

Smart Prototyping for Smart Toys

Geometoy, Jonathan Stapleton's design business, got its start in 2002 with a project for a college art class. It was an exercise in tessellation, which is typically defined as a process of tiling a plane with a collection of repeating figures that fill the plane with no overlaps and no gaps. Most of us have seen two-dimensional tessellation in the work of M.C. Escher, examples of which can be found at www.mcescher.com/Gallery/gallery-symmetry.htm. (For a hands-on exercise in two-dimensional tessellation go to www.shodor.org/interactivate/activities/Tessellate/, use your pointer to alter the starting shape, and click *tessellate* to see the result.)

What started on paper and in wood eventually became a complex shape resembling a three-dimensional, somewhat cubist turtle.

For Stapleton, that art class project became a bit of an obsession. "The assignment wasn't very tightly defined," he says, "but we were working in wood, so it seemed natural to start working in three dimensions."

His interest in 3D tessellation lasted far beyond the duration of the project, beyond college, and through years of teaching physics as well. What started on paper and in wood—Stapleton admits to several



Figure 1: Reptangles

close calls with table saw blades—eventually became a complex shape resembling a three-dimensional, somewhat cubist turtle (see Figure 1). Today, that design, now dubbed Reptangles™, has been licensed to Fat Brain Toys®, a manufacturer and distributor of educational and specialty playthings. Reptangles are produced in injection molded plastic and packaged in sets. Each plastic block has 56 patent pending connectors allowing any two blocks to be attached to one another in literally hundreds of ways (see Figure 2). A set of 24 blocks can be used to create a dizzying variety of designs. But getting from those initial wooden mockups to today's production

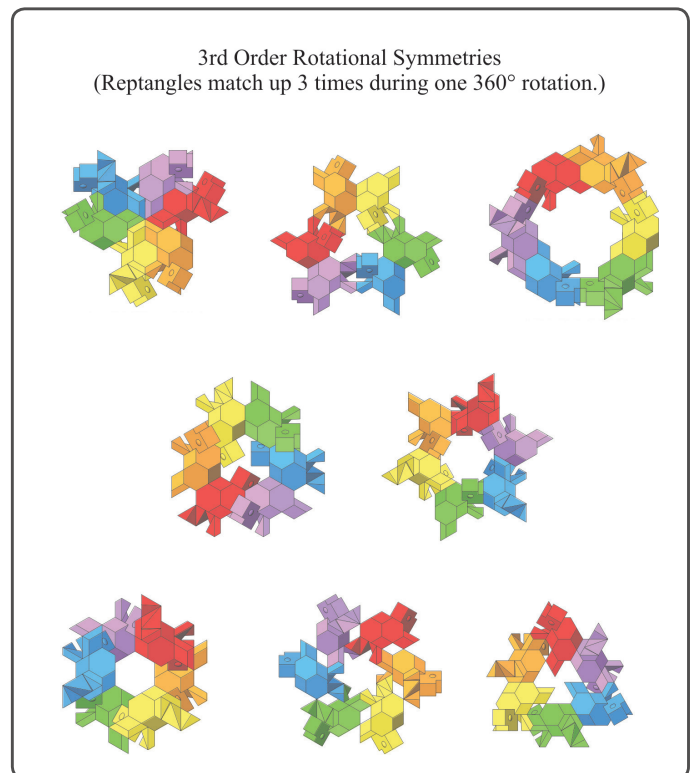


Figure 2: Reptangles can be connected in hundreds of configurations.

model—including a number of completed and pending patents and handful of injection molded prototypes—was no simple task.

“I chose a truncated octahedron for the turtle shell,” says Stapleton. “Then I took an extra turtle shell, cut it up, and made legs from the parts. As I soon discovered, when I lined up matching angles on the legs and the shell, I was aligning the entire turtle with a 3-D grid. The figure was guaranteed to fit together and line up. That was the easy part. Then I had to make them stay together, and finally I needed to find a way to produce such complex parts cost-effectively.”

The process involved a lot of sketches, a lot of computer aided design, and a lot of wood models before the first turtle was molded in plastic resin. Connectors turned out to be a significant challenge. “Something like standard LEGO blocks would have been easy,” says Stapleton. “Blocks that stack vertically can be held together with a simple friction fit, and because they connect top to bottom they can be made in a simple two-part mold. With Reptangles, the blocks have mating faces on the top, the bottom, and the sides, and even those aren’t at simple right angles. There have been other attempts to make tetrahedral, octahedral, and other style blocks connecting other than vertically, but the connectors have always been difficult. Designers have tried a variety of methods, magnets for example, but coming up with integrated connectors has always been the ‘Holy Grail’ that everyone was after.”

With connectors on every one of the block’s many faces, there was no existing connector that would meet the need, so Stapleton was moving into uncharted territory.

Complex as it was, finding a way to connect the blocks was relatively easy compared to the bigger challenge of molding. Stapleton recognized that, for financial reasons, he had to design parts that could be produced in two-part straight-pull molds (see Figure 3).

That meant there could be no features of the design—faces or connectors—that could be trapped as the mold opened, which, with connectors on many faces, would be no small task.

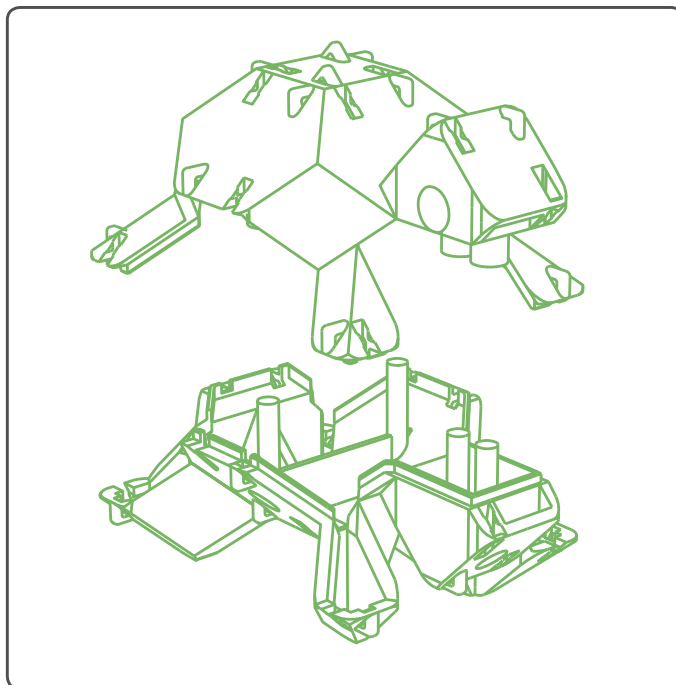


Figure 3: The completed block, because it was hollow, would be made of two parts that would snap together, but each of the two parts would have to be made in straight-pull molds.

With connectors on every one of the block’s many faces, there was no existing connector that would meet the need, so Stapleton was moving into uncharted territory.

“Typical connectors are perpendicular to the surface on which they are located, so almost by definition, any standard connector, male or female, not located on a top or bottom surface could represent an undercut,” says Stapleton. “If you imagine a pyramid, for example, with connectors on each face, you can see how a post rising from any one of the sides would be trapped by a mold half that was opening and closing vertically to form all four sides of the pyramid at once. The challenge was to develop a connector that could be produced in mold halves opening in one direction but connect in one or more other directions.”

“I knew that the connectors were going to be critical,” he says. “At first I tried a friction fit, but because of the complexity of the constructions and the resulting stresses on the connectors, the friction fit required unrealistically tight tolerances and restricted us to using resins that we didn’t want to use. We needed something that would snap into place. On the other hand, because the blocks are designed to be pulled apart and reused, we didn’t want a connector that would lock the way some clips do. In other words, the connectors had to snap positively together, but also release when pulled apart.”

Part of the challenge was that various faces of the completed turtle would be angles at 45°, 90°, or 135° to the direction of mold pull. The need to connect along different planes than those in which they'd be molded led Stapleton to think in terms of triangles. He eventually arrived at an arch-shaped connector that fits into a slot with stubby "fingers" that gripped the space under the arch, producing an interference fit (see Figure 4). In addition to providing a solid connection that can be broken with a pull, these connectors allow parts to be joined from any direction within a 90° arc. This lets parts be moved into tight locations in which a direct face-to-face approach is not feasible.

Slanting the end walls of the slot away from, rather than toward the male connector allows the slot to be formed in a straight-pull mold (see Figure 5). Here you can see the orientation of the part as it will be molded. The tops of the male connectors are formed by the A-side mold half; the space under the arch is formed by the B-side mold half, which projects through an opening in the floor of the part surface. The slot and its projecting fingers are formed entirely by the B-side mold half, which, again, protrudes through the open floor of the part surface and shuts off against the A-side mold half.

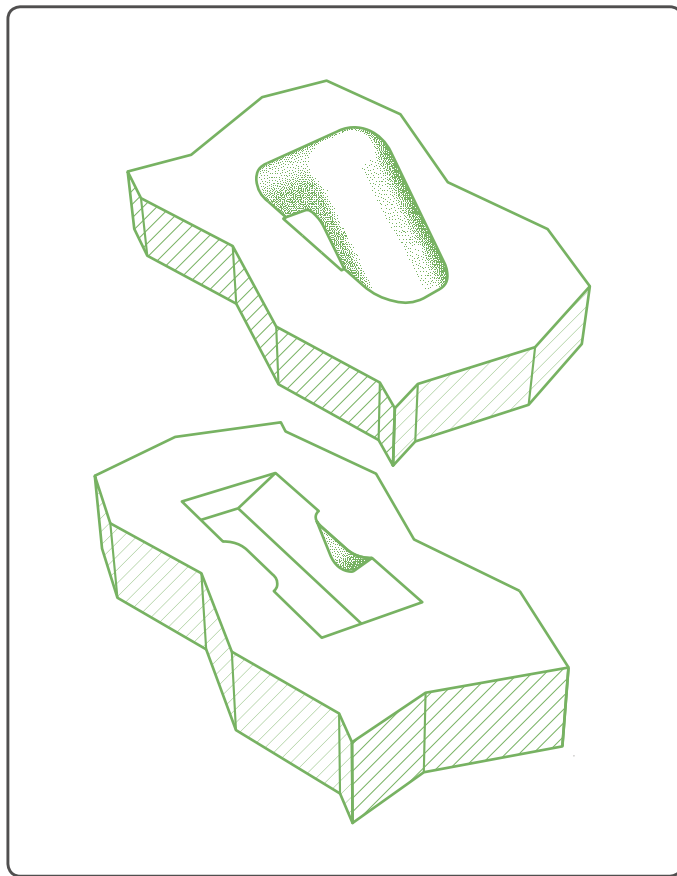


Figure 4: Arch-shaped connectors fit into a slot in an interference fit.

This design allows all of the connectors, regardless of orientation, to be formed in a straight-pull mold.

“I probably could have used other prototyping methods, but actual injection molding was the only method that would confirm the moldability of the parts, and that was critical.”

This elegant solution was the result of a lot of experimentation. “Friction fit connectors would have been a lot simpler,” Stapleton says. “The problem was that the tolerances had to be very tight. If there was any extra space the parts wouldn’t hold. I needed a snap, something that would click and take up the slop.”

In May of 2004, when he was ready for prototypes suitable for functional testing, a local molder in Seattle suggested that he try Proto Labs (then called Protomold). “I needed to know if the snaps would work and to know that they could provide solid connections and release as needed,” he says. “I also needed to be sure that they could be effectively made in straight-pull molds. I probably could have used other prototyping methods, but actual injection molding was the only method that would confirm the moldability of the parts, and that was critical.”

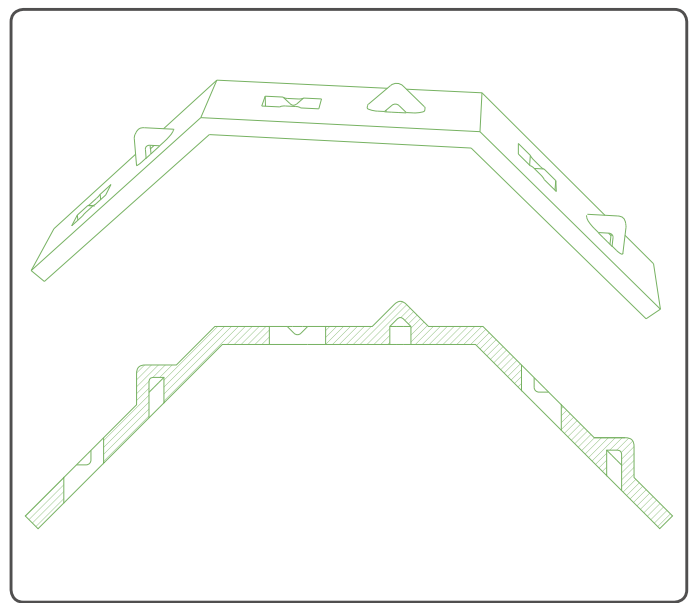


Figure 5: Slanting the end walls of the slot away from, rather than toward the male connector allows the slot to be formed in a straight-pull mold.

After the first set of parts came back, testing showed the need for minor modifications. These entailed slight increases in some part sizes rather than decreases, so they could be achieved by modifying the original mold rather than making a new one. With his design verified, Stapleton entered the marketing phase of the project, first selling Reptangles directly and ultimately licensing the product to a larger company. He has patented his turtles under the generic-sounding title “Multifaceted Nesting Modules.” He is also working on a patent application for the connectors themselves, recognizing that they have a variety of potential uses.

Having completed development and licensing of Reptangles, Stapleton moved on to his next project, a design for isosceles tetrahedral blocks. Unlike the turtles, these are simple four-sided blocks, but like Reptangles they can be combined to create a virtually unlimited array of forms (see Figure 6). Much of the thought and development that had gone into Reptangles was applied to the new project. The new blocks presented the same challenge addressed in Reptangles—connecting faces that were not in a plane perpendicular to the direction of mold opening—so they use the same type of connector.

Unlike Reptangles, the yet-to-be-named tetrahedra are single, rather than two-piece, blocks. As with the Reptangle halves, however, they had to be moldable in straight-pull molds. Stapleton solved that problem by partially skeletonizing the blocks, placing a skin over just half of each face and leaving the other half open to allow penetration by the mold. In this way, he was able to create hollow parts in a single operation, forming each face and connector from inside and outside at the same time. As with Reptangles, male and female connectors are formed by the interaction of A- and B-side mold halves, and some of the walls of the female connectors are canted to allow straight-pull molding. As with Stapleton’s previous developments, this one had led to a new patent application, this one for a method of designing cored out polyhedra.

In 2007 Stapleton again turned to Protomold for prototypes. Functional testing identified the need for minor design modifications, but as with Reptangles the new prototypes were made by modifying the original mold rather than making a new one. Stapleton hasn’t decided whether to market or license his new creation, but through careful prototyping he does know that his latest creation works as expected.

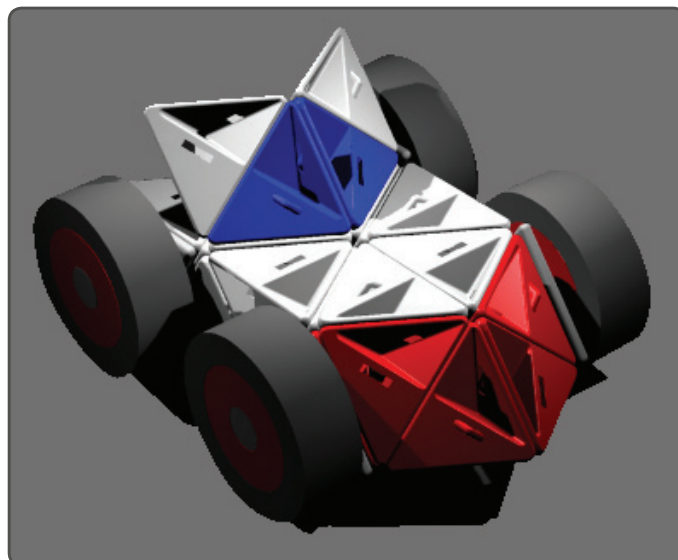


Figure 6: A car, one of the many creations that can be built with isosceles tetrahedral blocks.

“Everything about working with Proto Labs was simple,” he says. “Their ProtoQuote quoting system, was fast and easy; every time I ordered parts they arrived sooner than I expected, and the up-front costs were really reasonable. When I’ve had technical questions they’ve been right there with answers. For example, in designing the tetrahedon I didn’t think about ejector pins; they helped me design in pads for the pins to use to push the part out of the mold. I’m currently working on a new part with a living hinge and they’ve been happy to help.”

“The feeling it brought to mind was flying first class.”

“The other nice thing about rapid injection molding is that you can’t make anything that wouldn’t work in production; it keeps me honest. If you need to increase the size of any thing on the part you can tweak the mold. I got realistic dimensional accuracy with the same resin that would be used for production; I got to see if it was going to warp, and I could see if the angles came out right. The feeling it brought to mind was flying first class.”