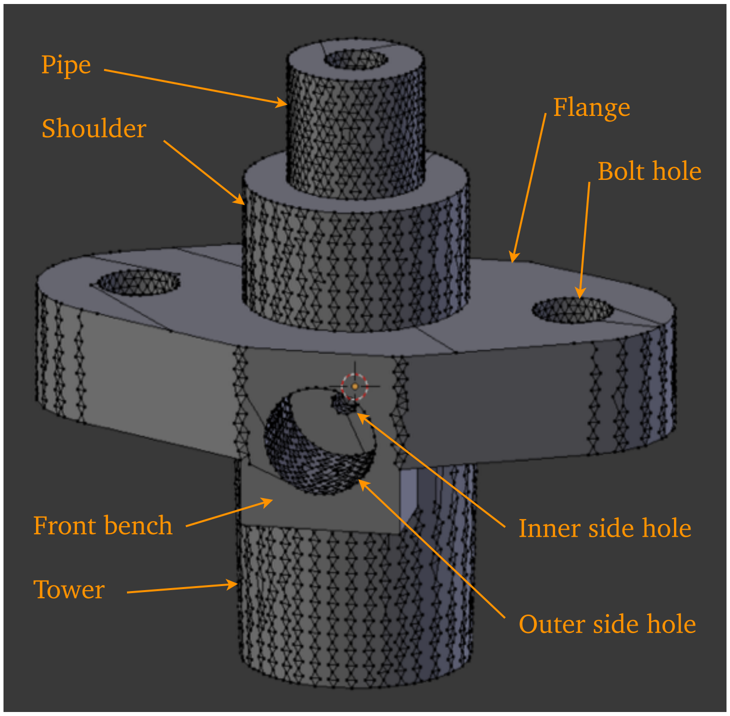


Again we show the model in Elmer, after it is saved in Gmsh. This mesh is relatively small, and within the resources of a typical laptop, many things could be done with it.

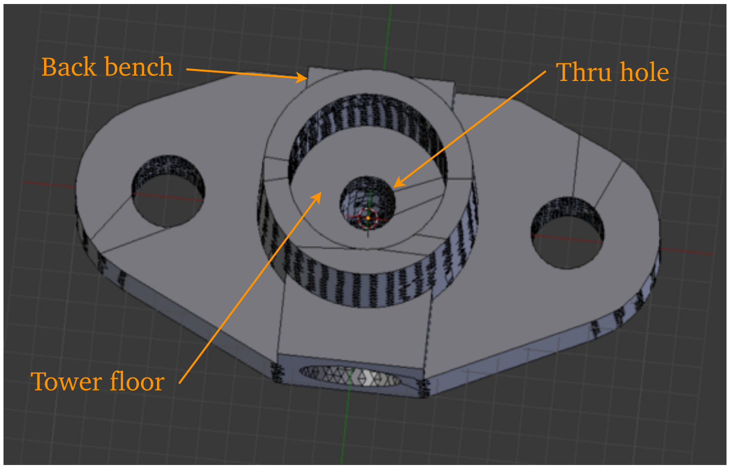


Demo 9

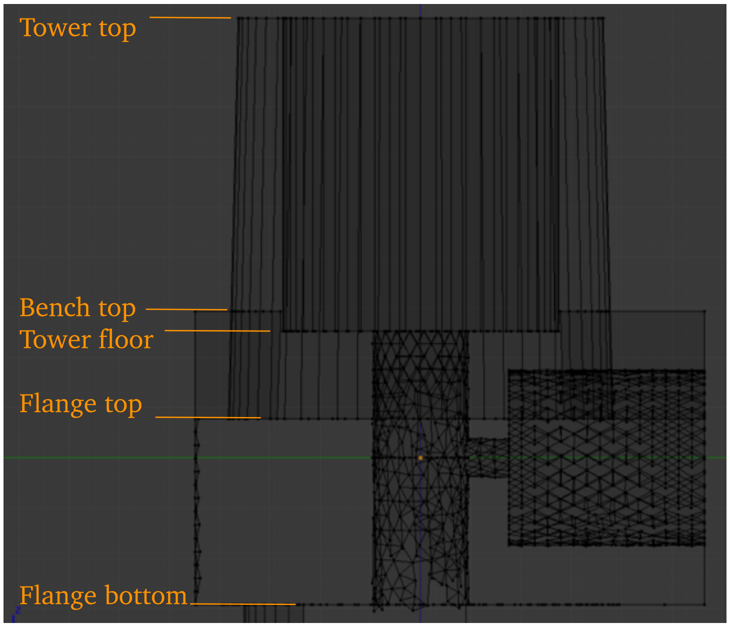
This object is a flange from the OpenFOAM Basic tutorials folder (see References). Its title is “flange”. The original .ans file is converted to OpenFOAM format with the utility ansystoFoam. Then the OpenFOAM file is converted to a triple .obj file with the utility writeMeshObj. A 3D .obj file is distilled by hand from the triple file, then Blender’s .obj import script imports it. We give it a Partial Dissolve treatment of 5 degrees, but the pattern of edges which remains is not useful.



In order to simplify reference to the parts of the model, we may have cause to refer to these areas with the arbitrary names contained in the pictures shown at right.



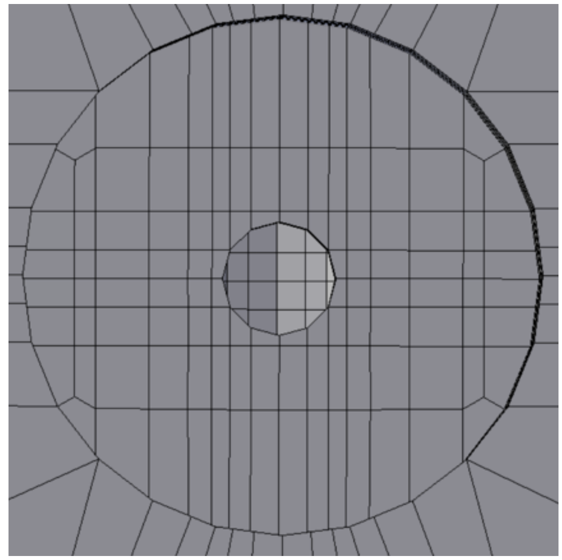
A section view shows some of the vertical landmarks.

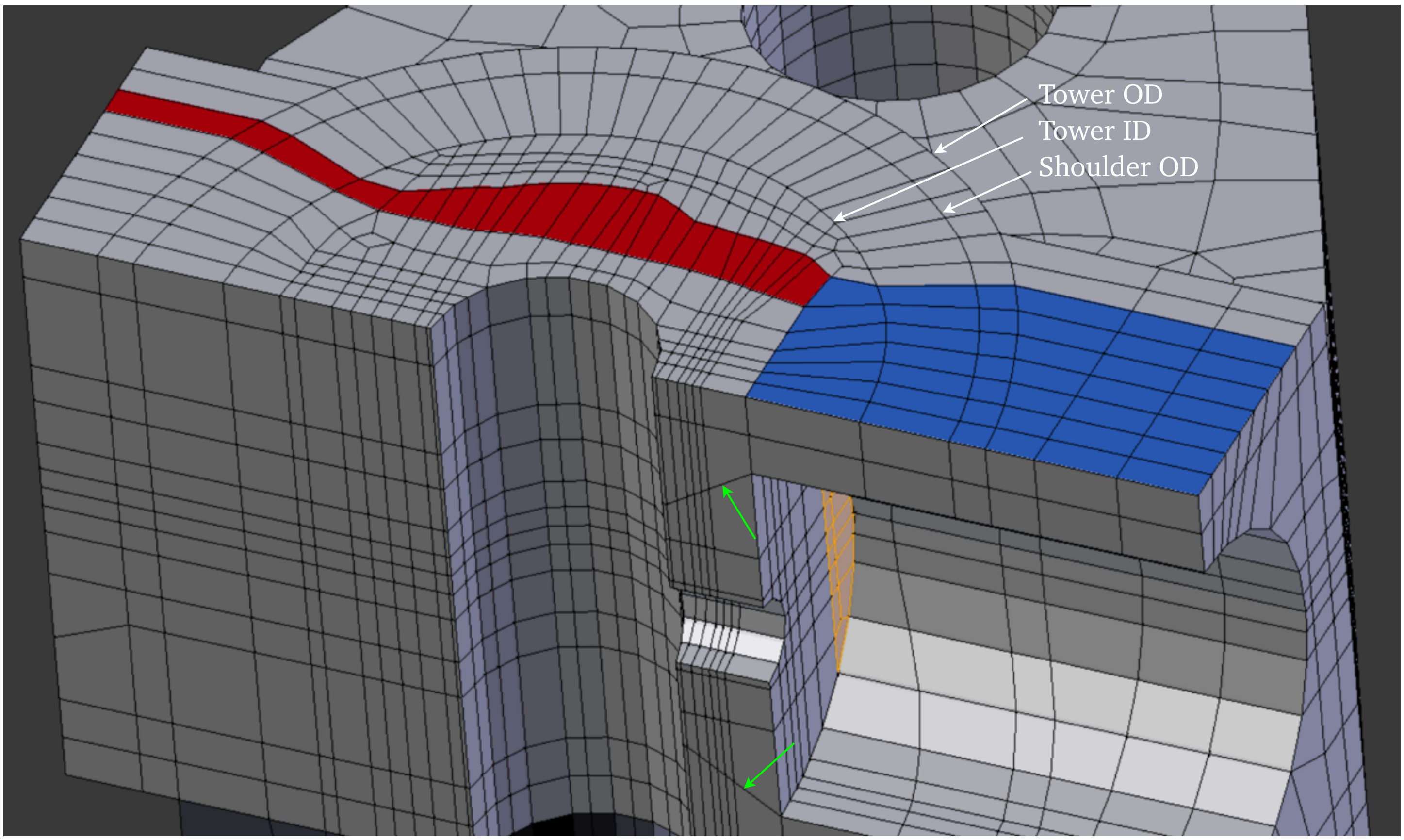


Those holding Blenbridge documentation below version 1.12 will see this demo handled with tetrahedra, due to its complexity. On re-examining it however, we found a path for building it out of hexahedral elements, which brings hexahedral consistency to the full set of demos presented here.

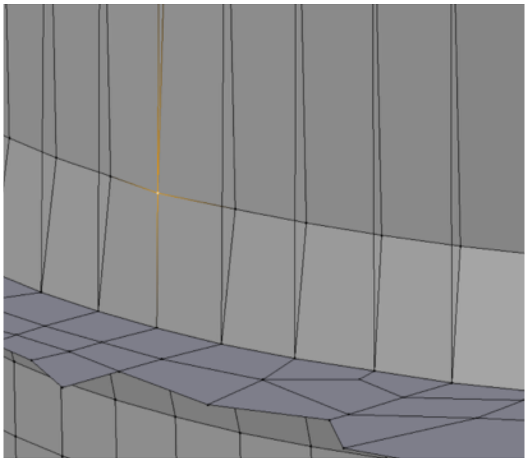
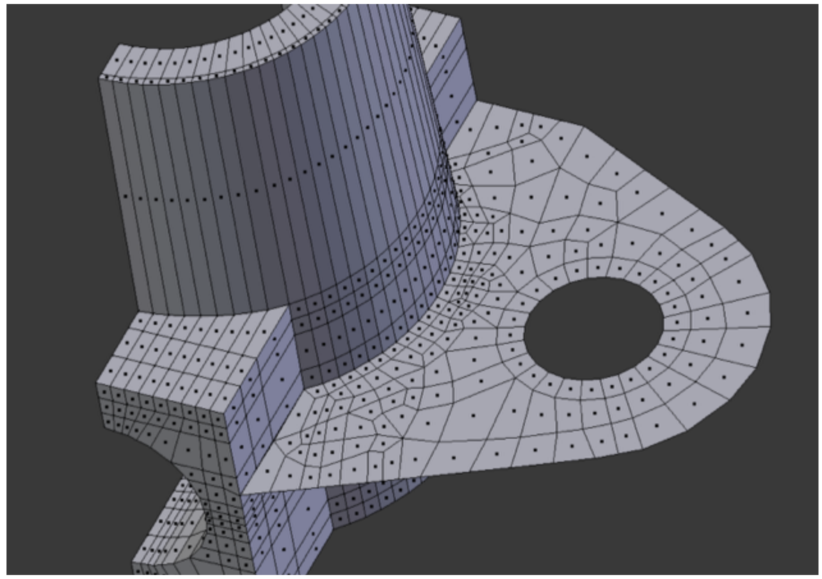
Since the internal diameters of the two side holes and the Thru hole represent the most difficult parts of the project, we decide to make the Bench first.

The pattern used for the Outer and Inner side holes is shown at right. Since it will be used for horizontal extrusions, its vertical lines represent the general direction of its dominance.

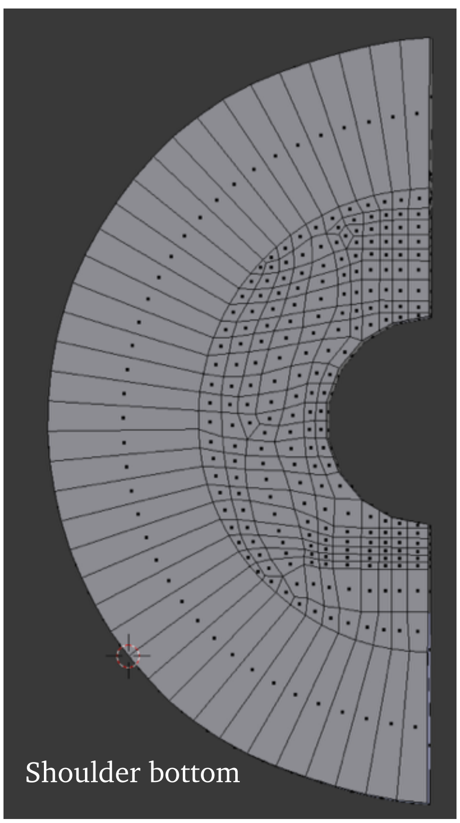


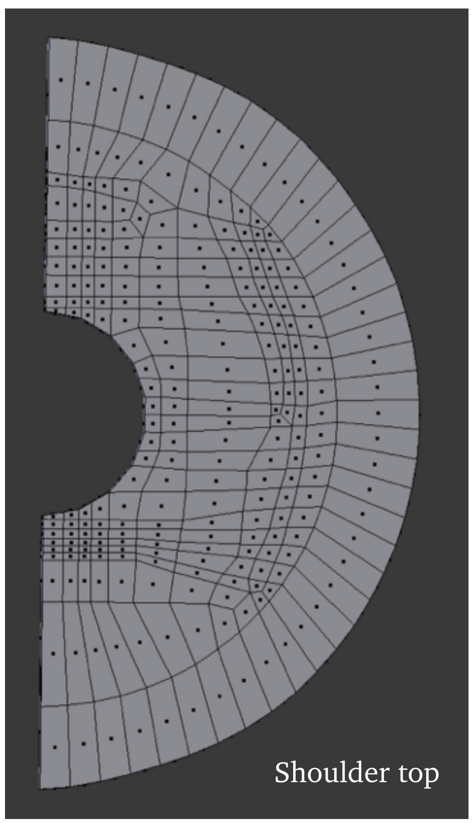


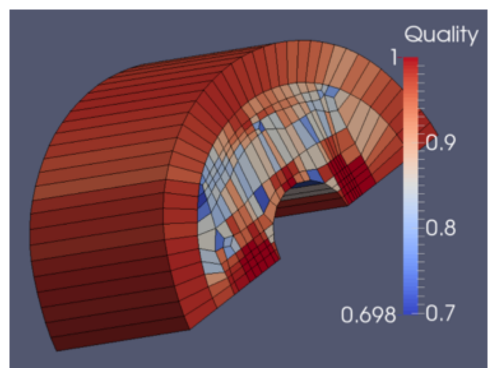
Looking back from a later stage, after various modifications, we can still see the basic construction technique for the Bench. The area of initial horizontal extrusion for the Outer hole is marked in blue. Then we do the Thru hole vertical extrusion, including Tower curves and Back bench. The Outer hole curved section of faces, orange, cannot be accommodated by a vertical extrusion, so we make a gap whose location is shown in red, and do a horizontal extrusion, with all else hidden. We designate each separating plane of this extrusion as a **vertex group**, and from a top view these can be rotated and moved without distortion to match the edges on either side. We cut and line the Inner hole without difficulty. Note the green arrowed lines showing the area where we blend the curved Outer hole circle to flat lines.

We build the Tower. The left picture shows the method we use to extend the Tower's tapered OD below the top of the Bench. We make a set of faces for the Flange using a typical motif.

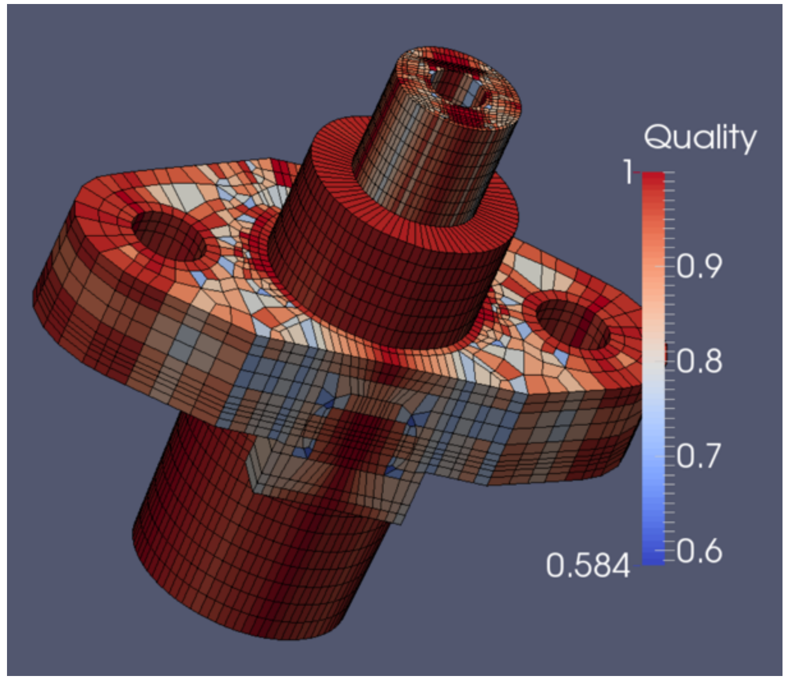


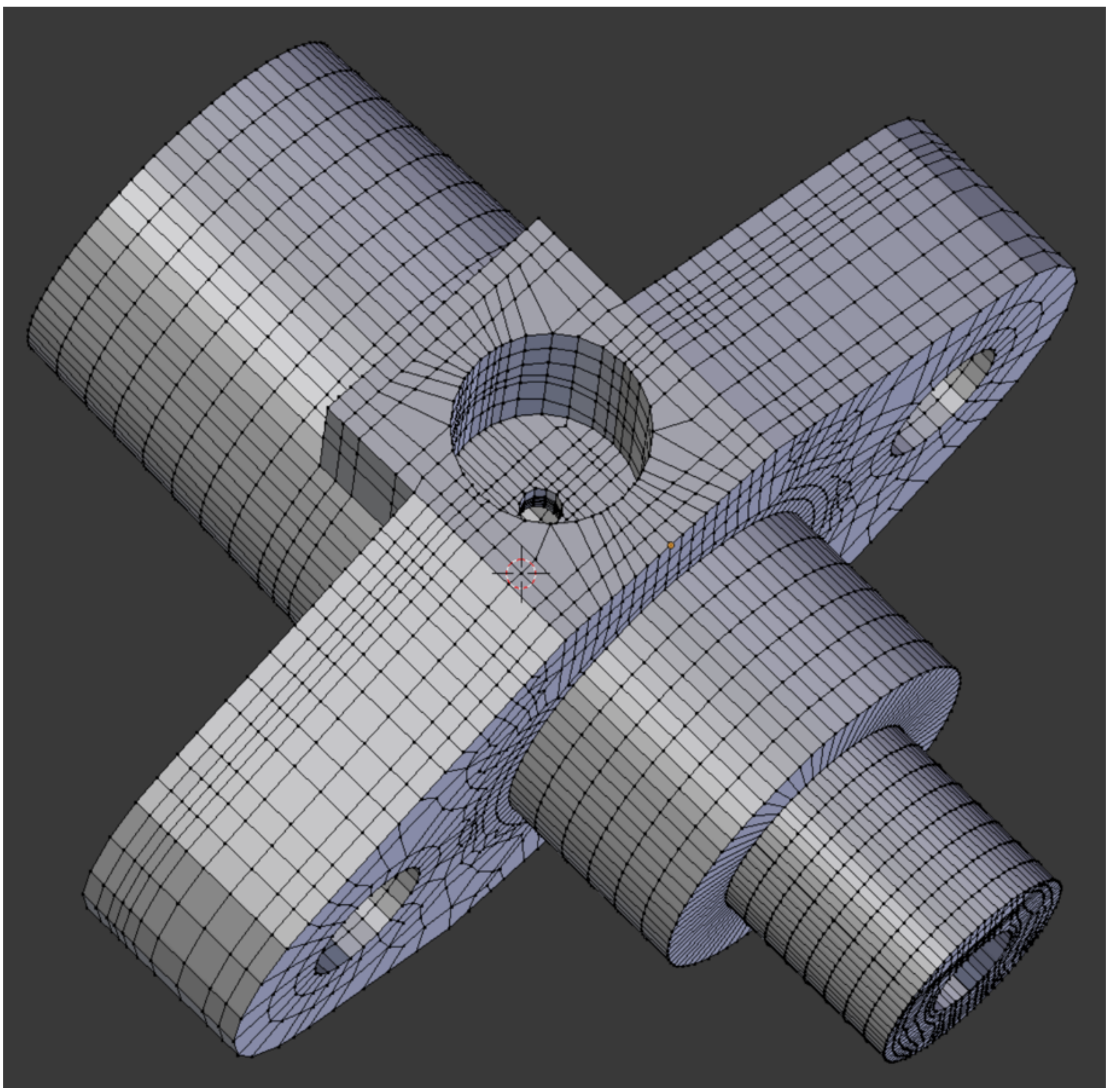




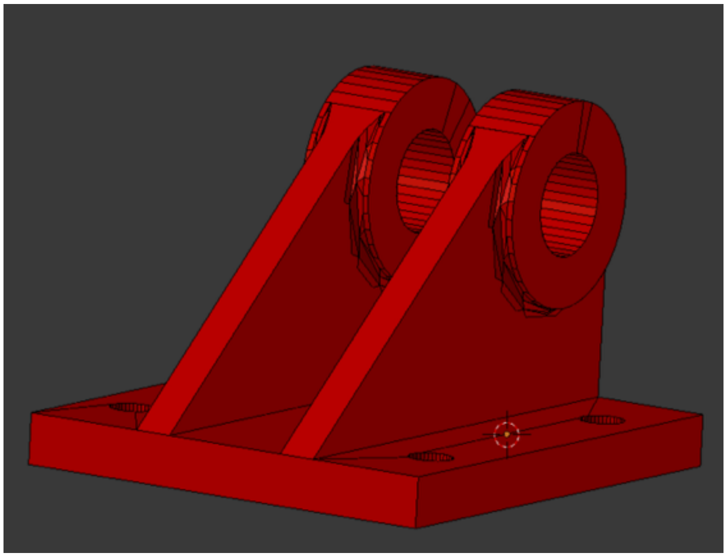
Turning our attention to the bottom of the mesh, we get a flat surface to work with because the Flange bottom is vertically flush with the Bench. We will re-purpose the Tower OD circle into the Shoulder OD circle, and the Tower ID circle into the Pipe OD circle. Analogous edges fit into their new boundaries without difficulty. A quality test tells us that the resulting tapering of elements does not detract from Scaled Jacobian quality.

The final quality test shows a Scaled Jacobian value of 0.584, well above the minimum acceptable. The final mesh contains 20,160 elements and 23,978 nodes.



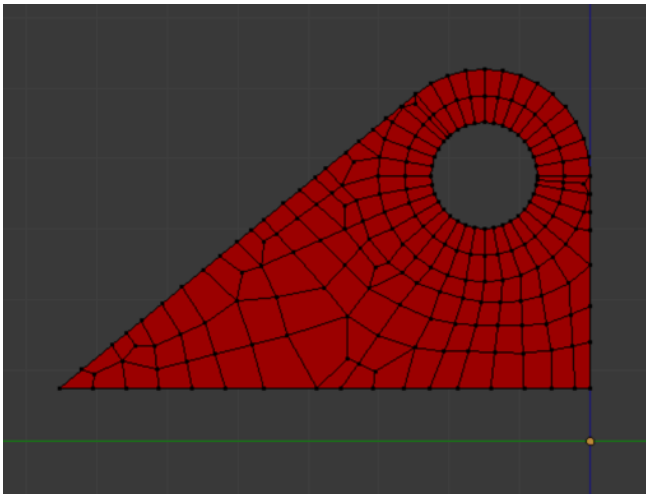


Demo 10

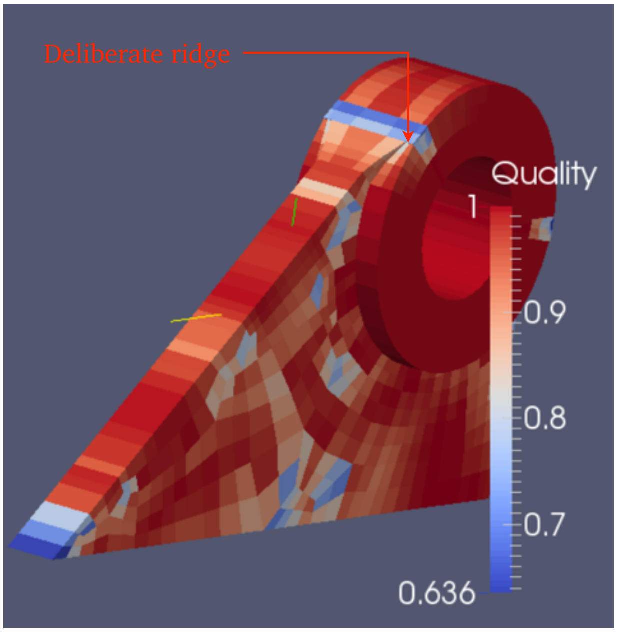


This object is a clevis bracket; the model is held at the INRIA model repository as a 3ds file, and is imported into Blender with Blender's .3ds import script. Its title is "Aries155" (See References). We apply the mesh command Tris to Quads and then Limited Dissolve at a level of 5 degrees.

The pin sleeves have a fillet zone which is poorly represented in the model. We choose to avoid this feature and simplify the sleeve ODs to meet the vertical plates at a right angle.



A flat plate of faces is shown ready to extrude.

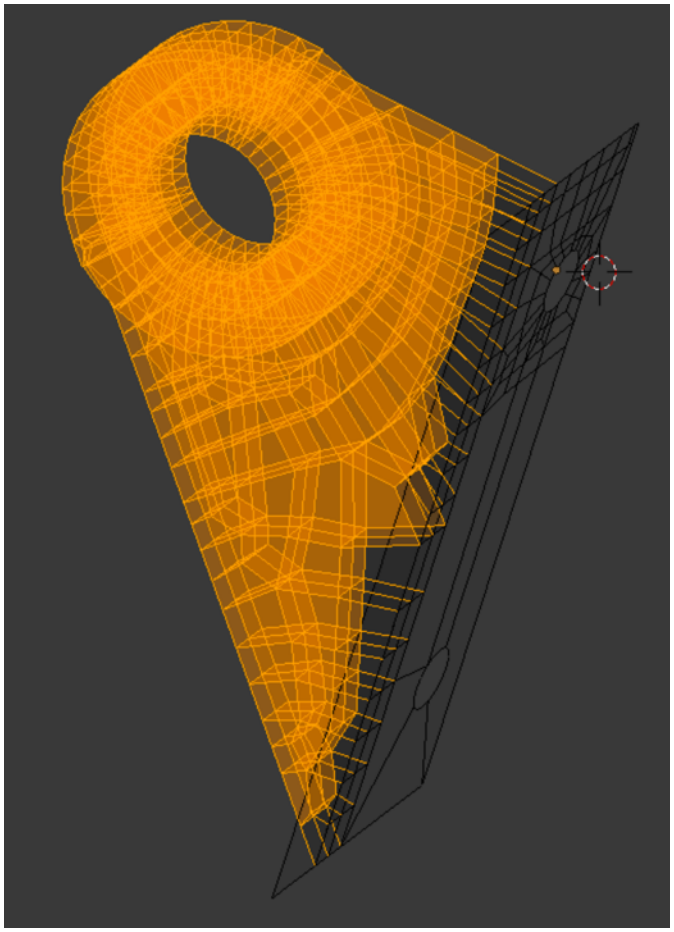


One of our 'ears' easily makes the Verdict quality level for Scaled Jacobian after passing through Gmsh.

Extrusion is in the plus x-direction.

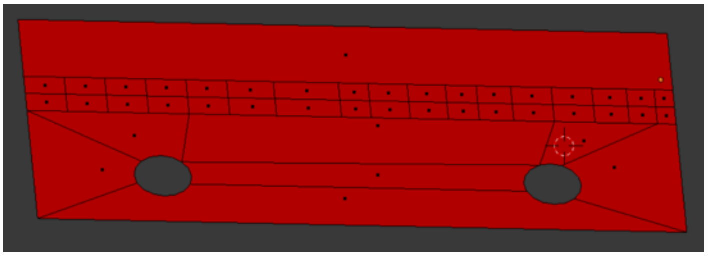
Vertices in the tangent area are adjusted after extrusion to approximate the designed 'flare'. A thin ridge remains as a compromise between mesh quality and hyper-proliferation.

The ‘ear’ is hidden while the base plate is worked on. A little care on our part in selecting edges for hiding allows a double strip of faces to be left on the base plate to guide the face creation procedure.

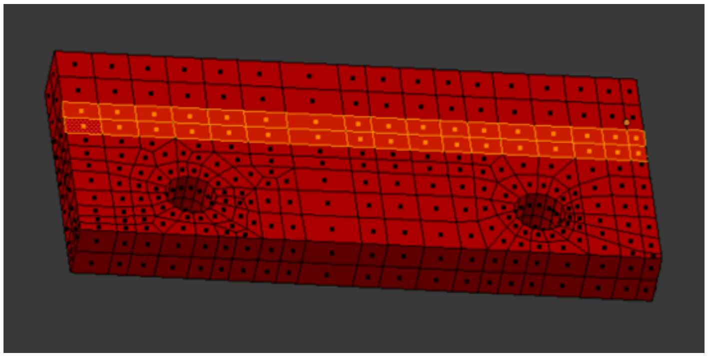


Half of a base plate is shown.

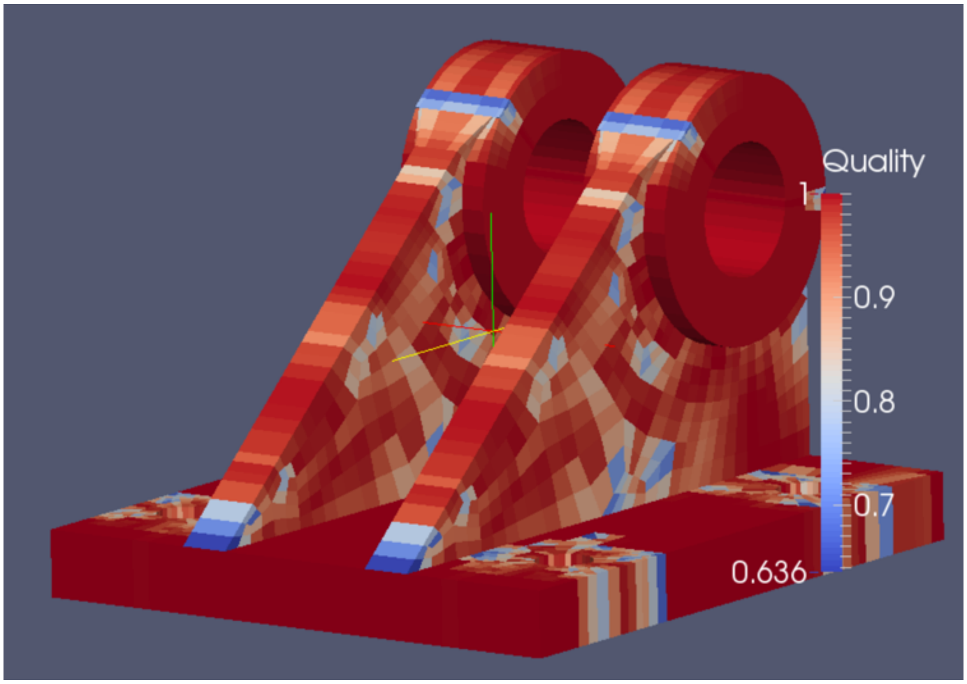
Hole circles will be replaced with 16-division circles.



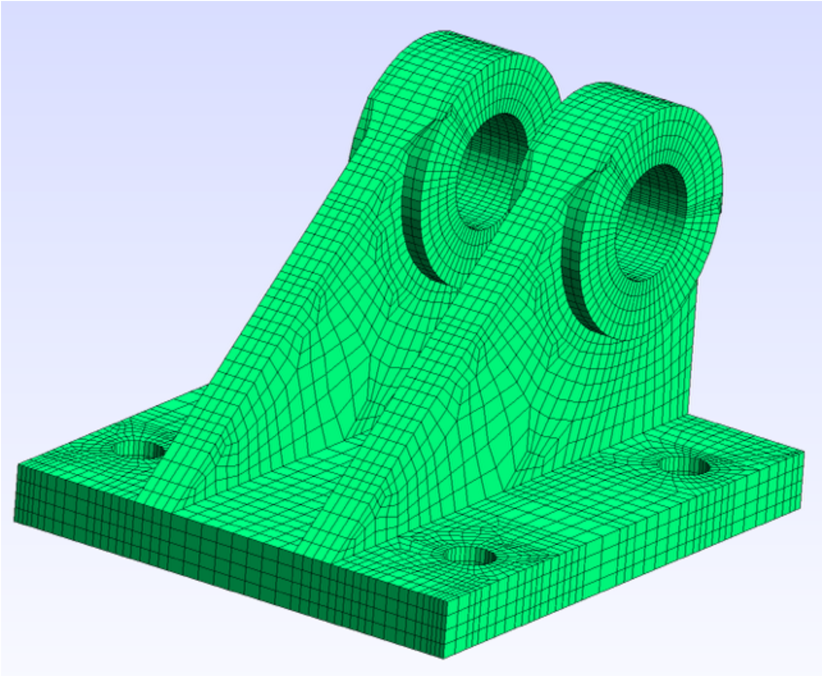
The element pattern is designed for the base plate. The selected faces show the reserved location of the still-hidden ‘ear’.



All elements meet the Verdict standard for Scaled Jacobian.



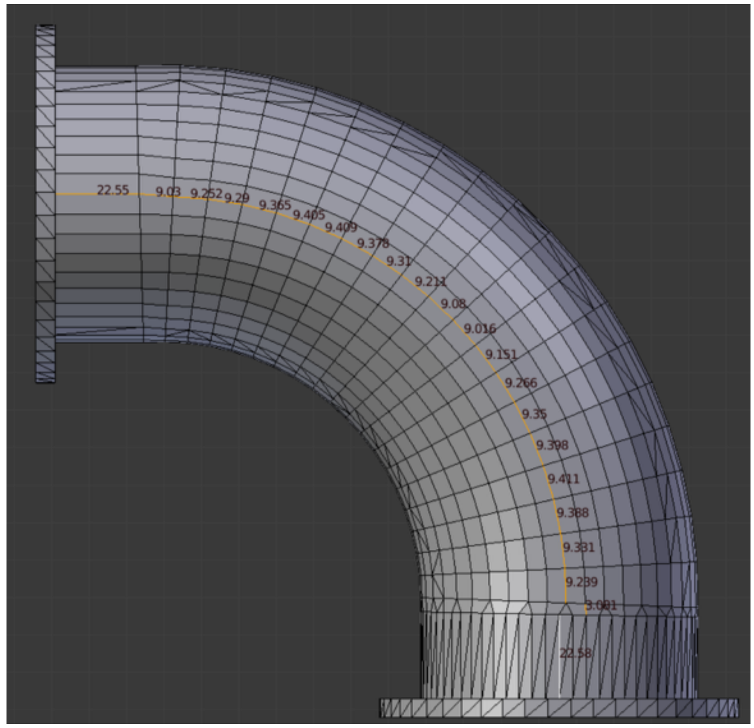
We do not record a spreadsheet for this demo, since the steps are simple. We extrude a half-ear in plus-x, then mirror it. We extrude half a base plate in the minus-z direction, then connect it with its ear. We then mirror the half-assembly and check the the seam for continuity.

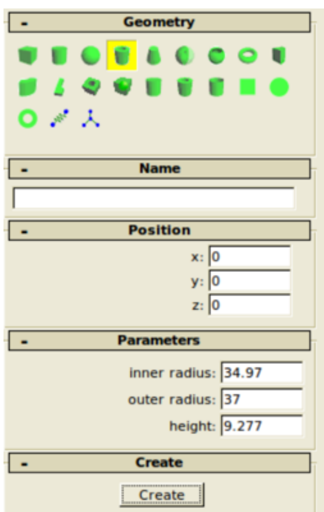


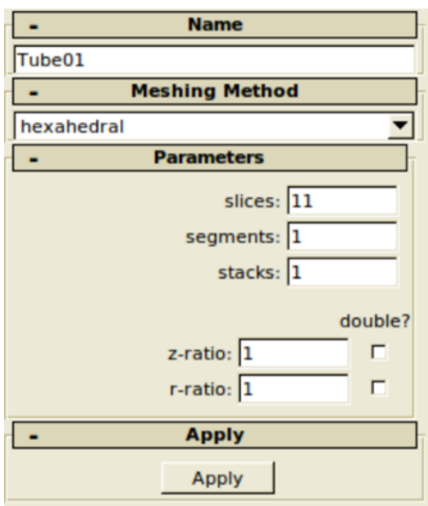
The bracket model contains a relatively small number of elements, 14,912. Our treatment has been a simple one; there are many ways the complexity could have been allowed to expand.

Demo 11

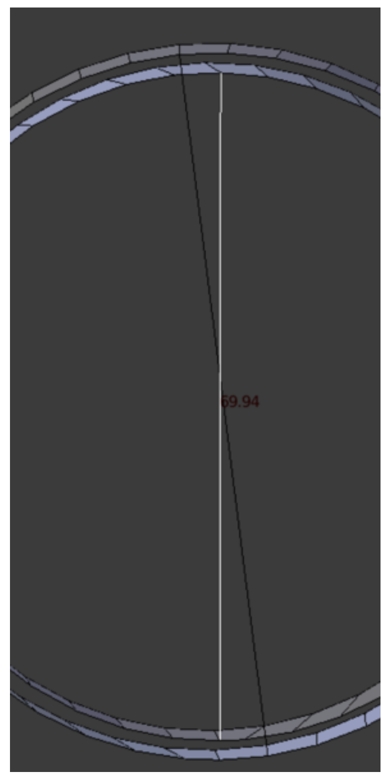
This object is a 90-Degree Ell; the model is held at the INRIA model repository as an .obj file, and is imported into Blender with Blender's .obj import script. Its title is "Y7034" (See References). We apply the mesh command Tris to Quads and then Limited Dissolve at a level of 5 degrees. A predominantly quad structure remains, but it is somewhat irregular, and internally a large number of faces would need to be created to attain enclosed elements throughout. We elect to rebuild the model. The picture at right shows the edge lengths revealed in Blender.







The Febio Preview dialog boxes are shown which produce one single segment of pipe mesh. After it is created, Blenbridge converts it to .ply format, which Blender imports. Of course we could have just as easily have created the pipe segment by extruding circles inside Blender.

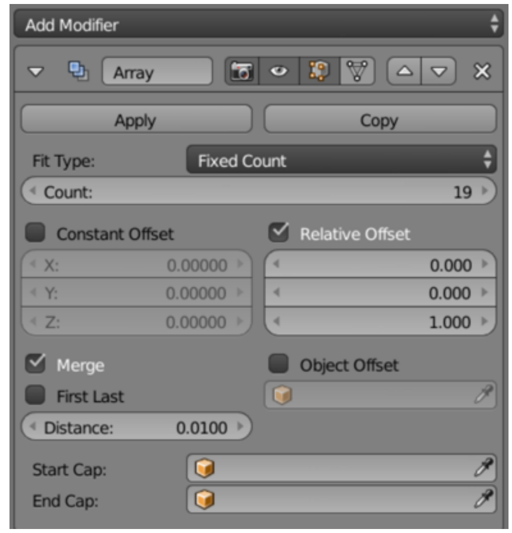


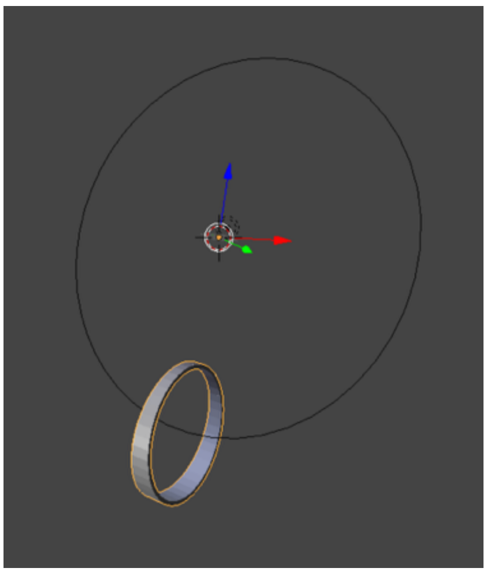
The Outer and Inner diameter of the original model are measured as shown.

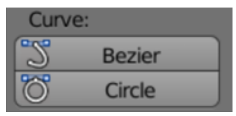
In Blender's Object mode, the single pipe segment is partnered with a bezier circle, created from the toolbox panel.

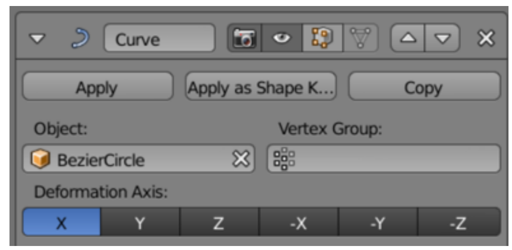
The array modifier is added to the segment, then a curve modifier is added on top of that.

When the created geometry meets all requirements, the two Apply buttons are pressed, and the bezier circle is no longer needed.

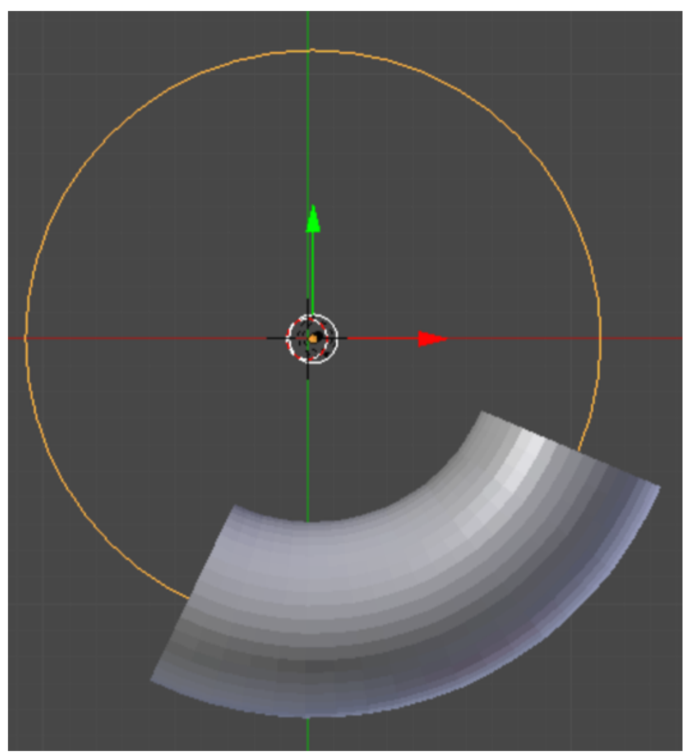


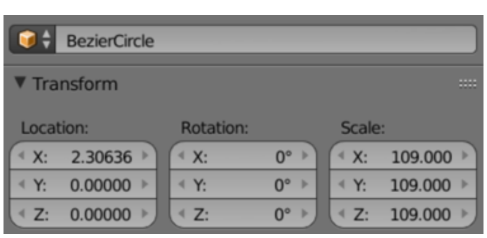




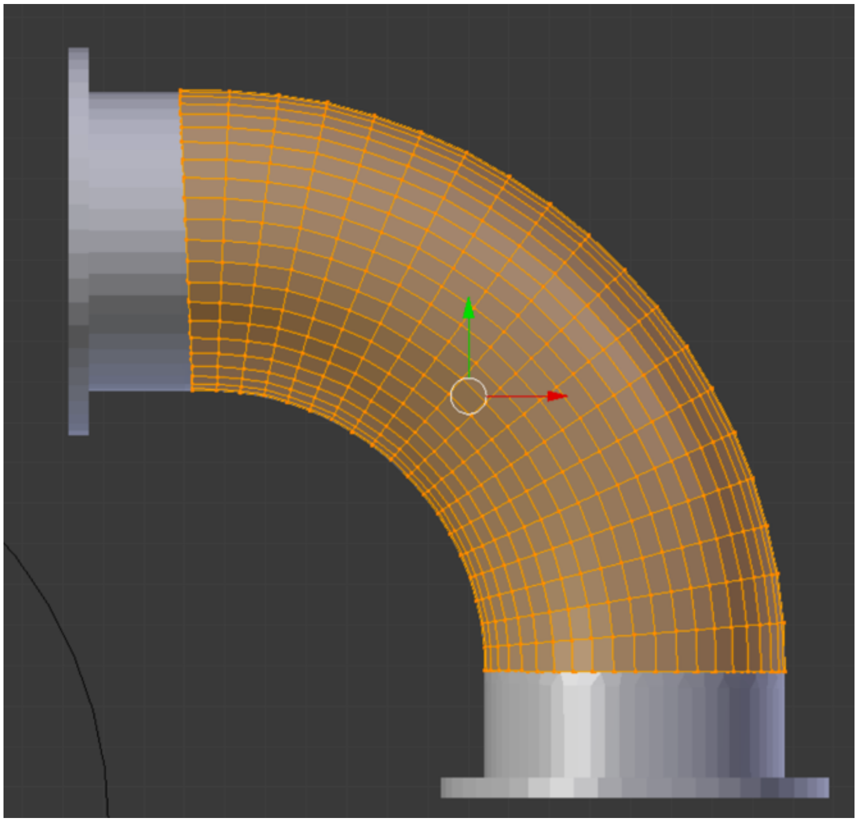


With all 19 pipe segments conforming to the bezier circle, the view looks as shown right. Note that if the bezier circle is edited in Edit mode, the curves of the group of pipe segments change. Theoretically, based on total length, the bezier circle should have a diameter of 112.2; however, the best fit was with a circle diameter of 109.

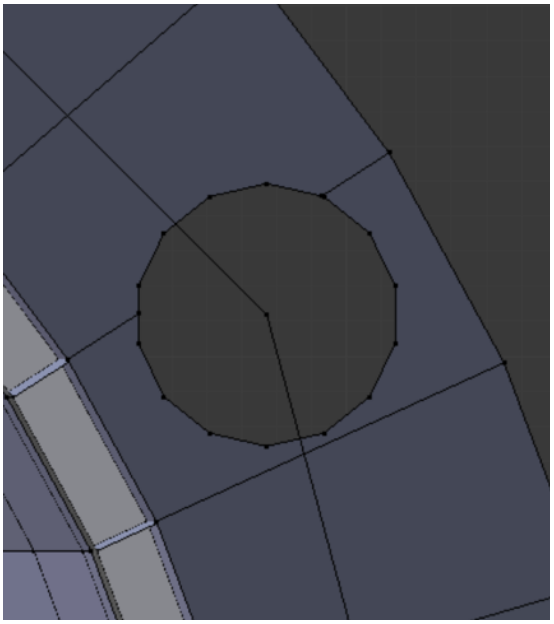




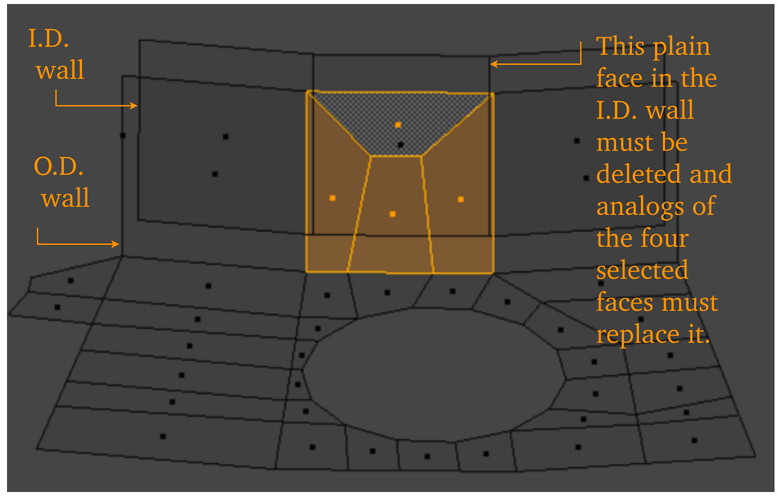
In orthographic perspective, the group of pipe segments is shown in front of the original model, which we have appended for the comparison.



When Blender adds a circle, it holds the requested number of vertices and the radius in memory and presents these values the next time it is called on to add a circle. This makes Knife Project easier. Circles are added, used as cutters, and then destroyed repetitiously, and the ‘drilling’ of the 12 holes in the flange is quickly done. The template hole circle itself (only one of twelve center points is shown at right) was constructed from the original flange holes. There we established the centers of two opposite holes by bisection, and then drew a temporary edge between, which showed the numerical distance.

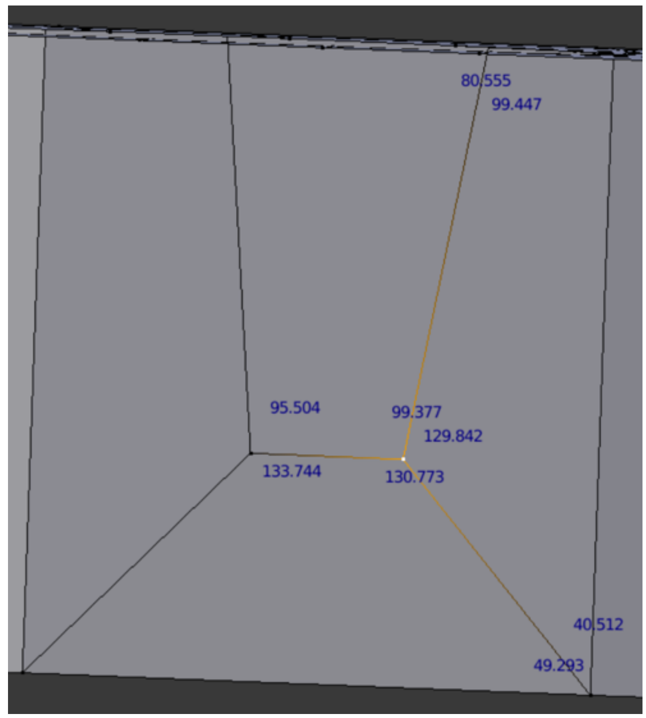


After the flange holes have been installed, we must add edge relief to some of the hole segments. At right are shown the relief faces that need to be transferred to the I.D. wall as duplicated faces. (The transfer method we use, making up the eleven steps explained below, may not be the most efficient possible.)



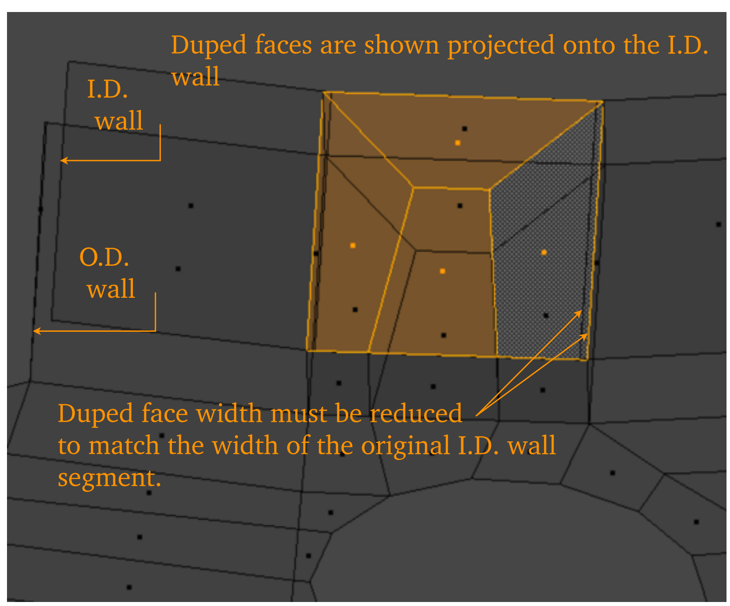
Step 1: The target I.D. face is deleted ('Only Faces').

Step 2: One of the O.D. progenitor faces is selected and Shift + '7' sets a flat perspective (at right it happens to flip the view). Now 'g' (grab) can be used safely. The progenitor corner angles are improved as much as possible.



Step 3: With the four progenitor faces selected, we press Shift + 'd', then Enter, to duplicate the faces.

Step 4: We press 'e' (extrude) plus the wall thickness to move the duplicated faces to the plane of the I.D. The faces are all slightly larger than they should be.



(This version of the extrude command extrudes the faces in a normal direction, which is what we need, and all that we ask.)