

Printing Food

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Abstract – This paper examines the possible applications of food as a raw material in freeform fabrication, and provides several demonstrations of edible three-dimensional objects. The use of edible materials offers several advantages: First, it opens the door to the application of SFF technology in custom food industry, such as manufacturing of complex confections with specialized geometries and intricate material compositions. For pedagogical purposes, edible materials provide an easily accessible, non-toxic and low cost way to experiment with rapid prototyping techniques using educational systems such as Fab@Home. For more traditional SFF technologies, food materials with appropriate rheological properties can serve as sacrificial, bio-degradable, bio-compatible or recyclable materials for structural support and draft-printing. We have used the Fab@Home personal fabrication system to produce multi-material edible 3D objects with cake frosting, chocolate, processed cheese, and peanut butter. These are just indicative of the range of potential edible materials and applications.

Introduction

The premise of printing food seems, at first glance, a trivial endeavor: a pastime that brings back memories of being scolded at the dinner table for playing with one's food. However, there are many potential uses for such a technique, perhaps most notably presenting the concept of rapid prototyping using a medium that is both familiar and accessible to peoples outside of more technical disciplines. While the idea of using thermoplastics or gas-atomized powders would cause most peoples' eyes to glaze over, the concept of working with food to do the same task is intriguing and fun.

Many different techniques are used in the manufacture of food items, but they are mostly optimized for mass production; in the case of custom-made food products, the process usually involves a specially trained artisan creating the desired piece by hand. Thus, there is a natural gulf that exists between the two, where a person without the necessary training (and/or a steady hand), and not needing a large number of pieces, is left to ordering a custom product at high cost from a specialist. Bridging this gap is certainly within reason, using the techniques outlined in this paper.

But beyond producing food products with complex geometries, there are other practical applications for this type of approach. Once a user has a model in mind, the part can be quickly created using food as a prototyping material, without committing to the high cost and permanency of more traditional rapid prototyping materials. This “pre-prototyped” model would be biodegradable, and therefore, easily disposable, perhaps even to the point of just eating it after checking for the desired result.

A combination of the two techniques mentioned above suggests the use of food as a support material to help create more complex permanent structures. Many commercial rapid prototyping systems use two materials: firstly, a durable material used to create the actual model; secondly, a soluble, powdered, or break-away material that is sacrificed during the process, utilized in supporting the actual model. Food products – especially sugar or starch pastes that harden in air - can be used in the role of support material.

The difficulty with printing food in such a manner is that no proper platform for exploring the deposition of a wide variety of edible materials in 3 dimensions has been readily available. With the development of the Fab@Home personal fabrication system (Malone and Lipson, 2007), such a platform is now available. The Fab@Home Model 1 can print essentially any material that can be extruded from a syringe at near ambient temperature, but building 3-dimensional objects requires that the materials have high enough viscosity to be self-supporting and stackable in layers with appropriate resolution. In the category of foods, such materials include many kinds of paste, batter, dough, and jelly, as well as fusible materials, such as ice cream or chocolate.

We have selected several candidate edible materials, including cake frosting, chocolate, processed cheese, and peanut butter. We have identified the deposition control parameters required to deposit these materials with a Fab@Home personal fabrication system, and in the case of chocolate, also developed a temperature-controlled syringe tool for the task. With this system of hardware and materials, we have successfully produced a variety of multi-material, edible 3D objects. We have also produced silicone rubber bakeware using the Fab@Home system and employed it to make baked goods. Our materials, methods, and results will be presented below.

Background

The idea of fashioning food into fun and aesthetically pleasing shapes takes many forms in the world today. Butter sculptures can be found at many fairs and exhibitions (Victor, 2007). Companies can order custom chocolate business cards to impress customers (Custom Chocolates, 2007). Made-to-order cakes are often a critical part of wedding receptions, despite costing up to \$15 per slice (E-Wedding Cake, 2007). Extreme cakes have become so popular, they've spawned television shows documenting their creation & construction (Food Network, 2007).

All of these different food projects are fantastic, but they are based on either having the skill to fashion them by hand, or the finances to hire a specialist to produce them. The notion of using a machine to create such custom products on a case-by-case has recently

become of interest. Some companies are now selling printers with edible sheets and edible inks (Icing Images) that can be used to print photos to set directly on cakes. A restaurant in Chicago has modified a ordinary ink-jet printer to print food-based inks, based on carrots, tomatoes, and potatoes, onto edible papers, which are then served to its patrons (Goodall, 2006).

These printers offer users a new level of customization, giving them them the chance to reproduce their likeness, or a photo of a loved one, with remarkable level of detail and accuracy; however, these methods are limited to two dimensions. One cannot truly create custom edible objects without access to the third dimension, a prospect that requires a level of manipulation that was unavailable until the development of the Fab@Home personal fabrication system.

The Fab@Home Model 1 is an open source kit that allows the user to build his/her own solid freeform fabrication system (or “fabber”, Figure 1). As mentioned above, the Model 1 deposits materials from a robotically controlled syringe (Figure 2) – a process known known as “robocasting”. The Model 1 hardware and software are designed to allow the user to build objects incorporating multiple materials. Material changes are achieved in hardware by manual exchange of the syringe barrel, and in software by tagging components of model geometry with material properties data, planning paths based upon that data, and prompting the user to change materials at the appropriate times. The material properties data is stored in user-editable text files (“.tool” files), and the properties are tuned by the user in a manual calibration process which involves selecting an appropriate syringe tip for the material, and iteratively depositing test paths and tuning the flow rates and delays until satisfactory paths are obtained, and finally recording the height and width of these paths.

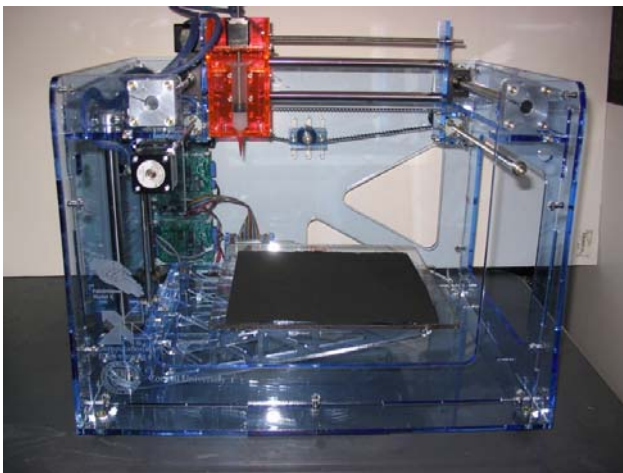


Figure 1 – Fab@Home personal fabrication device.

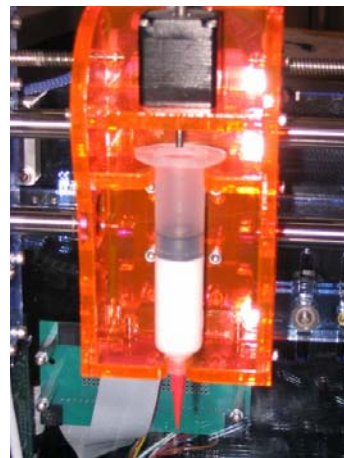


Figure 2 – A closer look at the deposition tool: a simple syringe/plunger system.

The standard Model 1 syringe deposition tool has no provision for temperature control of the materials contained in the syringe, which restricts useable materials to those of low enough viscosity to be deposited by the syringe tool motor (max pressure 460 kPa / 67

PSI), thixotropic materials, and materials which harden on exposure to ambient conditions.

Experimental

The materials described in this paper were selected for the reasons of availability and accessibility. Traditionally, solid freeform fabrication involves a material that requires special preparation (heating – thermoplastics) or application (sintering with lasers – metal powders). Food materials are unprecedented in their usability, being that we interact with them on a daily basis. Granted, some may require a degree of additional work to apply and use (heating chocolate, cooling butter), but many can be used straight out of their containers: frosting, spray cheese, and peanut butter, to name a few.

Once the desired material is selected, the process for calibrating the [Fab@home](#) is straightforward. For starters, the proper syringe tip needs to be selected; the simplest method is to load a syringe and try manually pushing the material out of various syringe tips. A safe rule of thumb is to pick the smallest tip that allows for easy manual material extrusion, because this will afford the user the finest resolution when printing an object. Once the tip is selected, the nozzle diameter can be used to specify the path width and approximate the path height (setting them equal is a good place to start). These two parameters are important to select prior to printing, as they cannot be adjusted during the build. The other major properties (deposition rate, suck-back time, push-out time) can be adjusted as the fabber prints.

From there, the user selects a shape (we typically use a simple block or flower shape) to test the material on. The deposition rate, suck-back time, and push-out time need to be specified (either arbitrarily or based on one of the tool files provided with the [Fab@home](#) software). As the machine begins fabricating, the three parameters mentioned above can be tweaked to get the desired result. With a few minutes of work, the fabber is fully ready to utilize the new material.

The idea of building 3-dimensional structures out of chocolate was sufficient motivation for us to develop a low-temperature heated syringe apparatus compatible with the Model 1 1-Syringe Tool (Figure 9). This comprises a 110V silicone/copper foil resistance heat blanket (Omega Engineering), a thermocouple (Omega Engineering), and a PD-temperature controller (McMaster-Carr). The thermocouple is placed directly against the syringe barrel where it is secured by a layer of silicone rubber tape. The heat blanket is wrapped around, and secured and insulated by several more layers of silicone rubber tape. Care was required to not overheat and melt the polyethylene syringe barrels.

For foods like spray cheese and frosting, the aforementioned parameter tuning process is sufficient for preparing the tool files for use. In the case of chocolate, however, the procedure is more involved. In addition to the five parameters above, the temperature needs to be fine-tuned. The chief difficulty here is that the viscosity of the chocolate is directly related to the temperature, so as it is changed, the optimum printing parameters change (even the necessary syringe tip changes). Perhaps more importantly, the

temperature needs to be low enough that the chocolate begins to harden on the substrate without flowing too much.

We rigorously tested the different possible permutations of chocolate parameters in an effort to optimize the fabrication of chocolate objects (Schaal 2007). They created the diagram below (figure 3) to help describe the different parameters, an excellent summary for anyone interested in the [Fab@home](#) calibration process. Figure 4 shows the results as the parameters are tweaked: some “candy bars” truly look like candy bars, while others have flowed and deformed.

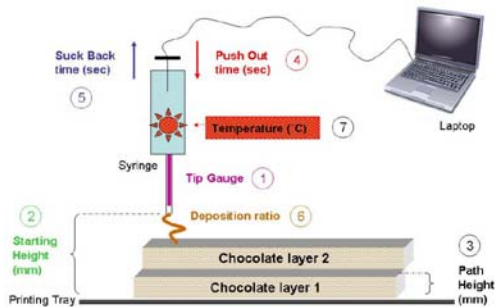


Figure 3 – Material parameters.

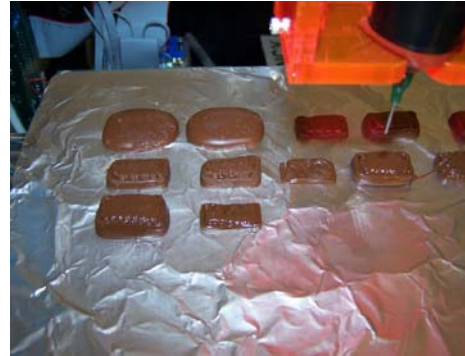


Figure 4 – Tuning chocolate parameters.

When testing the materials, we decided on several experiments that would represent a wide range of potential applications. For starters, the simple production of shapes that would otherwise be beyond our culinary skill served as a baseline. These are objects that have closely overlapping components, or 3D shapes that need an especially steady hand. While perhaps not useful on its own, this technique leads to more exciting possibilities: printing on other objects. For this paper, we selected crackers with flat and smooth surfaces (this is not a requirement, but merely the easiest way to test the hypothesis).

Next, we tested the role of food in support structures, both as the sacrificial base and as the supported material. First, we used frosting to support different silicone structures, looking for how easily the frosting was separated to leave the actual object and how the object compares to the desired result. Second, we produced silicone objects to serve as molds for food products: in this case, chocolate chip muffins. Again, we were examining how well the food came apart from the silicone, and how well the muffin resembled the shape of the mold. Results for these experiments are discussed below.

The food products used in this experiment were Betty Crocker Easy Squeeze Decorating Frosting, Nestle chocolate chip morsels, Kraft cheddar Easy Cheese, and Betty Crocker “Just Add Water” Chocolate Chip muffin mix. The silicone used was GE Silicone II.

Results and Discussion

Complex Confections

The most obvious application of the printing of food is for manufacture of edible objects that would be difficult to produce by hand. This could include pieces that are made up of

different materials, or even simply different colors of the same material (i.e. frosting). Figures 5 and 6 show some sample parts made of two different colors of frosting.



Figure 5 – The green arrow extends fully through the heart, and the red frosting is printed right over it, creating an integrated structure.



Figure 6 – Several different frosting items: overlapping hearts on the left, and a 2-part flower (completed on top, unfinished on bottom) on right.

More fundamentally, a “complex confection” could simply be a single material, but laid out in a complex way that would be difficult to make by hand. Figure 7 shows a house made from spray cheese, conveniently fit on the back of a cracker. Another advantage to printing food is repeatability. While simple, figure 8 below on the right shows identical logos printed on the backs of crackers. Granted, these logos could probably be done by hand, but it could just as easily be the cheese house, reproduced exactly from time to time.

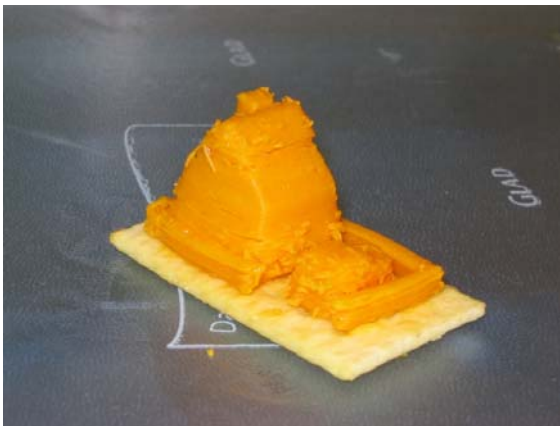


Figure 7 – A house made of spray cheese, complete with a fence and car in the driveway.

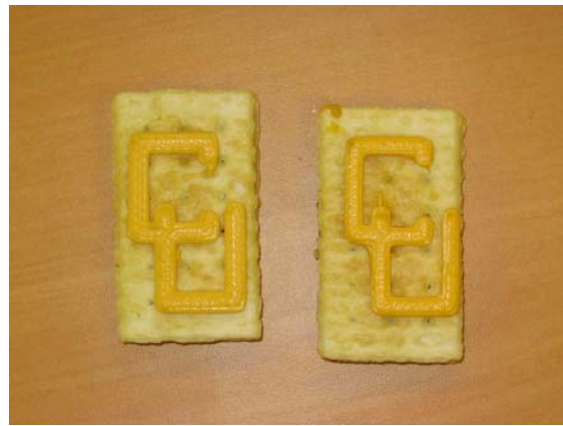


Figure 8 – A logo printed on the back of a cracker. The two logos are identical – repeatability is high.

Chocolate has also been successfully printed using the Fab@Home, although the process is more involved than frosting and spray cheese. The Schaals were able to print chocolate by using a heated syringe (figure 9) to keep it molten during the deposition process. After optimizing the temperature of the syringe, the other printing parameters were tweaked to get the desired results (figure 10).

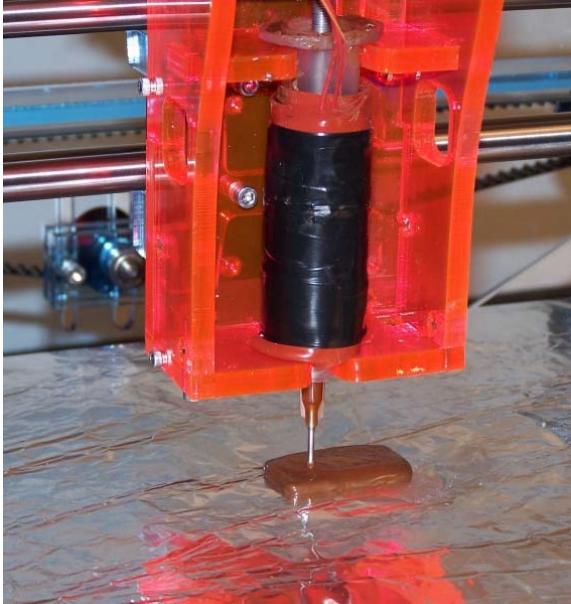


Figure 9 – The Fab@Home Model 1 1-Syringe Tool, modified with a resistance heater to enable temperature-controlled dispensing of chocolate.



Figure 10 – Customized chocolate bars.

Food as Support Material

Perhaps a more surprising use of food is as a support structure for permanent materials. While it is perhaps not relevant to industrial freeform fabrication, since food is obviously bio-friendly, readily accessible, and easily disposed of (edible if not contaminated by inedible materials), it makes an excellent support material for personal fabrication.

As a conceptual demonstration, we attempted to construct a variety of overhanging geometries from GE Silicone II, supported by Betty Crocker Easy-Squeeze frosting as a support material.

First, a simple geometry was attempted: a block of frosting supporting a silicone bridge; several of these bridges were constructed to test repeatability. The silicone did not stick to the frosting well, hence the wavy bridge, rather than the square bridge that was originally intended. Once the silicone had cured, the frosting (already dry and brittle) breaks away easily, as seen in figure 13. The finished product is shown in figure 14, supporting its own weight with no frosting left underneath.

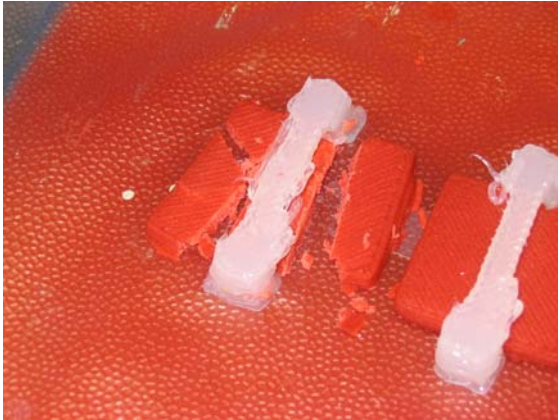


Figure 11 – The frosting breaks away easily...

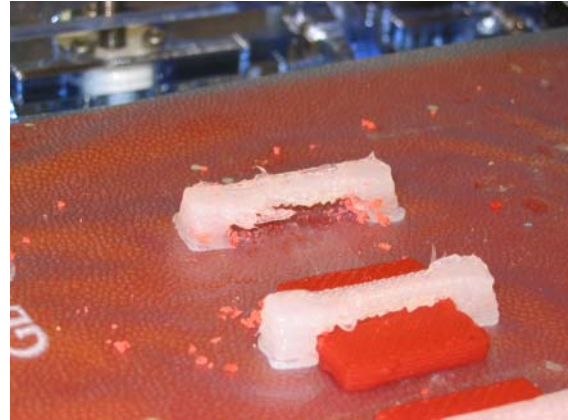


Figure 12– ...leaving a completed silicone bridge.

Frosting could also support the entire structure, allowing for more complex forms. First, a straightforward test to see how well this technique works: a trapezoidal shape extruded normal to its surface. Figure 13 shows the silicone trapezoid being fabricated on top of the support structure, while figure 14 illustrates the finished part removed from its supports.



Figure 13 – Silicone printed on top of a frosting support.



Figure 14 – A completed silicone shape.

The shape above is rather simple, so this technique was taken to the next step: the fabrication of a silicone sphere – a “bouncy ball” toy. Frosting was laid down to create a cup support to hold the silicone (Figure 15), and the silicone was printed directly inside of it (Figure 16).

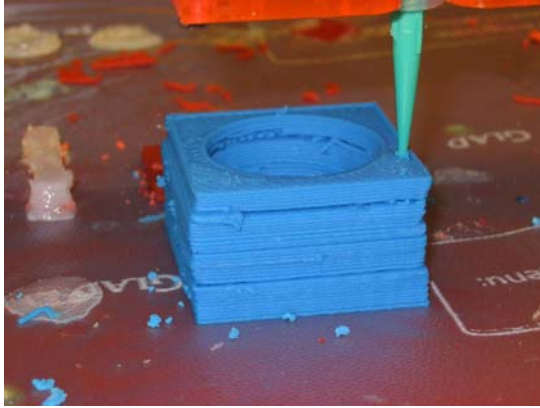


Figure 15 – The frosting mold for holding the silicone.

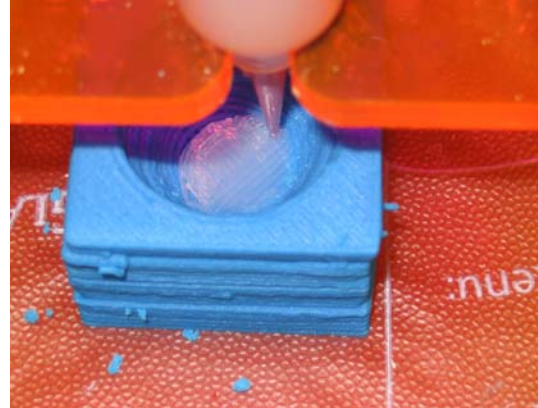


Figure 16– The silicone is printed directly onto the frosting support.

Continuing to print the silicone results in a completed ball (Figure 17). In this case, the frosting is sturdy enough to survive the removal process, and if treated gently, the mold may be re-used. The sphere and frosting cup can be seen in figure 18.

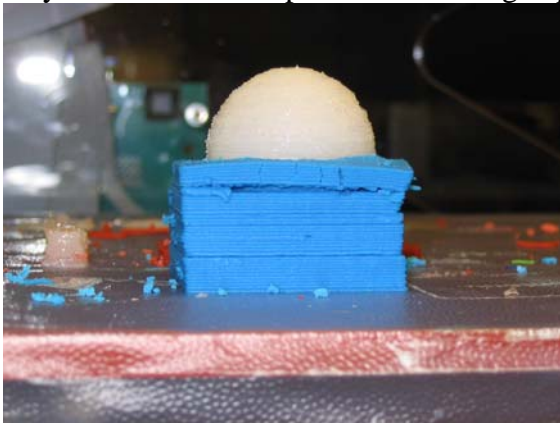


Figure 17 – The completed build, prior to removal.

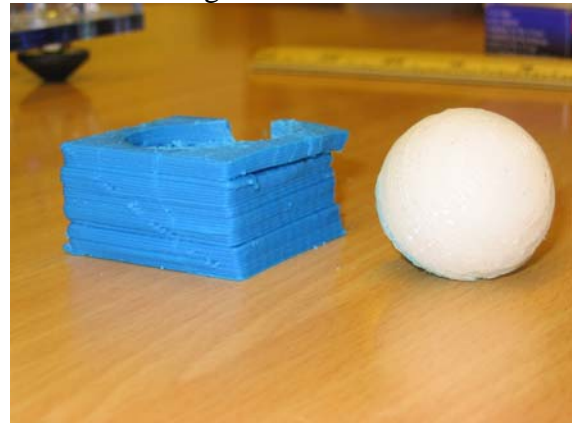


Figure 18 – Ball & cup, separated.

Lastly, as an inverse of the sacrificial food supports, food safe silicone can be used as a reusable mold to hold food, or for food preparation – especially baking. Cupcake, cake, and muffin molds come in all shapes and sizes (Kitchen Emporium), but truly custom molds are hard to come by. For convenience, in this demonstration we employed GE Silicone II which is not rated food-safe. Food safe silicones are readily available (Culinart Inc., 2007), however. We designed some holiday-themed molds (a Christmas tree, a heart-shape, a snowman), and fabricated them of silicone using the Model 1. The GE Silicone II is rated to 400°F, so we baked the muffins in the molds at 350°F to err on the side of caution. The resulting finished muffins replicate the mold geometry well, and are easily released from the molds. As was mentioned, the demonstration employed a non-food-safe silicone, and the smell of crosslinking byproducts was infused into the muffins, making a taste-test ill-advised. Figures 19 & 20 below show the results of these experiments.



Figure 19 – Snowman mold, with muffin.



Figure 20– Heart mold, with muffin.

Overall, the printing of food has been a great success. The complex shapes come out much cleaner than we could have done by hand, and can certainly be taken further, to fully test food's potential as a fabrication material. Our work with chocolate certainly shows that even foods that are solid at room temperature can be used as build materials, albeit with a little more initial effort at calibration than is required for frosting or spray cheese. Finally, using food materials as support structures worked superbly, offering users the opportunity to create permanent complex shapes without having to worry about disposal of the sacrificial base.

Further work can be done to produce even more elaborate objects, as this paper only scratches the surface of this technique. For example, a silicone mold could be printed, and then the cake mix automatically deposited inside by the machine. After baking, a frosting object could then be laid out on top of the cupcake. Of course, food-grade silicone would need to be used, but its material properties are not too different from the silicone used in this paper. In addition, there is always the opportunity for testing new products, to see what other foods can serve as fabrication materials.

Conclusion

Everyone can relate to the idea of building edible objects with food, whether it is a child sculpting her mashed potatoes at the dinner table, or a cake designer creating his confectionery masterpiece. The demonstrations provided here support the claim that food is, for several reasons a viable material for use in freeform fabrication. Firstly, food makes SFF technology more accessible to a layperson, by using benign, inexpensive, and readily accessible materials familiar to users without a technical background. Second, freeform fabrication with food allows creative and technically inclined cooks to realize food creations that would otherwise be beyond their skill level. Lastly, food may be used as a viable sacrificial support material or pre-prototyping material, widely available and easily disposable. The combination of food as a familiar and intriguing raw material with a simple, inexpensive multimaterial SFF system such as a Fab@Home Model 1, demystifies SFF technology, which should greatly enhance public awareness, interest, and creative application, to the benefit of both the society and the technology.

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