3D-printing plates without "support"

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When printing a plate (dish) using a 3D printer, normally, so-called "support" material, which is disposed after printing, is required to be printed and to support the plate. However, try to create thin plates without using such superfluous material! Some devices are required to print them, but it is not so difficult.

1. Printing plates by a conventional method

When creating something by using a 3D printer, first we design it by a computer-aided design (CAD) software tool, and generate a "model". The "model" is represented by a language format called STL. The model is sliced into thin layers and divided into strings, and translated into G-code, which is a language format used for 3D printers.

The above process makes the design printable. A type of 3D printer that layers melted plastic such as ABS or PLA is called fused deposition modeling (FDM) type printer. An FDM-type printer melts plastic into strings (filaments), and layers them according to a G-code program (**Figure 1**).
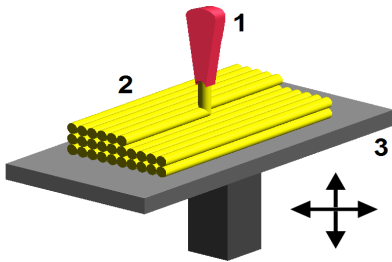

Figure 1. Process of FDM-type 3D printing
("FDM by Zureks" by Zureks - Wikimedia Commons)

When printing a plate by using an FDM-type printer by a conventional 3D printing method, round or overhung part of the plate must be supported by printed material that is called "support". **Figure 2** visualizes G-code that represents plate only (a) and G-code that represents plate and support (b). Support is disposed after printing, so it is wasteful. The support in Figure 2(b) can be smaller, but it may sometimes use more material than plate itself (For displaying G-code in this figure, Repetier Host (Macintosh version) is used).

Is there a method for shaping plates without support that wastes plastic? It is difficult while using conventional 3D printing methods. However, there are two methods that enable it. The next two sections introduce them.
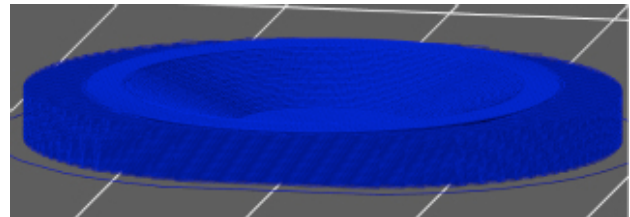
2. Shaping plates by helical printing method

A model to be printed is sliced into thin layers and they are printed one by one in conventional 3D printing methods. A "seam" is generated when transiting from one layer to the next layer. Such seams are highly visible when printing a thin object such as a plate.
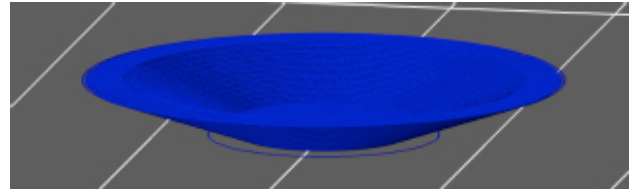
(a) Without support

(b) With support

Figure 2. Visualized G-code

Seams can be eliminated by printing helically instead of layer-by-layer. The helical printing method [Reference 1] enables this. This method not only eliminates seams but also enables free (i.e., non-horizontal) printing directions. This enables the direction of filament extrusion expresses shape formation [Reference 2]. However, it is out of scope of this article.

Figure 3 shows a plate printed by the helical printing method. Because this plate is made of transparent PLA and the printing direction and gradient of each part is designed to light reflection to a different direction, the plate reflects light to various directions and gives brilliance. Support, which spoils brilliance, is not used for this plate.

Figure 3. A small plate printed by the helical printing method

The process of printing a plate by the helical printing method can be observed by a video in YouTube

(http://youtu.be/5P1vaahzW98). Highly transparent PLA is not usually used in 3D printing. However, pure PLA (such as "PLAGO") has high degree of transparency and it is very attractive as filament for this type of 3D printing.

More than ten types of small plates are sold at around 150 yen in "Dasyn" shop in Yahoo! shopping (http://store.shopping.yahoo.co.jp/dasyn/ or http://bit.ly/1EZ4SZI). This shop sells various goods that include a transparent and empty globe shown in **Figure 4**. A more advanced printing technique is used in this globe, so the author will introduce it in another opportunity.)
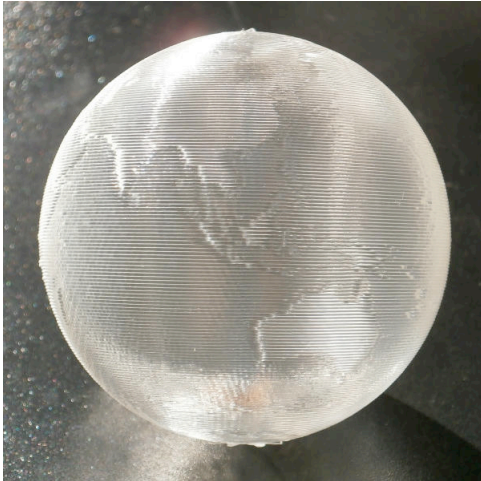

Figure 4. A small globe printed by the helical printing method

The design method for the helical printing method is different from that of the conventional 3D printing method. So, although conventional 3D printers can be used for this method, currently, it cannot be applied to models designed by conventional CAD software tools.

Then, is it not possible to print plates without support by using a software tool for conventional 3D printers? Yes! Actually, there is a method to enable it. The next section introduces this method.

3. Problems of printing plates and a solution

3.1 Problems of conventional 3D printing

The problem of conventional 3D printing of plates are, as written above, is that it is not possible to print it without support. **Figure 5** shows what happens when printing it without support. Figure 5(a) shows what happens when the direction of overhang and filament direction are orthogonal. The filaments drop down in this case. Figure 5(b) shows what happens when the direction of overhang and filament direction are parallel. The filament bends downward in this case.
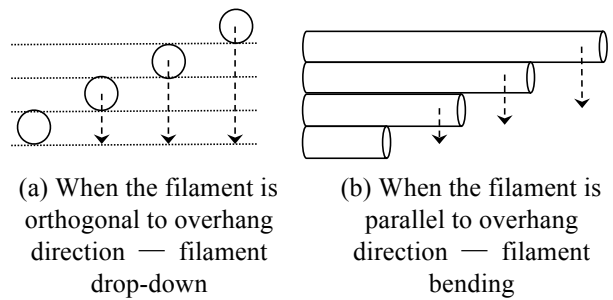

(a) When the filament is orthogonal to overhang direction － filament drop-down	(b) When the filament is parallel to overhang direction － filament bending

Figure 5. Problems of 3D printing with high-angle overhang

3.2 Outline of the solution

How can we solve the above-explained problem when printing a plate? The solution is, in short, to increase the amount of filament so that printed filament becomes thicker and sticks to the neighbor filament. Normally, if the layer thickness is 0.2 mm, the thickness of filament is set to a slightly larger than 0.2 mm. However, in this case, for example, it is set to 0.4 mm. It makes neighbor filaments stick together. This solution is explained more in the following.

3.3 Setting filament increase

The first step is that, by changing the configuration of the slicer, the amount of filament is increased. There are various slicers available, but Slic3r and Skeinforge are selected as representatives here. Both programs are widely used for 3D printing. The methods for increasing filament depend on the program. (Slic3r works better for printing a plate).

When using Slic3r, the value of parameter called extrusion multiplier should be set to between 4 to 6 instead of normal value around 1.0. (This means the amount of filament is 4 to 6 times larger).

Figure 6(a) shows the configurations for Slic3r. The value of "extrusion multiplier" is set to 6 in the configuration window of filament for Slic3r for Macintosh. In this window, the following parameters are also specified: the thickness of filament (1.75 mm), the temperature of extruding filament (about 200°C for PLA of good quality), and the temperature of print bed, i.e., the surface to start printing, (30°C, a temperature that PLA fits well to the print bed).

Figure 6(b) shows the configurations for Skeinforge. The value of "filament packing density" is set to 0.15 to 0.25 instead of normal value around 1.0. This means that the filament is increased 1/0.25 to 1/0.15 times. This figure shows that 0.25 is specified for Skeinforge for Macintosh. If you use another slicer, you should follow the own style of the slicer.
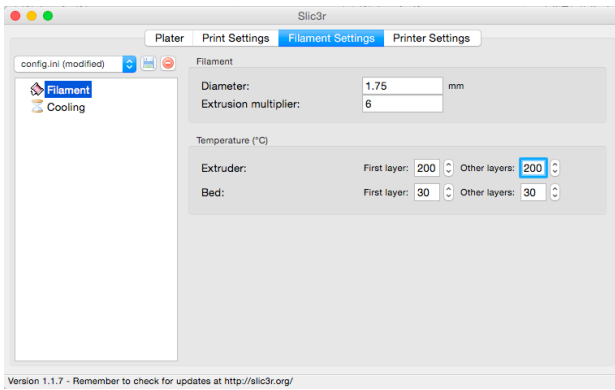
(a) Slic3r — changing extrusion multiplier
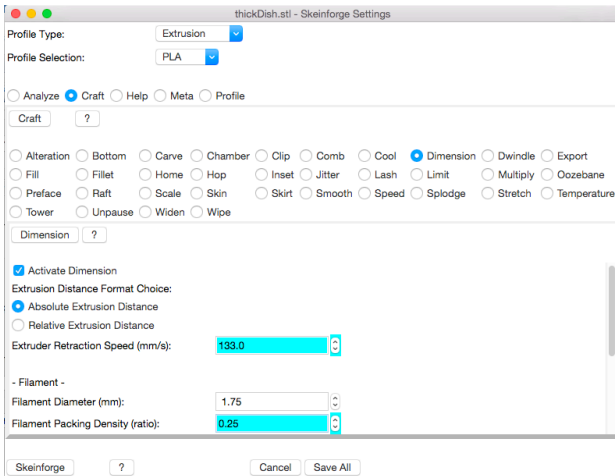
(b) Skeinforge — changing filament packing density

Figure 6. Slicer configuration change for increasing filament

Figure 7. Decision of layer height

3.4 Configuration change of layer height

The next step is to change the configuration of the slicer to adjust the layer height. The layer height is usually smaller than the diameter of the nozzle, which extrudes melted plastic. The nozzle diameter is usually 0.3 to 0.5 mm. If the diameter is 0.5 mm, normal layer height is, for example, 0.4 mm. However, the layer height is set to smaller value here.

The reason why layer height should be smaller is explained as follows. **Figure 7** shows part of a cross section of a plate. It is assumed that the filament is wound with the angle of 15° from the horizontal surface. If the diameter of the filament is 0.4 mm (or slightly larger), the difference of the heights from the neighbor filament is 0.4 sin 15° (= 0.1) mm. The layer height should thus be 0.1 mm. However, because the filament location that the slicer chooses may be different, so the height may have to be adjusted.

Figure 8 shows two windows for specifying the layer height, i.e., Slic3r (a) and Skeinforge (b). The layer height is 0.1 mm for both, but the first layer height is also set to 0.2 mm for Slic3r. This is because, if the height of the bottom layer is 0.1 mm too, it becomes difficult to adjust the printer for successful printing.
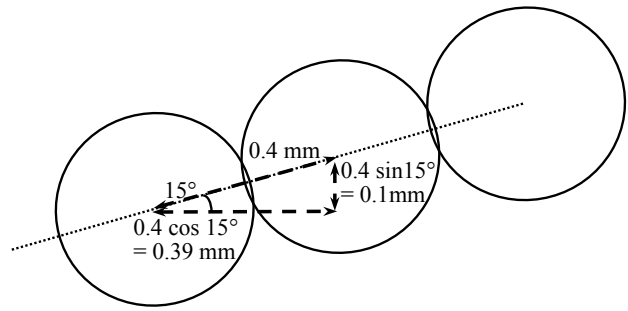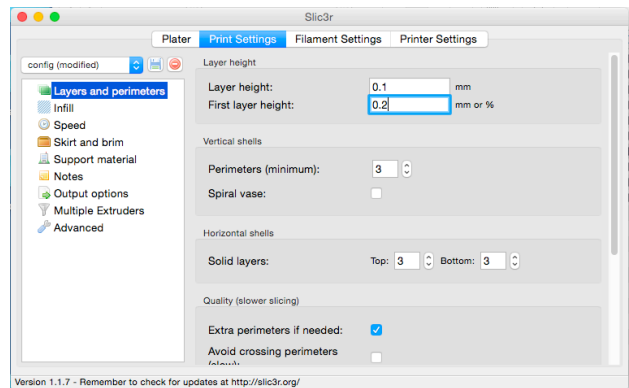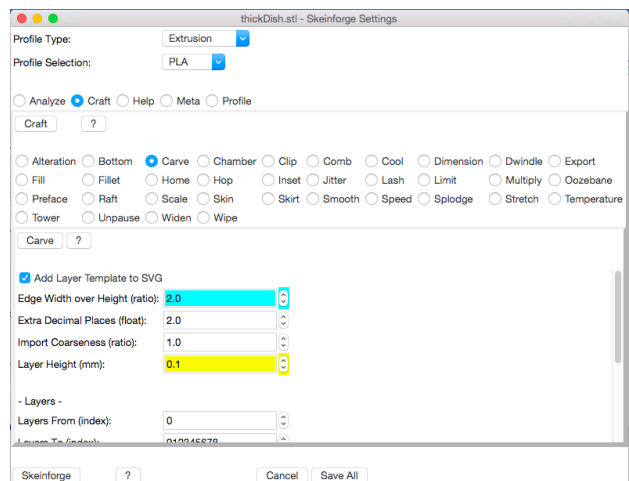

(a) When using Slic3r

(b) When using Skeinforge

Figure 8. Configuration change of slicer for specifying layer height

4. Let's design plates!

Now, let's design a plate to be printed by using a CAD software tool. That is, an STL file is prepared. Any CAD program can be used, but OpenSCAD [Reference 3], which is a free software tool, is used for example here. A Japanese Kindle book [Reference 4] explains all the programs including OpenSCAD used in this article.

Many CAD programs use graphical user interface (GUI) to create 3D models. However, a model is generated by a program by using OpenSCAD. This method takes more time when creating a model at first, i.e., writing a program, but once the program is created, it has an advantage that it is easier to modify the model

(program).

I am relatively accustomed to draw a two-dimensional shape such as shown in Figure 5 or 7 by using a program such as Microsoft PowerPoint, the method of drawing 3D shapes by using a CAD program is usually quite different so I am not accustomed to it. Therefore, I prefer to use OpenSCAD.

Many different methods can be used for drawing a plate by using OpenSCAD, but a relatively easy method is to use a "cylinder" with different sizes of top and bottom surfaces. That is, to use the following program. (The mostly the same program is available at http://www.kanadas.com/weblog/2015/02/cad.html (or http://bit.ly/173UG6b).

```
Angle = 15;
R1 = 10;
R2 = R1 + 20 * cos(Angle);
H = 20 * sin(Angle);
difference() {
    cylinder(h = H, r1 = R1, r2 = R2, $fn = 180);
    translate([0, 0, 0.2])
        cylinder(h = H, r1 = R1, r2 = R2, $fn = 180);
}
```

In this program, an expression, cylinder(h = H, r1 = R1, r2 = R2, $fn = 180), occurs twice. This expression represents a "cylinder" with the radius of the lower base is R1 and that of the upper base is R2, i.e., a plate filled (with something like water). One of the cylinders is placed 0.2 mm upper direction than the other by translate([0, 0, 0.2]). The upper cylinder is subtracted from the lower cylinder by difference(), so that the shape becomes a plate (without water).

By executing the above program, a plate with less than 0.2 mm thickness is generated. It is so thin because each layer consists of only a single wind of filament. The thickness of printed plate will be more than 0.2 mm because it is equal to the filament diameter. The OpenSCAD window after the execution is shown in **Figure 9**.
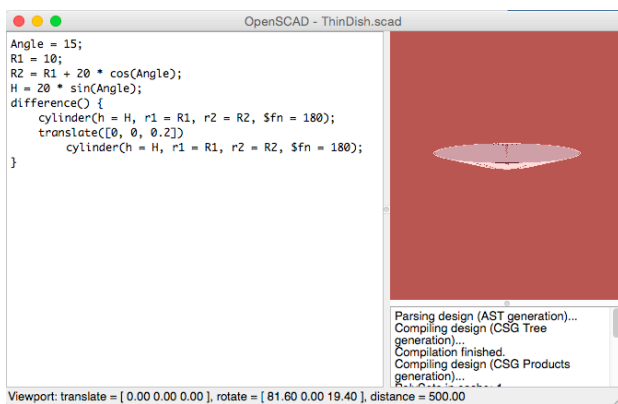

Figure 9. OpenSCAD window after executing the program

When using OpenSCAD, 3D models are represented by programs and can be stored or modified freely, but they can also be stored in STL format, which are execution results. The STL file of the plate shown in Figure 9 can be downloaded from http://www.kanadas.com/weblog/ThinDish15.stl (or http://bit.ly/174wxfR). Because OpenSCAD cannot display shapes very clearly, a free software tool called netfabb Basic OpenSCAD was used for displaying the plate in **Figure 10**. A slicer can convert this STL file to a G-code program that can be executed (printed) by a 3D printer.
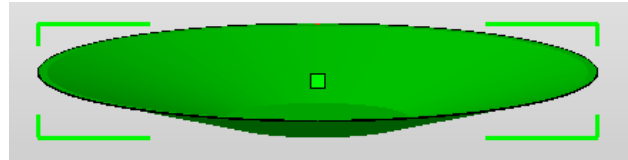

Figure 10. A plate designed by OpenSCAD (displayed by using netfabb Basic)

5. Let's print the plate!

Now, let's print the designed plate. I use a 3D printer called Rostock MAX (**Figure 11**), but any other types of 3D printer can be used for this purpose. The nozzle diameter of my printer is 0.5 mm. The time required for printing the plate is about 6 minutes. However, to shorten the printing time, the printing speed may have to be changed by changing the configuration of the slicer.
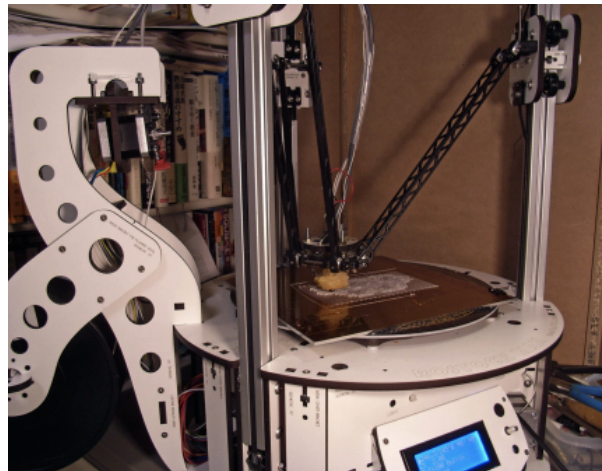

Figure 11. My 3D printer used for printing plates (Rostock MAX)

Figure 12 shows photos of the results of printing plates with 15° gradient round by using Slic3r (a) and Skeinforge (b). The layer height is 0.15 mm, which is relatively thicker because the estimated filament diameter is 0.56 mm (much larger than 0.4 mm). The amount of filament is four times as much as the original value. However, the amount of filament is still smaller than the theoretical value; that is, the calculated diameter is less than 0.56. (This is a mystery!) The photos seem to show both worked well, but actually the filaments draw more exact concentric circles in the case of Slic3r. In addition, maybe because the layer height is too large, the stability of printing seemed to be low and small-scale asperity exists in this case.

Because the amount of filament is tuned to the round with 15° gradient, the amount of filament is four times as much as required at the bottom. However, the bottom still seems to be good.
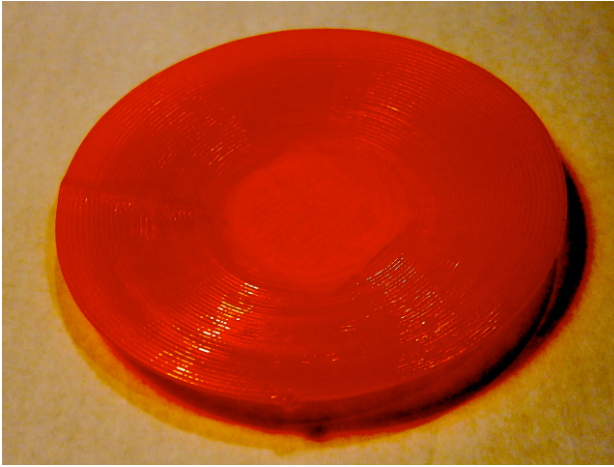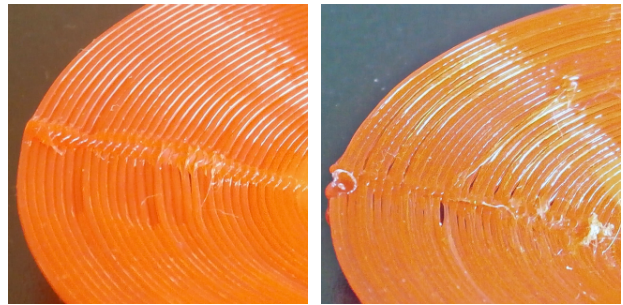

(a) When using Slic3r

(b) When using Skeinforge

Figure 12. Printed plate with 15° gradient round
(layer height: 0.15 mm)

The major problem in these print results is the layer seam. You can probably see the seam in the left side in both Figures 12(a) and 12(b), but they are not very clear. So **Figure 13** zooms into the seam. Especially in Figure 13(b), i.e., in the case of Skeinforge, several gaps that spoil the plate can be observed around the seam, but they can also be observed in Figure 13(a), in the case of Slic3r. Compared with the helical printing method, in which no such seams or gaps are generated, they can be regarded as a fatal defect. However, it is probably possible to conceal them by using an advanced method. I have not yet tried, but why don't you try to print a better plate? In addition, you can probably more easily see that the filament arrangement (array) is better for Slic3r by this figure.

The asperity had become smaller except the seams when the layer height is set to 0.135 mm. **Figure 14** shows a photo of a plate using Slic3r. The estimated filament diameter is still 0.50 mm, but the seams have become bumpier. Although this plate seems to have

holes in this photo, but it just reflects light and it does not have holes. In addition, although the holes cannot be observed, there is a large hole between the bottom and the round part. The bottom should be thicker (e.g., consists of three or more layers) by changing the design.

(a) When using Slic3r   (b) When using Skeinforge

Figure 13. Layer seams of printed plate
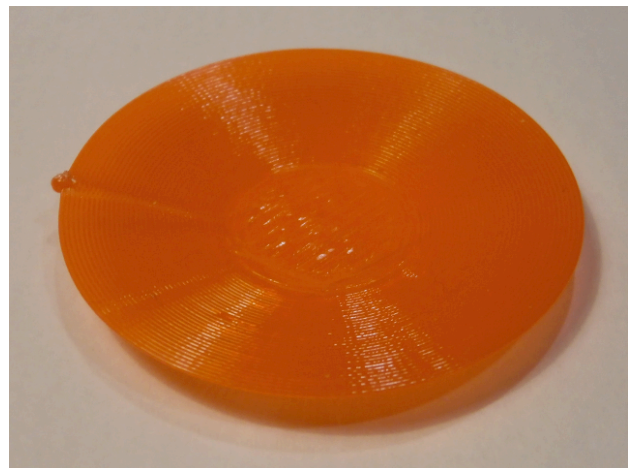(layer height: 0.15 mm)

Figure 14. Printed plate with 15° gradient round
(layer height: 0.135 mm, using Slic3r)

In addition, **Figure 15** shows the results of printing plates with 30° and 45° gradient round. In both cases, Slic3r was used. The layer height was 0.25 mm and the extrusion multiplier was 2.5 for the former and the layer height was 0.35 mm and the extrusion multiplier was 1.5 for the latter. Both are well printed except the seams.

6. Concluding Remarks

3D printers are widely used and studied in companies in Japan. Especially, FDM-type printers gradually become familiar to personal users. Although few personal users have their own 3D printers, they can use 3D printers by rentals in FabLab or DMM.MAKE.

Most of people who use 3D printers use CAD tools in the conventional method. However, there must be many more different ways to use 3D printers, i.e., different printing methods, design methods, and so on. This article showed that a new method for printing a plate without support. As described in Section 2, I tried a completely different method called the helical printing method, but the method introduced in this article is a compromised

method, i.e., pseudo layered method. There must be other much more interesting methods. Why don't you try one?

(a) When the gradient is 15°

(b) When the gradient is 30°

Figure 15. Printed plate with 30° gradient and 45° gradient (by Slic3r)

References

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[2] Kanada, Y., "Method of Designing, Partitioning, and Printing 3D Objects with Specified Printing Direction", *2014 International Symposium on Flexible Automation* (*ISFA 2014*), 2014-7, http://bit.ly/1EqhV5d

[3] "OpenSCAD User Manual", WikiBooks, http://en.wikibooks.org/wiki/OpenSCAD_User_Manual/

[4] Kanada, Y., "Assembling and adjusting a cheap 3D printer Printrbot -- sweat and tears" (Japanese Edition), Kindle version, Dasyn.com, http://www.amazon.com/dp/B00D5DYME4/