Demonstrating TrussFab: Fabricating Sturdy Large-Scale Structures on Desktop 3D Printers

Figure 1: *TrussFab* allows users to fabricate large structures sturdy enough to carry human weight. TrussFab uses bottles as beams to form *trusses*.

Figure 2: TrussFab generates 3D printed hubs. Users assemble them following embossed IDs.

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Abstract

We demonstrate *TrussFab*, an end-to-end system that allows users to fabricate large-scale structures that are sturdy enough to carry human weight. TrussFab achieves the large scale by complementing 3D print with plastic bottles. It does not use these bottles as “bricks” but as beams that form structurally sound structures, also known as *trusses*, allowing it to handle the forces resulting from scale and load.

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Introduction

Personal fabrication tools, such as 3D printers have become popular in HCI, where they have been used for fast prototyping [5] as well as to fabricate interactive objects [2] or kinematic characters [1]. Since 3D printers today are available in a desktop form factor, they have been able to spread to the maker community [7] and are now increasingly reaching the consumer market [6]. In contrast, the fabrication of *large* objects still has remained a privilege of industry, which has access to specialized equipment, such as robotic-arms capable of 3D printing [3]. The owners of the widespread desktop devices, in contrast, cannot participate in this evolution, because the underlying technology does not scale.

Going larger, however, is not only about scale and print volume. For large objects, the main design objective is typically to withstand large forces, as forces grow

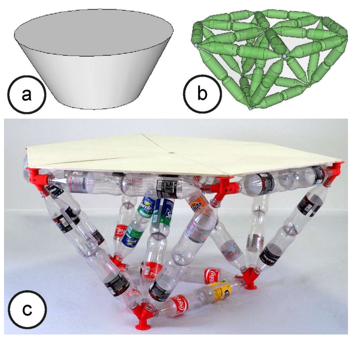

Figure 3: (a) TrussFab's converter turns this 3D model of a coffee table, into (b) a sturdy tetrahedral honeycomb structure, (c) which fabricated serves as a functional table.

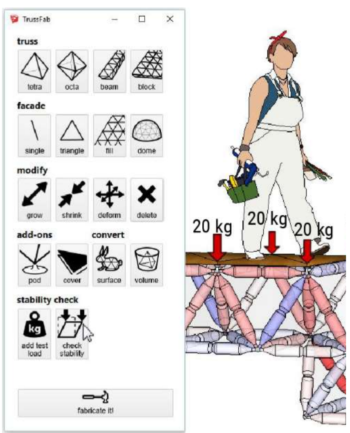

Figure 4: TrussFab's editor is implemented as an extension for *SketchUp* and provides structural stability check in runtime.

cubed with the size of the object. Also, large objects afford substantial external loads; furniture, bridges, and vehicles, for example, all must be engineered to hold the weight of a human. Designing for large forces, however, requires substantial engineering skill [8] from envisioning appropriate structures in the first place to verifying their structural integrity.

Here, we demonstrate *TrussFab*, an integrated end-to-end system that allows users to design large structures that are sturdy enough to carry human weight (Figure 1a). TrussFab achieves this by taking a different perspective on bottles. Unlike previous systems that stacked bottles as if they were "bricks", TrussFab considers them as beams and uses them to form structurally sound node link structures based on closed triangles, also known as *trusses*. TrussFab embodies the required engineering knowledge, allowing non-engineers to design such structures. TrussFab also allows users to validate their designs using integrated structural analysis (Figure 1b). Our main contribution is this end-to-end system.

TrussFab system: a walkthrough

TrussFab allows users to create structures either by modeling from scratch or by converting existing 3D models.

Step 1: Automatic conversion. One way to create TrussFab structures is to convert an existing 3D model using TrussFab's *converter*. As shown in Figure 3 this converts the volume of the model into a tetrahedral honeycomb structure, allowing it to bear substantial load.

Step 2: Editing. TrussFab's editor allows users to refine an object created by automatic conversion or to start a new object from scratch. We implemented TrussFab's editor as an extension to the 3D modeling software *SketchUp*. TrussFab's editor offers primitives that are elementary trusses (tetrahedra and octahedra), tools that create large beams in the form of trusses, and tools for tweaking the shape of structures, while maintaining their truss structure. In Figure 4, the user placed a human weight on top of the bridge design. TrussFab's integrated structural analysis shows no warnings, suggesting that the bridge is structurally sound.

Step 3: Hub generation. After designing a structure, TrussFab's *hub generator* generates the 3D models of all hubs. Figure 2 shows our 3D printed hub design; the connector on the top snaps into the bottleneck, while the bottom ones are holding the bottles by their threaded neck. When designing structures to carry a human weight, these hubs experience large forces. We discuss the details of TrussFab's hub designs in section "Hubs and Members".

Step 4: Fabrication. Users then send the 3D model files produced by the hub generator to one or more 3D printers in order to manufacture them.

Step 5: Assembly. Users now manually assemble their structures by following unique IDs embossed into each hub (Figure 2).

How TrussFab achieves structure stability?

The key ideas behind TrussFab are (1) to employ bottles in their structurally most sturdy way, i.e., as beams from bottom to bottleneck and (2) to afford

Figure 6: A functional boat created using TrussFab.

Figure 7: A chair designed using TrussFab's ability to check structural stability to ensure it can support the user's own weight.

sturdy "closed frame structures", also known as *trusses* [4]. While freestanding bottles tend to break easily, truss structures essentially consist of triangles. In such an arrangement, it is the structure that prevents deformation, not the individual bottle. The main strength of trusses is that they turn lateral forces (aka bending moments) into tension and compression forces along the length of the edges (aka *members*). Bottles make great members: while they buckle easily when pushed from the side, they are *very* strong when pushed or pulled along their main axis. (c) The resulting structures, such as this tetrahedron, are strong enough to bear the weight of one or more humans.
(d) TrussFab affords building trusses by combining tetrahedra and octahedra into so-called tetrahedral honeycomb structures.

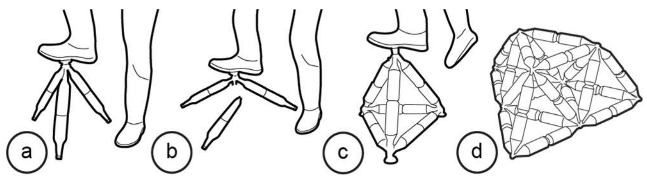

Figure 5: (a) Large objects involve large levers, causing them (b) to break under load. (c) TrussFab instead affords structures based on closed triangles, here forming a tetrahedron. Such structures are particularly sturdy. (d) TrussFab extends this concept to tetrahedron-octahedron trusses of arbitrary size.

Demonstrating TrussFab with examples

We now demonstrate five structures built with TrussFab, in particular: a chair (Figure 7), a table (Figure 3), a boat that seats two (Figure 6), a bridge (Figure 1) and a dome structure (Figure 8).

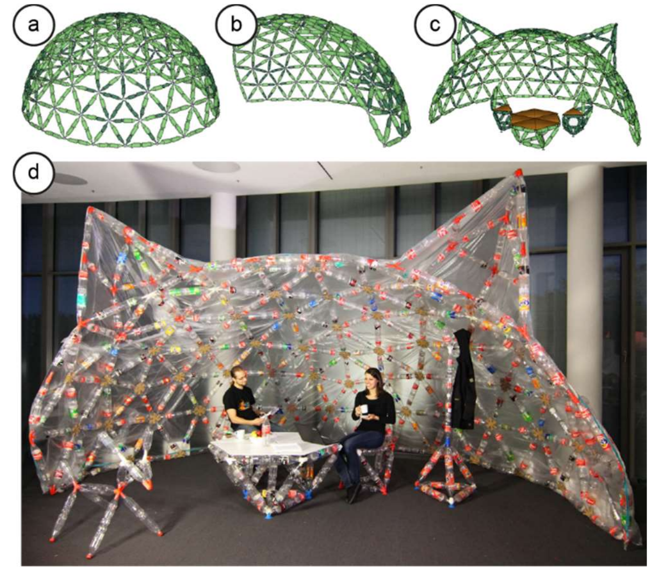

Figure 8: (a) Dome created using the *dome* tool. (b) We make the opening using the *delete* tool, and (c) add decoration using the *triangle* and *line* tools. (d) The resulting dome is built using 512 bottles.

Conclusion

TrussFab is an integrated end-to-end system that allows users to fabricate large structures that are sturdy enough to carry human weight on desktop 3D printers. Unlike previous systems that built on up-cycled plastic bottles combined with 3D print, TrussFab considers bottles not as "bricks", but as beams that form structurally sound node link structures also known as *trusses*, allowing users to handle the forces resulting from scale and load. TrussFab embodies the required engineering knowledge, allowing non-engineers to design such structures and allows users to validate their designs using integrated structural analysis.

Personal fabrication of large-scale objects opens up a range of new challenges. Unlike for desktop-scale objects, software systems need to consider how to (1) assure structural integrity to guarantee safety. (2) Consider dynamic forces, such as human movements and wind forces. (3) Use material consciously. (4) Optimize fabrication time. (5) Take into account the effect of environmental factors on longevity, such as temperature, weather, UV light, etc.

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