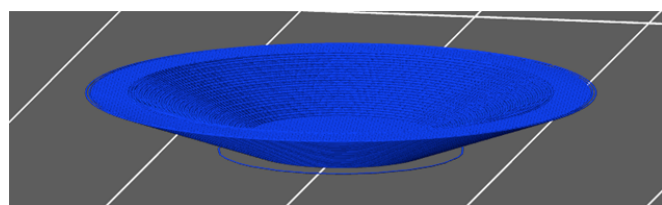# 3D-Printing Plates without "Support"*

Yasusi Kanada

Abstract—When printing a plate (or dish) by an FDM 3D printer, the process normally requires support material, which causes several problems. This paper proposes a method for forming thin plates without using wasteful support material. This method requires several extraordinary parameter values when slicing plates. The experiments show that the plates can, for the most part, be successfully formed using a conventional slicer and a 3D printer; however, seams between layers spoil them and the quality of printed objects strongly depends on the slicer.

Keywords—Fused deposition modeling (FDM), 3D printing, Support-less, Layer seam, Slicer.
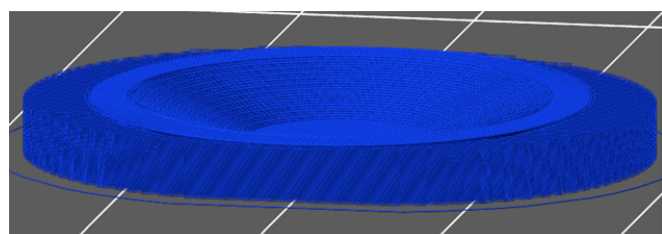
I. PRINTING PLATES USING A CONVENTIONAL METHOD

WHEN shaping an object with a 3D printer, we first design it using a software tool for computer-aided design (CAD) and generate an object model. The model is represented by a language format called STL (Stereolithography or Standard Triangulated Language). The model is then sliced into thin layers, divided to strings, and translated into G-code [7], which is a language format used by 3D printers.

The above process makes the design printable (i.e., able to be formed). One type of 3D printing that layers melted plastic, such as Acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) is called fused-deposition-modeling (FDM). An FDM-type printer melts plastic into strings (filaments) and layers them following a G-code program.

(a) Without support

(b) With support

Fig. 1 Visualized G-code

Yasusi Kanada is with Dasyn.com, Nakano-ku Yayoi-cho 4-2-16, Tokyo, 164-0013, Japan (e-mail: yasusi@kanadas.com).
*Part of this paper was published in a magazine article in Japanese [5].

When printing a plate using an FDM-type printer with a conventional 3D-printing method, round or overhung parts of the plate must be supported by printed material that is called "support." Fig. 1 visualizes G-code that represents a plate only (a) and G-code that represents a plate and support (b). Support material is disposed of after printing is completed, so it is wasteful. The support in Fig. 1 (b) can be smaller, but it may still sometimes use more material than the plate itself. (To visualize G-code, a 3D-printing tool called "Repetier Host" (Macintosh version) was used for these figures.)

This paper studies a method for printing plates without the support material that waste plastic when using conventional tools and printers. Printing a plate using this method is difficult to do with conventional 3D printing methods. Two methods do exist, however, that enable printing plates without support. The next two sections introduce these methods.

II. PRINTING PLATES USING A HELICAL/SPIRAL PRINTING METHOD

One problem caused by conventional 3D printing methods is that "seams" between layers are easily generated (see Fig. 2). By using a conventional 3D printing method, a model to be printed is first sliced into thin layers, which are printed one by one. A seam is generated when transiting from one layer to the next. Such seams are highly visible in thin printed objects, such as plates.
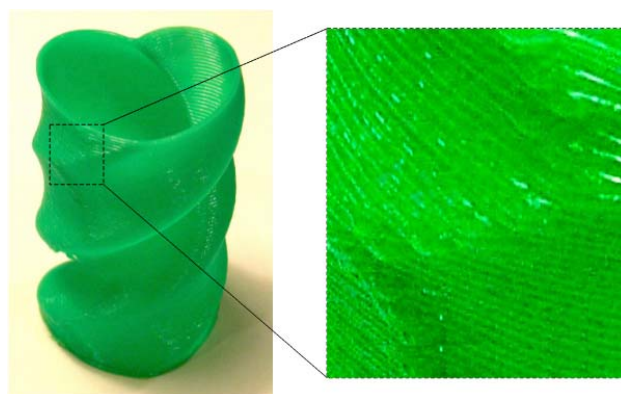

Fig. 2 Seams between layers

Seams can, however, completely be eliminated by printing helically instead of layer-by-layer, which is accomplished through the helical/spiral printing method [3], [1]. This method not only eliminates seams, but it also allows free (i.e., non-horizontal) printing directions. This enables the direction of filament to express the natural direction of the object [4], [2]. However, the natural-direction printing [4], [2] is out of scope of this paper.

Fig. 3 shows a plate printed by the helical/spiral printing method. Because this plate is made of transparent PLA and the printing direction and gradient of each part are designed for obtaining various directions of light reflection, the plate reflects light in many directions and acquires a brilliant luster. Support material, which would spoil the brilliance of such a model, is not used for this plate. The process of forming a plate by the helical/spiral printing method can be observed via a YouTube video [13]. Highly transparent PLA is not usually used in 3D printing; however, pure PLA has a high degree of transparency and it is very attractive as filament for this type of 3D printing.

Fig. 3 A small plate printed by the helical/spiral printing method

More than ten types of small sample plates can be observed and are available [14]. Various goods, which include a transparent and empty globe shown in Fig. 4 are also available there. A more advanced printing technique used in this globe is introduced in another paper [6].


Fig. 4 A small globe printed by the helical/spiral printing method

The design method for the helical/spiral 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 3D models designed by conventional CAD software tools. The next section introduces a method for printing plates without support using conventional 3D printers and software tools.

III. PROBLEMS OF PRINTING PLATES AND A SOLUTION

A. Problems of Conventional 3D printing

The problem with the conventional 3D printing of plates is, as stated above, that it is not possible to form the exact shapes of plates without support. Fig. 5 shows what happens when printing a plate without support. Fig. 5 (a) shows an instance where the direction of overhang and the filament direction are orthogonal. In this case, the filaments drop down. Fig. 5 (b) shows an instance where the direction of overhang and filament direction are parallel. In this case, the filaments bend downward.
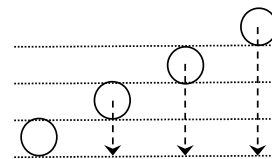
(a) When the filament is orthogonal to the overhang direction, the filaments drop down
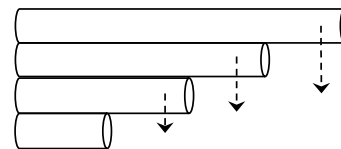
(b) When the filament is parallel to overhang direction, the filaments bend downward

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

B. Outline of the Solution

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

C. Setting Filament Increase

The first step involves changing the configuration of the slicer to increase the amount of filament. There are various slicers available for 3D printing; however, Slic3r [8], [11] and Skeinforge [11] are selected as representatives here. Both programs are widely used. Each slicer has its own method for increasing filament. Slic3r works better when printing a plate. The value of the Slic3r-specific parameter, called the extrusion multiplier, should be set to between 4 and 6 instead of the normal value of 1. (This means the amount of filament is 4 to 6 times larger than the normal value).

Fig. 6 (a) shows the configuration window and parameters for Slic3r. The value of the extrusion multiplier is set to 6 in the filament configuration window of Slic3r for Macintosh. In this window, the following parameters are also specified: the

diameter of the filament (1.75 mm), the temperature of extruding filament (about 200°C for PLA of good quality), and the temperature of the print bed, which is the surface on which printing begins (30°C is a temperature at which PLA sticks well to the print bed).

Fig. 6 (b) shows the configuration window and parameters for Skeinforge. The value of a Skeinforge-specific parameter, called filament packing density, is set to between 0.15 and 0.25 instead of the normal value of 1.0. This means that the filament is increased 1/0.25 to 1/0.15 times. The figure shows that 0.25 is specified for Skeinforge for Macintosh. If another slicer is used, its own style and parameters must be used.
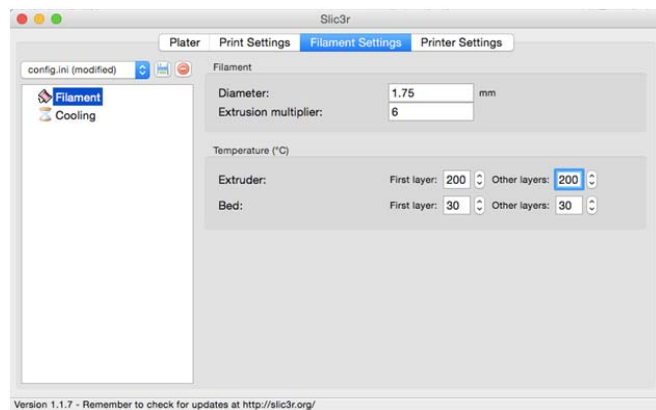
(a) Slic3r—changing extrusion multiplier
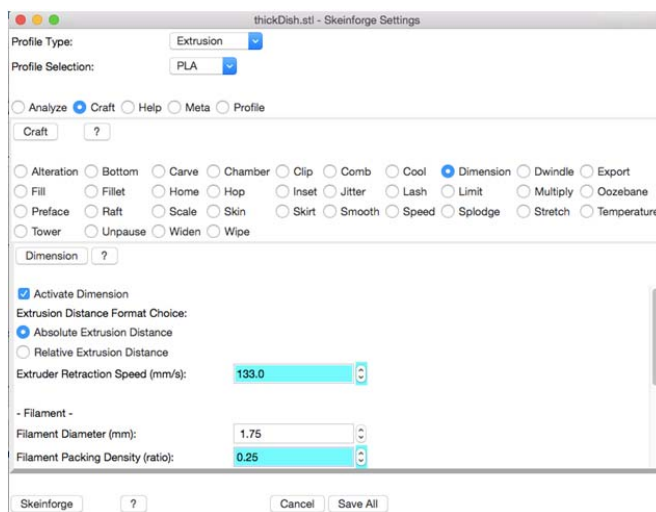
(b) Skeinforge—changing filament packing density

Fig. 6 Slicer configuration change for increasing filament

D. Configuration Change of Layer Height

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

The reason that layer height should be smaller is explained as follows. Fig. 7 shows part of a cross section of a plate. It is assumed that the filament is wound at an 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 of the neighboring filaments is 0.4 sin 15°, which equals 0.1 mm. The layer height should thus be 0.1 mm. Because the horizontal filament location that the slicer chooses may be different from this figure, however, the layer height may have to be adjusted.
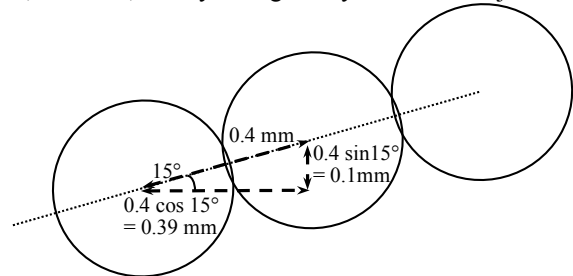

Fig. 7 Decision of layer height

Fig. 8 shows the windows for specifying the layer height in Slic3r (a) and Skeinforge (b). The layer height is 0.1 mm for both, but the first layer height is set to 0.2 mm for Slic3r. This is because if the height of the bottom layer is 0.1 mm, the printer is difficult to adjust in order to achieve a successful printing.

IV. DESIGNING PLATES

A plate to be formed can be designed with a CAD software tool using the following method. First, an STL file should be prepared. Any CAD program can be used, but OpenSCAD [9], [10], which is a free software tool, is used for example here.

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

If the designer of the model is relatively accustomed to drawing two-dimensional shapes such as those shown in Figs. 5 or 7 using a program such as Microsoft PowerPoint, the method of drawing 3D shapes by using a CAD program will probably be quite foreign, so the designer might not be accustomed to the modeling process. It may thus be better for him/her to use OpenSCAD.

Many different methods can be used for drawing a plate with OpenSCAD, but one relatively easy method is to use a tapered cylinder with different sized top and bottom surfaces. That is, to use the following program. (A program mostly the same as this program is available [15].)
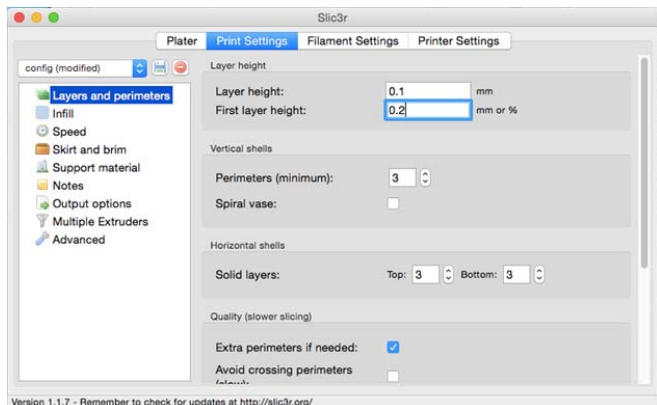
(a) When using Slic3r
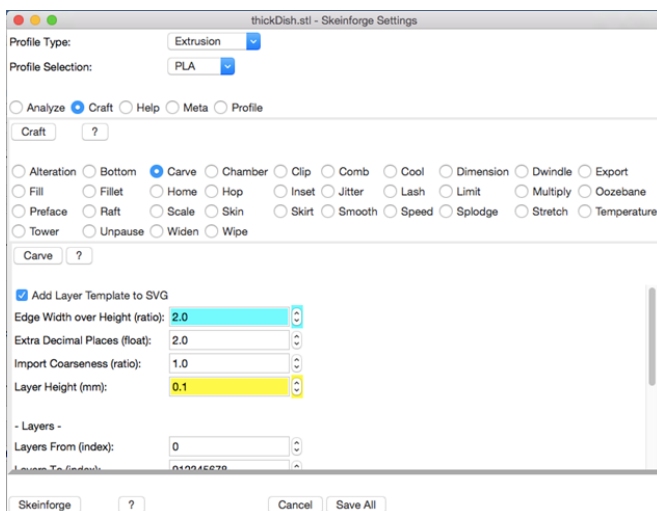
(b) When using Skeinforge

Fig. 8 Configuration change of slicer for specifying layer height

```
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" where the radius of the lower base is R1 and that of the upper base is R2. One of the cylinders is placed 0.2 mm above the other using translate([0, 0, 0.2]). The upper cylinder is subtracted from the lower cylinder by difference(), so that the shape becomes a plate.

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 the 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 Fig. 9.

3D models are represented by programs in OpenSCAD and can be stored or modified freely; however, they can also be stored in STL format, which represent the execution results of the programs. The STL file of the plate shown in Fig. 9 can be downloaded from the WWW [15]. Because OpenSCAD does not display shapes very clearly, a free software tool called "netfabb Basic" (a free version of netfabb) was used to display the plate in Fig. 10. A slicer can convert an STL file to a G-code program that can form the shape using a 3D printer.
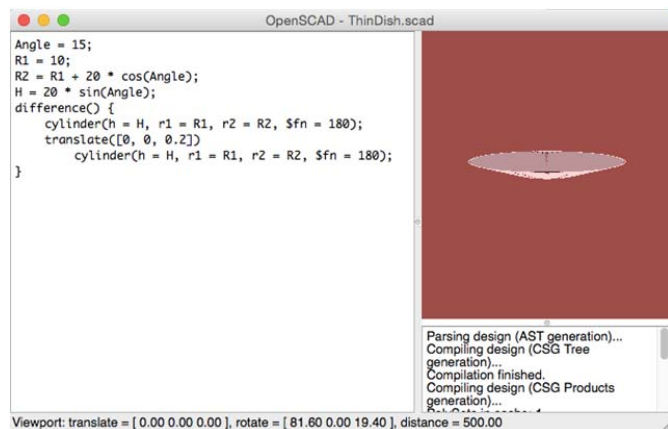

Fig. 9 OpenSCAD window after executing the program
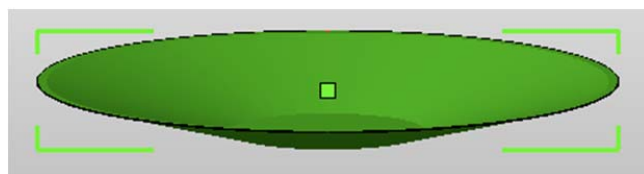

Fig. 10 A plate designed by OpenSCAD (displayed using netfabb Basic)

V. PRINTING THE PLATE

The designed plate can be printed by using the following method. The author used a 3D printer called Rostock MAX (Fig. 11), but any other type of 3D printer could be used for this purpose. The nozzle inner-diameter used in this example was 0.5 mm. The time required for printing the plate was about 6 minutes. To shorten the printing time, however, the printing speed may be changed by modifying the configuration of the slicer.

Fig. 12 shows photos of the printed plates with a 15° gradient round by using Slic3r (a) and Skeinforge (b). The layer height is 0.15 mm, which is much larger than the height in Figs. 7 and 8, i.e., 0.1 mm, and is the expected value when the filament diameter is 0.6 mm. Although the expected amount of filament is (only) twice larger than the original value, the specified amount of filament was four times larger than that. The cause of this mismatch is not known. The photos seem to show both slicers worked well, but actually, the filaments draw more exact concentric circles in the case of Slic3r. Additionally, the

stability of printing seemed to be low and small-scale asperity exists in this case, maybe because the layer height is too large.
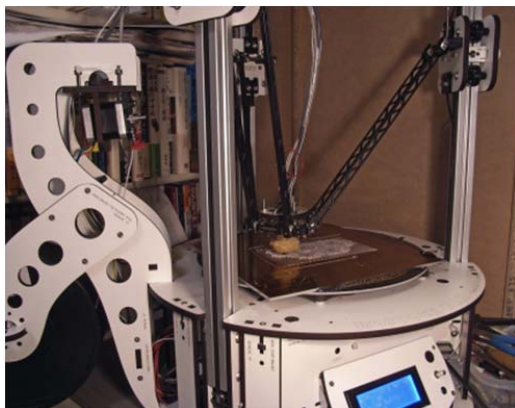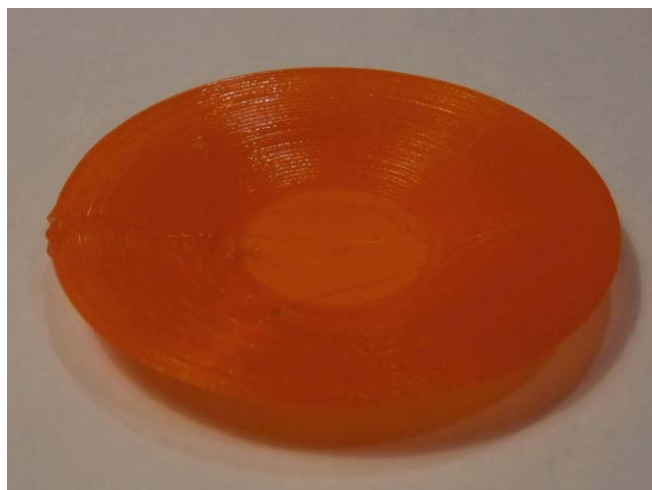

Fig. 11 The 3D printer used for printing plates (Rostock MAX)
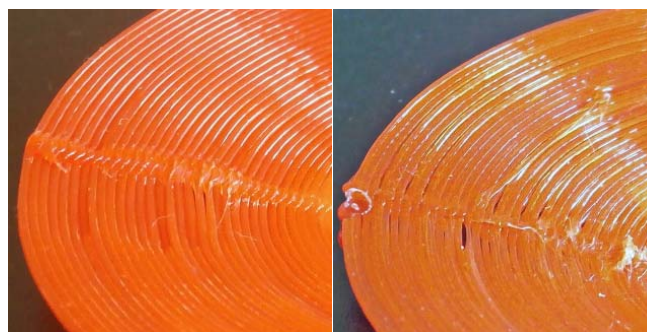
(a) When using Slic3r

(b) When using Skeinforge

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

The parameters of filament, which are tuned to the round with a 15° gradient, are also applied to the bottom, so the amount of filament is four times as much as required at the bottom. The formation of the bottom, however, still seems to be good.

The most serious problem in these printed plates is the layer seam. Seams can be observed on the left side of the plates in both Figs. 12 (a) and (b); however, they are not very clear. To clearly show these seams, Fig. 13 zooms in. These seams are especially noticeable in Fig. 13 (b), which displays a plate created with Skeinforge, and several gaps that spoil the plate can be observed around the seams. While slightly better, these gaps can also be observed in Fig. 13 (a), which displays a plate created with Slic3r. Compared with the helical/spiral printing method, where such seams and gaps can be completely avoided, these may be regarded as fatal defects. It may be possible to conceal them by using an advanced method, but the author has not yet discovered one. This figure shows that the filament arrangement (array) is better when using Slic3r.

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

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

The asperity was smaller, except for with the seams created when the layer height was set to 0.135 mm. Fig. 14 shows a photo of a plate of this type, which was created using Slic3r. The estimated filament diameter is 0.50 mm. In this case, the seams are bumpier. Although in this photo the plate in Fig. 14 seems to have holes in it, these are actually light reflections; the plate does not have holes in the bottom. However, the plate does have holes that cannot be observed in this photo. For example, there is a large hole between the bottom and the round part. To avoid this, the bottom must probably be thicker (i.e., consist of three or more layers).

Fig. 15 shows the results of printing dishes 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 for the seams.

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

(a) When the gradient is 30°

(b) When the gradient is 45°

Fig. 15 Printed plate with 30° gradient and 45° gradient using Slic3r

VI. Conclusion

When printing a plate (or dish) using an FDM 3D printer, the process normally requires support material, which causes several problems. This paper proposes a method for printing thin plates without using wasteful support material. This method requires that several extraordinary parameter values be used when slicing plates. The experiments show that the plates can be mostly successfully formed, for the most part, by using conventional slicers and a 3D printer. Seams between layers, however, spoil the printed objects. The quality of the objects strongly depends on the slicer. To obtain better results, some parameters are required to be changed from the theoretically-decided values.

Future work should include non-conventional design and printing methods for 3D printing. In most of the projects for which 3D printers are used, CAD tools that follow the conventional method are also used. However, there must be many additional ways to use 3D printers (e.g., different printing methods, design methods, and so on). Section 2 showed a completely different method, called the helical/spiral printing method, but the method introduced in this paper is a compromised method (i.e., pseudo layered method). There may be other much more advanced methods to be studied. Future work should thus include developing such methods.

References

[1] Kanada, Y., "3D-printing of Generative Art by using Combination and Deformation of Direction-specified 3D Parts," *4th International Conference on Additive Manufacturing and Bio-Manufacturing* (*ICAM-BM 2014, Beijing*), November 2014, http://bit.ly/1zcMCaO
[2] Kanada, Y., "Method of Designing, Partitioning, and Printing 3D Objects with Specified Printing Direction," *2014 International Symposium on Flexible Automation* (*ISFA 2014*), July 2014, http://bit.ly/1EqhV5d
[3] Kanada, Y., "3D Printing of Generative Art using the Assembly and Deformation of Direction-specified Parts," *Rapid Prototyping Journal*, accepted for publication, 2015.
[4] Kanada, Y., "Natural-Direction-Consistent 3D-Design and -Printing Methods," *International Journal of Computer, Control, Quantum and Information Engineering, WASET*, Vol. 9, No. 4, pp. 689-693, 2015.
[5] Kanada, Y., "Let's make a plate by a 3D printer without using support," I/O, Kogakusha, April 2015 (in Japanese).
[6] Kanada, Y., "Creating Thin Objects with Bit-mapped Pictures / Characters by FDM Helical 3D Printing," *8th International Conference on Leading Edge Manufacturing in 21st Century* (*LEM21*), October 2015.
[7] Kramer, T. R., Proctor, F. M., Messina, E., "The NIST RS274NGC Interpreter - Version 3," National Institute of Standards and Technology (NIST), NISTIR 6556, August 2000.
[8] Moore, D. M., "Instant Slic3r," Packt Publishing, September 2013.
[9] Büttrich, S., "3D Modeling with OpenSCAD - *Part 1*," in Canessa, E., Fonda, C., and Zennaro, ed., "Low-cost 3D Printing for Science, Education, and Sustainable Development", pp. 83–86, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.410.790&rep=rep1&type=pdf#page=85
[10] Kintel M., "3D Modeling with OpenSCAD - *Part 2*," in Canessa, E., Fonda, C., and Zennaro, ed., "Low-cost 3D Printing for Science, Education, and Sustainable Development", pp. 87–90, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.410.790&rep=rep1&type=pdf#page=89
[11] Ranellucci, A., "Reprap, Slic3r and the Future of 3D Printing," in Canessa, E., Fonda, C., and Zennaro, ed., "Low-cost 3D Printing for Science, Education, and Sustainable Development", pp. 75–82, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.410.790&rep=rep1&type=pdf#page=77
[12] "Skeinforge", http://fabmetheus.crsndoo.com/wiki/index.php/Skeinforge
[13] Dasyn.com, "Printing a Dish by Helical Head Motion," http://youtu.be/5P1vaahzW98

[14] Dasyn.com, "Dasyn", http://store.shopping.yahoo.co.jp/dasyn/ (or http://bit.ly/1EZ4SZI) (in Japanese)
[15] Kanada, Y., "A Challenge of Printing Dishes using CAD software and without Supports", http://www.kanadas.com/weblog/2015/02/cad.html (or http://bit.ly/173UG6b) (in Japanese)

Yasusi Kanada received a B.E. in mathematical engineering from the University of Tokyo in 1979 and an M.E. in information engineering from the University of Tokyo in 1981. He has been working for Hitachi, Ltd. since 1981. He is a part-time lecturer at Kogakuin University. He worked at Carnegie Mellon University from 1988 to 1990 and at Tsukuba Laboratory of the Real World Computing Partnership (RWCP) from 1992 to 1995. He received a Ph.D. from the University of Tokyo in 1992. Additionally, he studied programming, programming languages, and emergent computation in the University of Tokyo and in Hitachi, he studies and teaches computer networks in Hitachi and Kogakuin University, and he studies new 3D printing methods for Dasyn.com.