Building Pentagonal Icositetrahedra

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Abstract

I became obsessed with building pentagonal icositetrahedra, a 24-sided Catalan solid. Presented is a ~9' diameter, 3000 lb work made of waterjet cut and press-brake bent ¼" COR-TEN steel.

Figure 1: *The piece during final assembly at Loupe in Portland, OR*

How It Started

After several years of design and fabrication of plywood components on our shop's 3-axis CNC (Computer Numerical Control) router, I began to wonder whether I might be able to create novel parts beyond the limits of the typical orthogonal joinery I had been producing to that point. Wikipedia's polyhedra pages revealed a pleasing shape that would become my obsession: the pentagonal icositetrahedron [3], a 24-sided isohedral Catalan solid with uniform dihedral angles and a quirky chirality.

Initial Prototypes

Using Autodesk Fusion 360 [1], I designed and modeled the face geometry, a set of CNC machine fixtures, a custom pill-shaped strap, and the cutting tool paths for an initial prototype. This process required the parts to first be flat cut from sheet stock, then mounted in fixtures to cut the bevel angle and fastener features. Altogether the piece required a total of 121 separate CNC cutting operations.

(a) (b) (c)

Figure 2: *Initial mockup in plywood: (a) parts mounted in fixtures for bevel cutting, (b) midway through the assembly process, (c) fully assembled form*

Transition to Bent Sheet Metal

Because of the many discrete operations and manual loading required to complete the piece on the shop CNC machine, I decided to teach myself the sheet metal bending design capabilities in Fusion 360 as a way of simplifying fabrication. These tools enable complex 3D part designs made from flat sheet stock that are bent to precise angles with standard industrial equipment.

This design method is also well suited to hobbyist cutting machines like the Cricut cutter, which can cut and crease bend lines on posterboard materials.

(a) (b) (c)

Figure 3: *results with sheet metal bending design tools: (a) steel parts with outward dihedral bends, (b) small child inside larger steel piece with inward dihedral bends, (c) partially assembled Cricut cut posterboard model assembled with prong fasteners.*

Large Scale Concept

Parametric CAD modeling software like Fusion 360 allows for easy changes to dimensions in designs while maintaining geometric constraints. Playing around with the model one day, I made the ball dimensions significantly larger and inserted a 3D scan of myself in a rendering as a joke. As I thought about it more, the concept slowly transitioned from a joke to something that needed to happen for real.

The final design is made up of 24 84-lb faces, with a long edge length of 34 inches. The complete piece has an overall height of approximately 9 feet and weighs just over 2000 lbs. Two M16 bolts and nuts are used between adjoining folded edges.

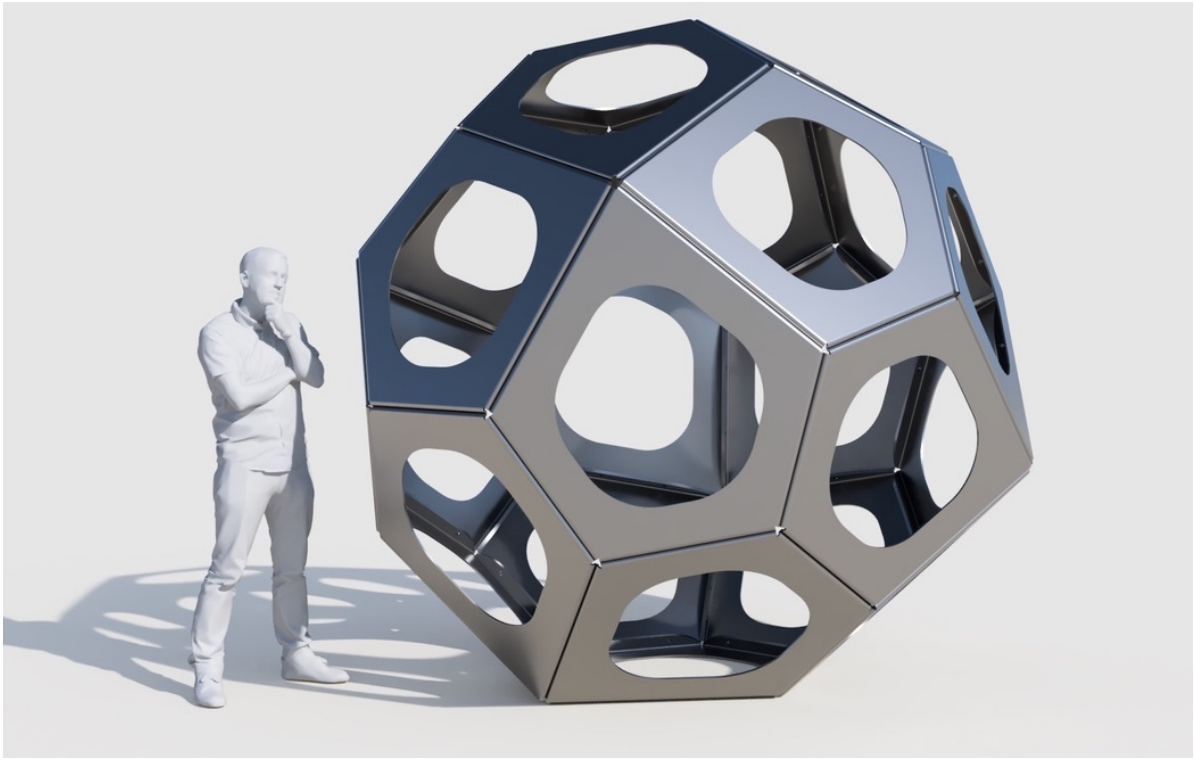
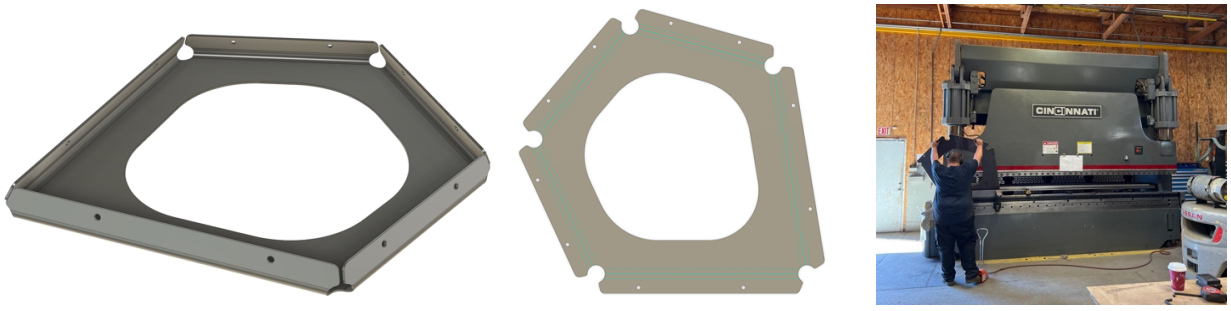


Figure 4: *Concept rendering of large ball*

Fabrication

In collaboration with fabricators Solid Form [2], we redesigned the faces to ¼" sandblasted COR-TEN steel with larger edge bend radii and corner reliefs to accommodate the press brake tooling that would be used during the production process.



(a) (b) (c)

Figure 5: *Face sheet metal design and fabrication: (a) 3D form showing final shape, (b) flat pattern for waterjet cutting, (c) part being bent in a CNC press brake at Solid Form*

Final Assembly

Thanks to the reliability of the fabricators and the standard processes used in production of these faces, I was able to mostly assemble the piece single-handedly with occasional assistance from friends and the large robot installed in Loupe's lab workspace. A 1000-lb circular baseplate was added to prevent the ball from rolling if people were to climb on the outside edges.

(a) (b) (c)

Figure 6: *Assembly process: (a) custom lifting jig for easy handling of 80-lb faces, (b) vertex detail showing bend relief at corners, (c) large robot used as assembly and positioning crane*

Figure 7: *Author with finished piece installed at Loupe, Inc in Portland, OR*

Summary and Conclusions

Keep building and you may end up in interesting new places and scales. I've built many more of these pentagonal icositetrahedra in the meantime and have endless plans for future embodiments.

References

[1] Autodesk, *Fusion 360.* https://www.autodesk.com/products/fusion-360/

[2] Solid Form, McMinnville, Oregon, USA https://teamsolidform.com/

[3] Wikipedia, *Pentagonal icositetrahedron* https://en.wikipedia.org/wiki/Pentagonal_icositetrahedron