ADMC 2017

Catalogue

Asian Digital Modeling Contest 2017

ADMC 2017

Catalogue

Asian Digital Modeling Conte st 2017
ADMC 2017 Catalogue

Contents

Asian Digital Modeling Contest 2017

Asian Digital Modeling Contest 2017

The Asian Digital Modeling Contest 2017(ADMC2017) will be held in conjunction with the 11th Asian Forum on Graphic Science (AFGS2017) which is primarily sponsored by the Japan Society for Graphic Science. ADMC2017 is presently inviting original 3D models which can be built using 3D printers. The contest aims to spread fundamental technologies for inspiring the creation of three-dimensional mechanisms and objects in new innovative environments led by additive manufacturing (3D printers). Over the past 10 years, the Japan Society for Graphic Science has been holding the Digital Modeling Contest in Japan. Based on its experience accumulated through these contests, this time the society expanded the areas eligible for entering works and invited entries from abroad. Entries selected for the final round be attended to make a presentation on their work and participate in the poster exhibition in the final judgment of ADMC2017 held during AFGS2017.

3D printers are used widely, from making machines to architecture, molding designs, everyday goods, toys, characters, and so on. The 3D data used is made by methods which continue to progress based on innovative concepts and technologies such as creating modeling data by measuring target objects using 3D scanning devices, large-scale shape data processing, etc. In the areas of robot engineering and medical engineering for example, 3D printers are used to build 3D models for resolving various problems. We welcomed entries from areas developing such novel applied technologies, 3D shapes made by additive manufacturing, 3D models built using original and innovative 3D shape production methods, etc. For details of digital modeling contests held by Japan Society for Graphic Science in the past, please access: http://www.graphicscience.jp/contest/list.html

Judging schedule
    August 7, 2017   Short talk
    August 8, 2017   Gallery talk
    August 10, 2017   Awards ceremony

Venue
    21 Komaba Center for Educational Excellence (21 KOMCEE)
    the University of Tokyo, Komaba I Campus
    3-8-1 Komaba, Meguro-ku, Tokyo 153-8902

Jury Committee
  Jury committee Chair
          Jun MITANI   Japan
  Jury committee Vice-Chair
          Misako NISHII   Japan
  Jury committee members
          Erik DEMAINE   USA
          Sang Kwon GOO   Korea
          Yasushi IKEDA   Japan
          Eri MATSUI   Japan
          Henry SEGERMAN   USA
          Yongtian WANG   China
          Hisashi SATO   Japan
          Tsutomu ARAKI   Japan
          Michio KATO   Japan
          Aya SAITO   Japan
          Tatsushi TANAKA   Japan
          Emiko TSUTSUMI   Japan
          Yasushi NIITSU   Japan
          Koichi MATSUDA   Japan
          Yoshiaki MACHIDA   Japan
          Toshio MURAMATSU   Japan
          Kazuko MENDE   Japan
          Tatsuya MOCHIZUKI   Japan
          Yohei NAMBU   Japan
          Yayoi YOKOYAMA   Japan
Executive committee Chairman
          Kunio KONDO   Japan
Vice-chairman
          Hisashi SATO   Japan
          Misako NISHII   Japan
Committee member
          Ryuta MOTEGI   Japan

Cosponsors   ALTECH Co., Ltd.
                  Autodesk, Inc.
                  Lattice Technology Co.,Ltd.
                  Stratasys Japan Co.,Ltd.

Contact   info-admc2017@graphicscience.jp

Organized by   Japan Society for Graphic Science   JSGS

This conference is supported by JSPS KAKENHI Grant Number JP16HP0706.

3

1. Comments by ADMC2017 Jury

Over the past 10 years, the JSGS (japan society of graphic science) has been holding the Digital Modeling Contest in Japan. Based on its experience accumulated trough these contests, JSGS decided to hold ADMC2017. We expected more submissions. There were 27 submissions from 7 different countries including Asia and Europe. All of the works were very interesting. Many of the works showed the possibilities of Digital Modeling and 3D printers. Some of the works showed that it is possible to make shapes using 3D printers in various fields such as education, medical care and so on. There were also some works showing the difference between existence as digital data and as a real object. We believe that this contest shows the possibility of 3D printers and Digital Modeling.

2. Judging and Awards

(1) Judging criteria

Entries are judged according to the following criteria comprehensively.

■Modeling ability

· Ability to build 3D data and models taking into account the ideas and method for building the model.

■Structures and mechanisms possible with 3D printers

· Complicated mechanisms which could not be built easily with cutting techniques and casting until now.

· Materialization of geometrical figures.

■New fields of application

· Use of 3D data for new fields for resolving various tasks.

(2) Selection of finalists

We had 27 submissions from 7 different countries, and we selected 11 finalists.

(3) Election of Awards from finalists

A short talk session and a gallery talk session were held on 7th and 8th Aug respectively. The nominees hold presentations with slides at the short talk session. The posters and the 3D printed objects were presented at the gallery talk, and the nominees answered questions from jury members and participants of ADMC and AFGS. Each jury committee member selected three excellent works and voted for them with comments. After the gallery talk session, a jury committee held a meeting. After a discussion based on the vote result, nominees for one grand prize, two award for excellences, and one special jury award were selected.

(4) Award Winners

Grand Prize

Duality: Masanori Nakayama, Issei Fujishiro

Award for Excellence

Pre-programmed deformable material:
Taisuke Ohshima, Tomohiro Tachi, Yasushi Yamaguchi
Chladni Towers: Martin Skrodzki, Ulrich Reitebuch, Konrad Polthier

Special Jury Award

OJIGI TOKURI: Shoko KAWATA, Kazuki TAKENOUCHI

Grand Prize

Duality   Masanori Nakayama, Issei Fujishiro

Awards reason:

The algorithms for Voronoi diagrams and Delaunay diagrams are employed for the modeling process. It is impossible to create the form without digital modeling techniques. It is a representative model of the challenges that today's 3D printing is facing such as generative algorithm, mesh generation, and weight saving. The appearance of its precise structure is beautiful. The technique of setting different strength place by place could be practically used in the medical field for when 3D printing the shape of the internal organs.

Award for Excellence

Pre-programmed deformable material   Taisuke Ohshima, Tomohiro Tachi, Yasushi Yamaguchi

Awards reason:

Although almost rigid materials are used, it succeeded to generate the intended curved surfaces from a flat sheet by controlling its geometrical pattern. It is surprising that curved surfaces with different Gaussian curvatures can be created from regular and simple patterns. This structure has potential to be applied to new material design in many industry fields.

Award for Excellence

Chladni Towers   Martin Skrodzki, Ulrich Reitebuch, Konrad Polthier

Awards reason:

The form is constructed from a layered Chladni figure which is derived from physical phenomena. Visualization of sound is often performed by two-dimensional figures, but by using a layered structure, an additional dimension is expressed in the height direction, and the vibration of sound is expresses in a 3D space. The idea is novel and the realized form is elegant. This is a splendid work that visualizes an invisible physical phenomena.

Special Jury Award

OJIGI TOKURI   Shoko KAWATA, Kazuki TAKENOUCHI

Awards reason:

It has succeeded in designing a novel Tokuri, a Japanese traditional sake bottle, which has new functions and values with a humorous point of view. Japanese tradition and fabrication technique are well integrated, and its geometrical form is also attractive.

Award Winners & Finalist

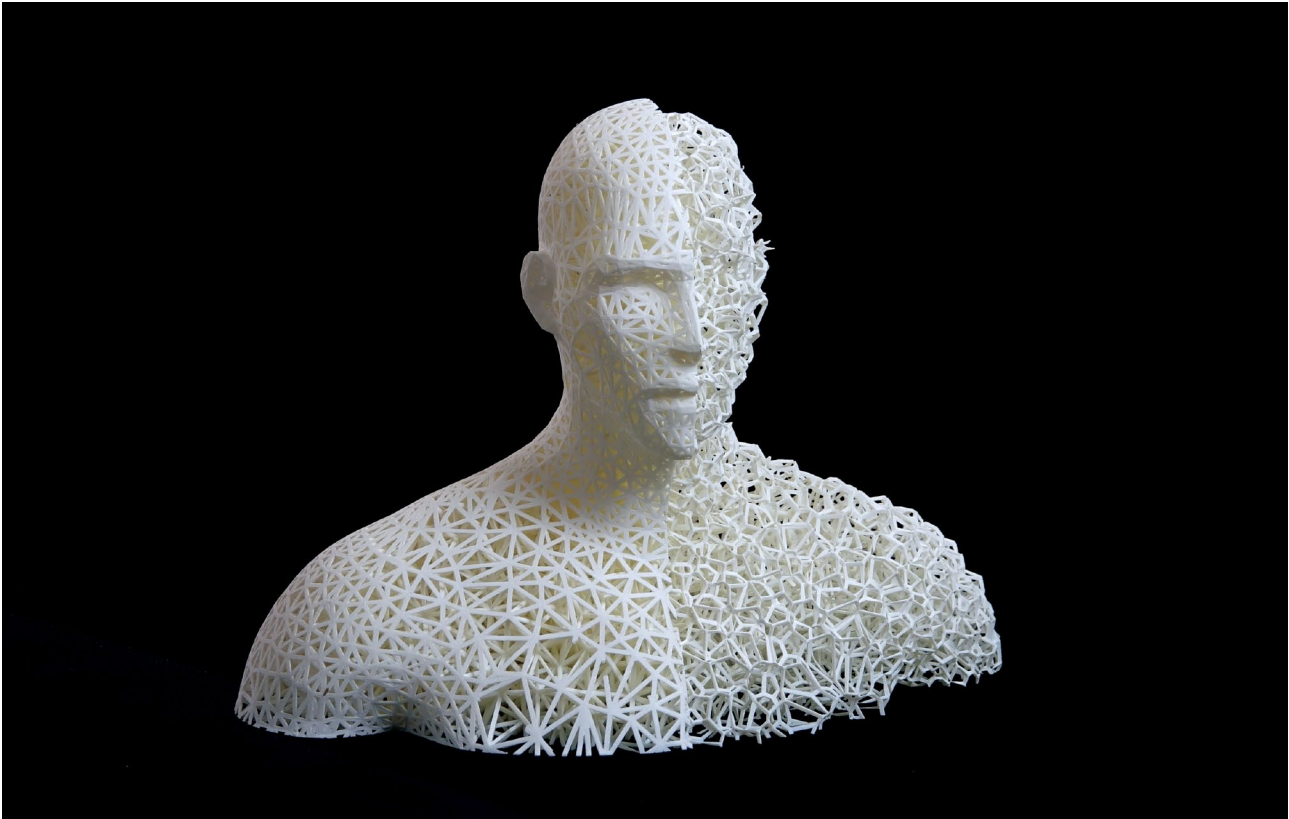# Duality

Masanori Nakayama, Issei Fujishiro

Masanori Nakayama, Issei Fujishiro "Duality" 2017, Material: VeroWhite, Size: 246W x 120D x 189H (mm)

In the present work, we attempted at expressing human "two-facedness" by the "two-sidedness" of the 3D structures. In the field of geometry, there exists a two-facedness called "duality," which represents the relationship between diagrams that switch between faces (cells) and vertices. Delaunay diagram and Voronoi diagram give a typical example. We have developed an algorithm to generate a Poisson-disk distribution in an arbitrary shape to make sculptures with those diagrams. The Delaunay diagram generated by Poisson-disk distribution point cloud makes up the uniform tetrahedral mesh (except for the surface). Since those cells are close to a regular tetrahedron, Voronoi vertices located on the circumcenters also have an almost uniform distribution.

Keywords: Tetrahedralization, Delaunay diagram, Voronoi diagram
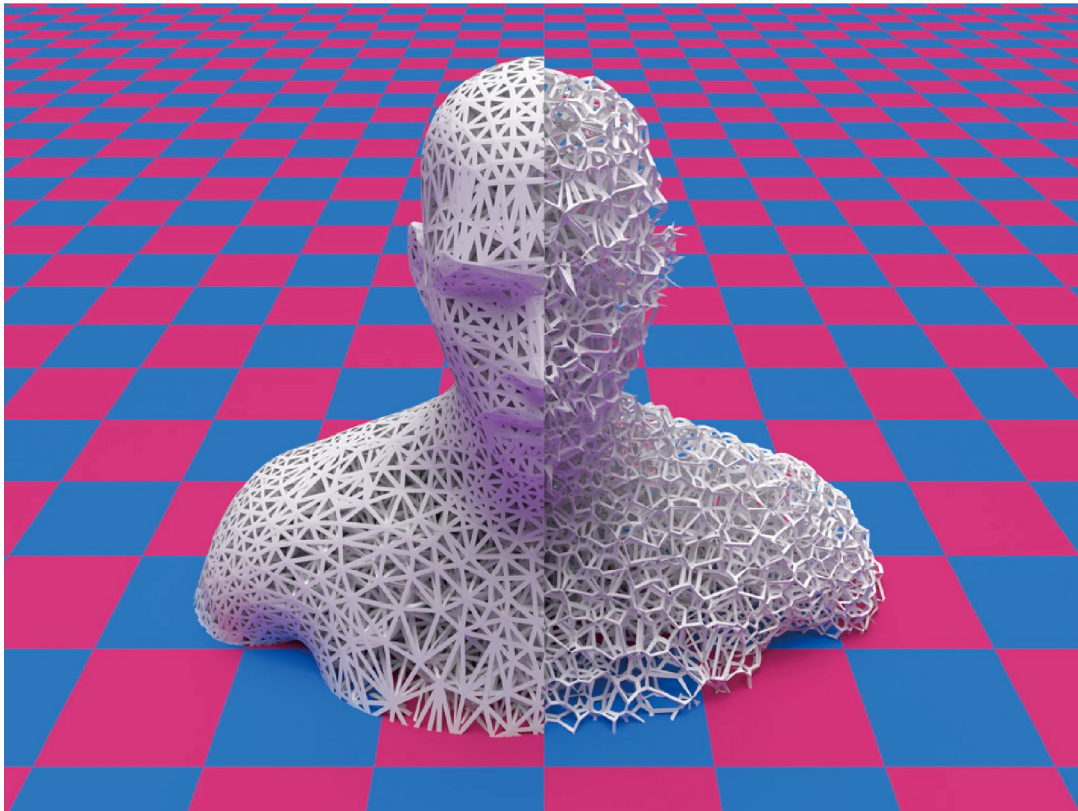
1 Concept

We have worked on an optimal subdivision algorithm to discretize a given arbitrary shape. In 2D, we built on Delaunay diagram to subdivide an arbitrary closed curve region into a uniform triangular mesh with Poisson disk distribution (Fig. 1). By embedding the 2D Delaunay diagram in 3D, we succeeded to subdivide an arbitrary closed surface volume into a tetrahedral mesh with Poisson disk
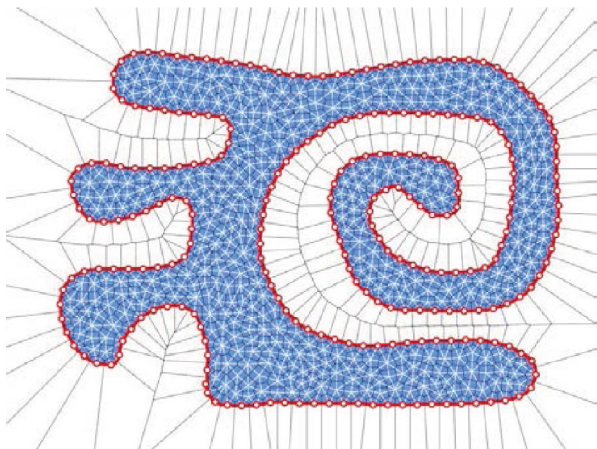
Figure 1: Poisson-disk triangulation.

distribution (Fig. 2). In comparison with Guo's prior work [2], the incorporated non-polygonal isosurfacing increases the versatility in terms of input volume, simplifies meshing steps, and improves the quality of output meshes.

All of our works root commonly in the "duality" of Delaunay diagram and Voronoi diagram—both structures are mutually convertible by swapping the roles of faces and vertices. In the present work, we attempted at expressing human "two-facedness" with the "two-sidedness" of the two diagrams.

2 How to Make

There exists a de facto standard tetrahedralization library called *Tetgen* [3]. For edgy curve surfaces that can be defined in a piecewise manner, a specific type of tetrahedralization algorithm was devised in [4].

In our tetrahedralization scheme, we first generate a Delaunay diagram with vertices on the target's surface, and thereby making separate inside and outside of the target
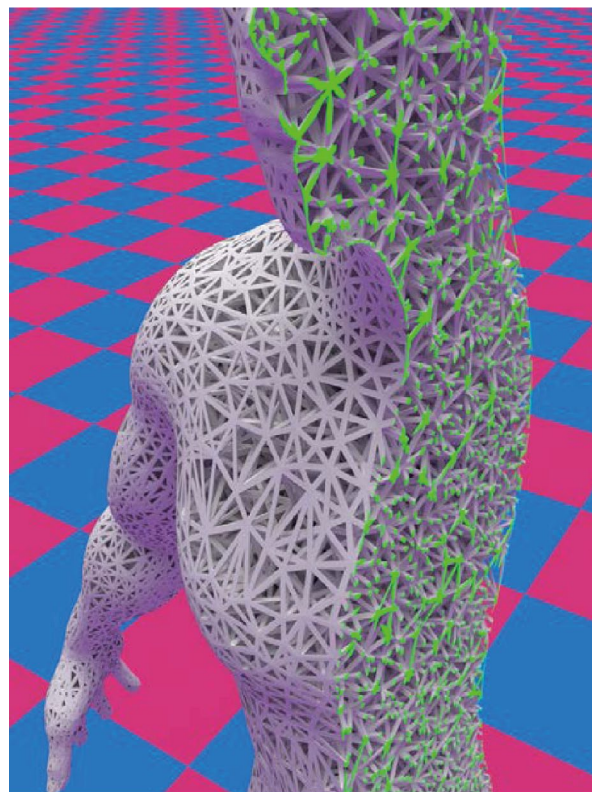

Figure 2: Poisson-disk tetrahedralization.

shape. Fig. 3 simply represents this in 2D.

Next, we add points only in the inside region. Note that in order to uniformly distribute vertices, we should not insert them randomly. For each tetrahedron, we search for the largest circumscribed sphere, and insert a point at the center of the sphere (Fig. 4). The position of the point is nothing less than the vertex of the Voronoi diagram, indicating the most distant location from the existing points in the largest blank area.
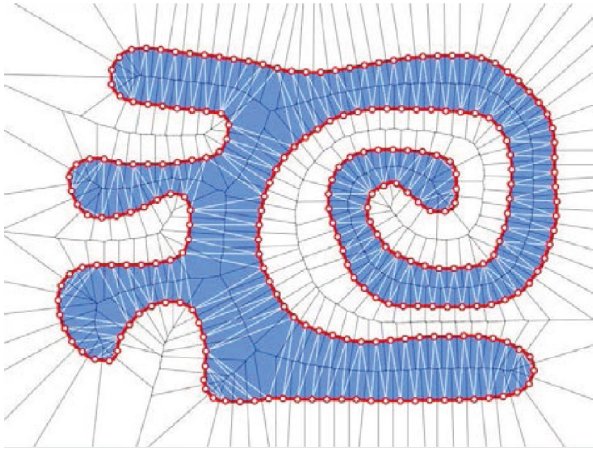
Figure 3: Delaunay diagram of edge points.

Figure 4: Voronoi vertices in empty circle.

By repeating the process, the vertex distribution automatically converges to a Poisson disk distribution, and resulting in the most uniform tetrahedral mesh. Variational tetrahedral meshing in [1] can further improve the location of all the vertices gradually, but works slowly.

In the process, the Voronoi diagram is generated together with the Delaunay diagram, whereas the Voronoi diagram itself has no utility value. In the present work, however, by juxtaposing the two diagrams, we intended to express the interest of geometry.

3 Software & System

All the programs have been implemented in the *Object Pascal* language using an integrated development environment *Embarcadero Delphi*. For editing/rendering the model, the 3DCG software *Cinema 4D* was used.
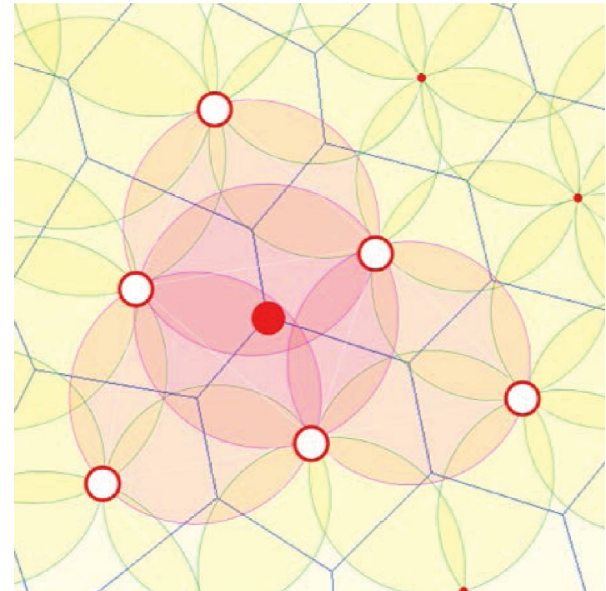
References

[1] P. Alliez, D. Cohen-Steiner, M. Yvinec, M. Desbrun, Variational tetrahedral meshing, *ACM Transactions on Graphics*, Vol.24, No.3, pp. 617–625, 2005.

[2] J. Guo, D. Yan, L. Chen, Tetrahedral meshing via maximal Poisson-disk sampling, *Computer Aided Geometric Design*, Vol.43, No.C, pp. 186-199, 2016.

[3] H. Si, Tetgen, a Delaunay-based quality tetrahedral mesh generator, *ACM Transactions on Mathematical Software*. Vol.4, No.2, Article 11, 2015.

[4] J. Tournois, C. Wormser, P. Alliez, M. Desbrun, Interleaving Delaunay refinement and optimization for practical isotropic tetrahedron mesh generation, *ACM Transactions on Graphics*, Vol.28, No.3, Article 75, 2009.

Pre-programmed deformable material

Taisuke Ohshima, Tomohiro Tachi, Yasushi Yamaguchi
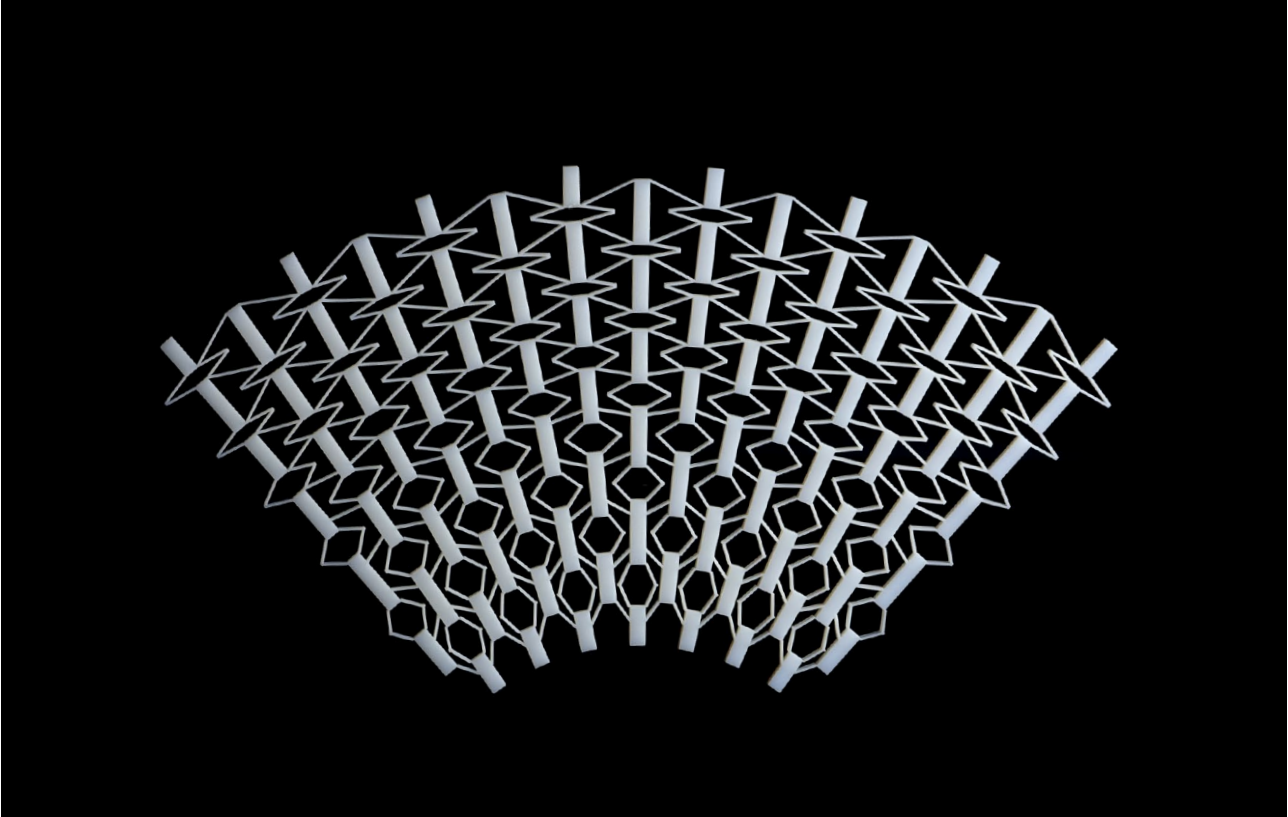
Taisuke Ohshima, Tomohiro Tachi, Yasushi Yamaguchi "Pre-programmed deformable material" 2017, Material: VeroWhite, Size: 320.1W x 181.5D x 6.6H (mm)

"Pre-programmed deformable material" is a material which transforms into preprogrammed shape. It's flexible in one preprogrammed deformation but stiff in the other deformation. The transformation into freeform curved surfaces from flat state is difficult because it should have three different Poisson's ratio within one material. The Poisson's ratio is related to Gaussian curvature in surfaces of deformation, ie. positive Poisson's ratio realizes curved surfaces whose Gaussian curvature is negative and negative Poisson's ratio realized curved surfaces whose Gaussian curvature is positive. Proposed material has explicitly distributed Poisson's ratio and realizes double curved freeform surfaces.

Description

We propose structures to transform into preprogrammed surfaces (Figure 1). Submitted material is the structure that transforms into torus. The torus is a surface with three Gaussian curvatures (K), negative, zero and negative. If the deformation shape is K ≤ 0 such as saddle shape or developable surfaces, materials must have positive poisson's ratio. However, if K > 0 such as dome shape, materials must have negative poisson's ratio (Figure 2).

Proposed material has combined three Gaussian curvatures and corresponding three poisson's ratio. In order to generate this structure, we developed original software. This software is the system to generate structure from target shape. Target shape is defined by principal curvature lines. Generated structure naturally transforms into target shape from simple external force.
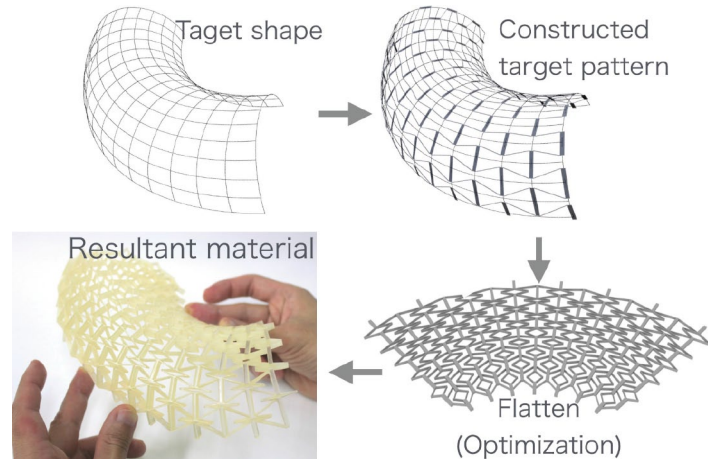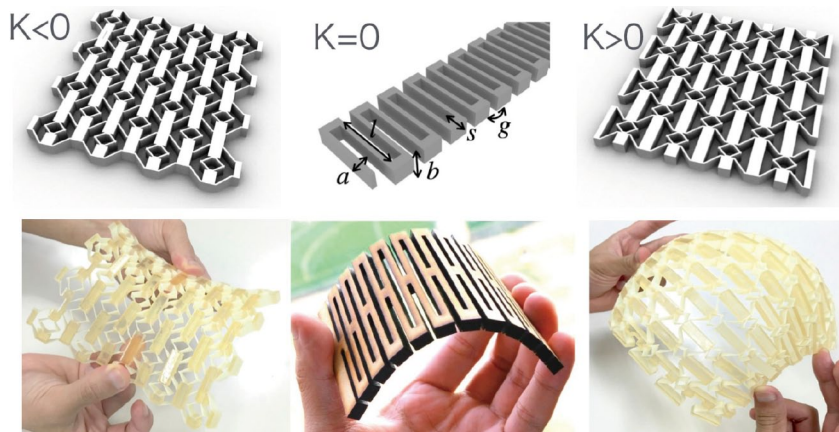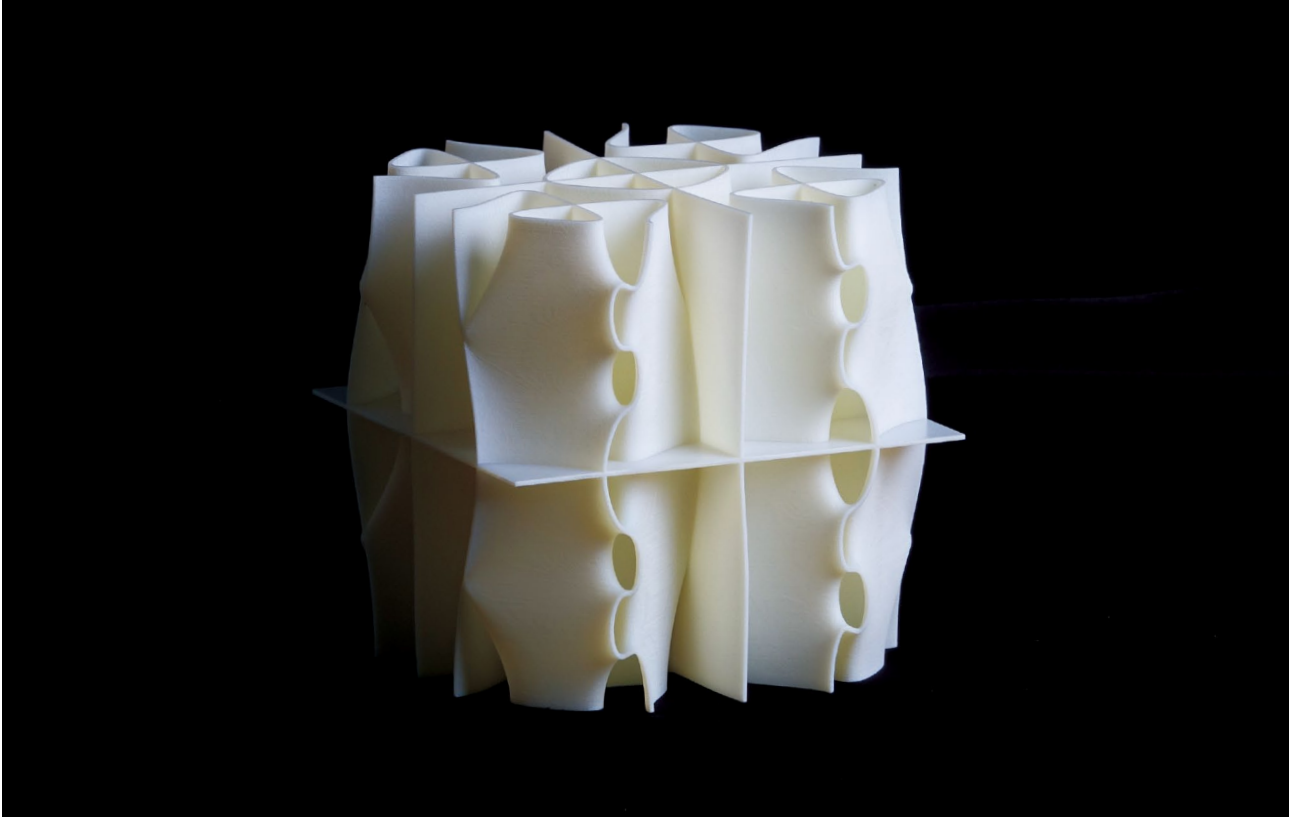

Figure 1: Proposed structure

Figure 2: Three structures used in proposed materials. K is Gaussian curvature.

13

Chladni Towers

Martin Skrodzki, Ulrich Reitebuch, Konrad Polthier

Martin Skrodzki, Ulrich Reitebuch, Konrad Polthier "Chladni Towers" 2017, Material: RGD720, Size: 101.6W x 101.6D x 103.4H (mm)

In 1802, Ernst Florens Friedrich Chladni published his book "Acoustics" containing visualizations of vibration modes in 2D. We generalize the well-known concept to 3D. Via computer simulations, we solve a corresponding physical system and thereby obtain an isosurface in a cubical model. This isosurface visualizes the elimination of sound waves and their reflections, showing points in three-space where different frequencies vanish. Using a 3D printer, these vanishing points can be physically realized. Application are given in instrument design or architecture of music halls. With transparent filament, constructors or architects can print problematic regions directly into their prototypes for awareness.

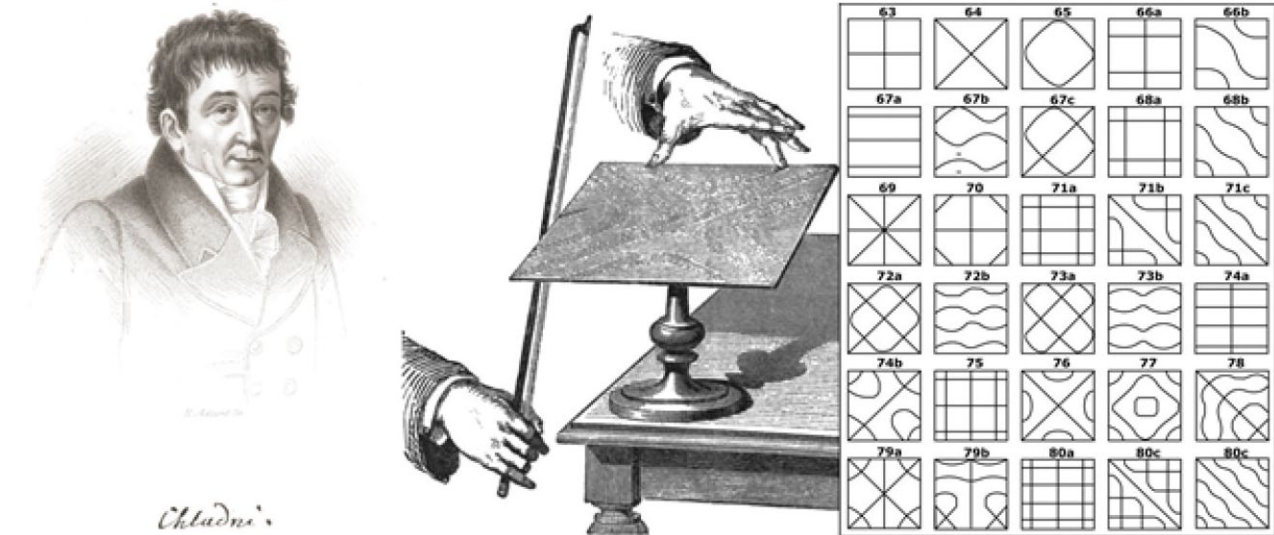Keywords: Vibration Modes, Acoustics, Chladni Figures

Figure 1: *Left*: Portrait of Ernst Florens Friedrich Chladni by H. Adlard, 19th Century. *Center*: Illustration of the violin bow experiment, taken from [3]. *Right*: Table of Chladnis figures from Chladni's book "Acoustics", 1802.

1 Introduction

In 1802, Ernst Florens Friedrich Chladni (November 30th, 1756 – April 3rd, 1827, see portrait in Figure 1) published his book "Acoustics". The book describes amongst other things an experiment by which different modes of vibration can be visualized. Namely, sand is distributed over a thin metal plate. A violin bow is then struck alongside the plate, causing it to oscillate, see Figure 1 for an illustration. Chladni found that the sand grains form different patterns corresponding to the varying vibration modes of the plate. His book contains a table of patterns he was able to create in his experiments, see Figure 1.

Since its first description, several other scientists like Margaret Watts-Hughes, Henry Holbrook, or Hans Jenny have further developed the Chladni experiment [1]. Despite
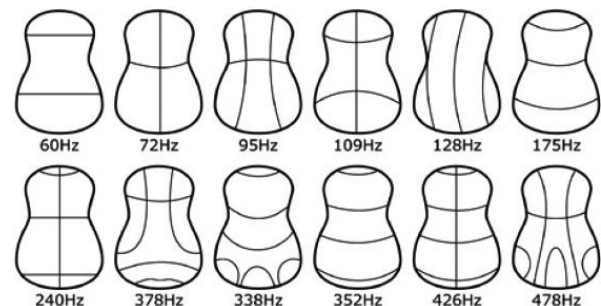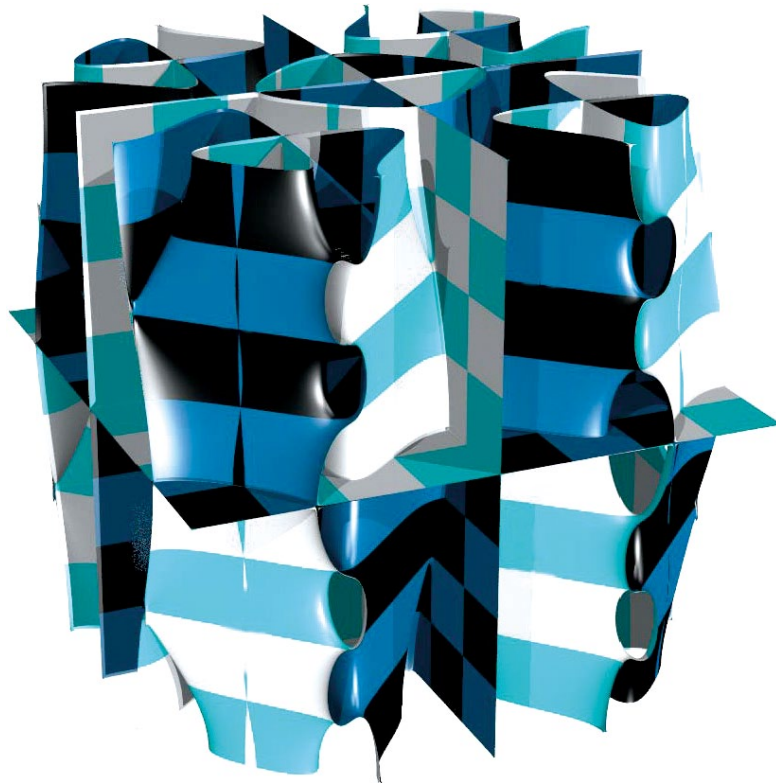

Figure 2: Application of Chladni Figures in building musical instruments.

their elegance and artistic value, Chladni figures have applications in the construction of musical instruments as illustrated in Figure 2.

We generalize Chladni's concept to the third dimension. In terms of a corresponding physical experiment, this consists of distributing light particles in some viscose fluid. For example, speakers are then used to stir the fluid and the particles form stable patterns, just as in the two-dimensional case. However, we do not build a physical experiment, but simulate the outcome of it, to print it via a 3D-printer.

Applications of our method can be found for example in Architecture, where the printed model gives an impression of the acoustics of a given room.

2 Physical and Mathematical Background

For simplicity, we generalize Chladni's patterns from the square-shaped plate to a cubical model. In the following, our cube will be assumed to occupy space $[-1,1]^3$. Starting from the physical formulation of a damped oscillation of a string, we combine the solutions to the wave equation to obtain a

formulation of a one-dimensional Chladni pattern as the zero set of an expression on the string. From this formulation, we can obtain a three-dimensional pattern as the zero-set of the following expression:

$$A \cdot \sin(\mu \cdot \pi \cdot x) \cdot \sin(\nu \cdot \pi \cdot y) \cdot \sin(w \cdot \pi \cdot z)$$
$$+B \cdot \sin(\mu \cdot \pi \cdot x) \cdot \sin(\nu \cdot \pi \cdot y) \cdot \sin(w \cdot \pi \cdot z)$$
$$+C \cdot \sin(\mu \cdot \pi \cdot x) \cdot \sin(\nu \cdot \pi \cdot y) \cdot \sin(w \cdot \pi \cdot z)$$
$$+D \cdot \sin(\mu \cdot \pi \cdot x) \cdot \sin(\nu \cdot \pi \cdot y) \cdot \sin(w \cdot \pi \cdot z)$$
$$+E \cdot \sin(\mu \cdot \pi \cdot x) \cdot \sin(\nu \cdot \pi \cdot y) \cdot \sin(w \cdot \pi \cdot z)$$
$$+F \cdot \sin(\mu \cdot \pi \cdot x) \cdot \sin(\nu \cdot \pi \cdot y) \cdot \sin(w \cdot \pi \cdot z).$$

Note that the formulation permits two different types of figures: Those with sine (as shown) and those with cosine formulations. These correspond to different boundary conditions on the wave equation. For further details on the mathematical and physical background, as well as other visualizations, see [2].

The particular model generated for the Asian Digital Modeling Contest and shown as title image has been named "Chladni Towers". Its exact parameters are given in Table 1 and it corresponds to Dirichlet boundary conditions on the wave equation.

3 Software & System

Our approach consists of plotting the zero level set of the expression given above in a cubical bounding box. This corresponds to visualizing the isosurface given by the expression. To do so, we utilize the marching cubes algorithm [4]. The algorithm has been implemented in the JavaView Framework [5]. Within this framework, we visualize the zero set for different prescribed values of

$$A, \dots, F \in \mathbb{R}, u, v, w \in \mathbb{Z}.$$

Given the first rough visualizations, more elaborate pictures like the title image are created with the PovRay Raytracer software [6]. Finally, from these, a model is chosen for 3D printing.

Table 1: Exact parameter values of the "Chladni Towers" Model

Objects	Caption
Integral Parameters	u=1, v=2, w=4
Real Parameters	A=0.5, B=0.0, C=0.5, D=8.0, E=0.5, F=8.0

References

[1] Findeiß. F., *Die Entdeckung der Chladnischen Klangfiguren. Ursprünge und Weiterentwicklung im historischen Kontext* (in German). Leuphana Universität Lüneburg, Germany, 2015.

[2] Skrodzki, M., Reitebuch, U., and Polthier, K., *Chladni Figures Revisited: A Peek Into The Third Dimension*. Proceedings of Bridges 2016: Mathematics, Music, Art, Architecture, Education, Culture. pp. 481-484, 2016.

[3] Stone, W.H., *Elementary Lessons on Sound*, Macmillan & Company, 1879.

[4] Lorensen, W.E. and Harvey, E.C., *Marching cubes: A high resolution 3D surface construction algorithm*. ACM Siggraph Computer Graphics, Vol. 21, No. 4, pp. 163-196, 1987.

[5] Polthier, K. et al, *JavaView*, www.javaview.de

[6] Persistence of Vision Pty. Ltd. Raytracer (version 3.7), http://www.povray.org

OJIGI TOKURI Self-Tilting Sake Bottle

Shoko Kawata, Kazuki Takenouchi

Shoko KAWATA, Kazuki TAKENOUCHI "*OJIGI TOKURI* (Self-Tilting Sake Bottle)" 2017, Material: VeroWhite, Size: 94W x 94D x 86H (mm)

OJIGI TOKURI can tell the remaining quantity of sake inside by changing its tilting position, while remaining sake is invisible in a traditional one made of opaque china. This unique behavior of the tilting is generated by its computationally optimized asymmetrical inner configuration, which changes the center of gravity with a decrease of sake with holding a stable tilting position in 4 steps. Moderate movement to the next stable position is given by double curved surface patches. Elegant openwork and deep extrude cut figured with cherry blossoms implicitly show the mechanism of tilting.

1 Introduction

In a Japanese traditional style of drinking sake for two, sake is served in a *tokuri*, one of Japanese traditional bottles for sake holding standard content volume of 180ml or 360ml called as 1-*gou toukri* or 2-*gou tokuri*, respectively. As a manner in this case, drinkers are expected to fill sake each other into partner's small sake cup, *sakazuki*, and at every filling sake in the *tokuri* gradually reduces. As such *tokuri* is in general an opaque china, the remaining quantity is estimated by shaking the tokuri or by looking into it, and the empty *tokuri* is often laid down as a sign of drinking up. All these behaviors are however against good manners.

The authors' work *OJIGI TOKURI* at the top of this page helps drinkers and servers see the quantity of sake in the bottle without impolite behaviors by tilting depending on the remaining. The name *OJIGI TOKURI* comes from a Japanese traditional greeting, *ojigi*, making a bow; tilting behavior of *tokuri* is similar to *ojigi* in terms of both moving and having some of degrees as illustrated in the top right figure.

2 Idea and design requirements

Since tilt of *OJIGI TOKURI* is caused by a move of the center of gravity with a decrease of sake in *tokuri*, its asymmetrical inner surface configuration not interfering with

the flow of sake should be carefully determined to satisfy the statics in accordance with the outer contour. In addition to the above requirements, the authors imposed following design requirements to the *tokuri* for a practical use:

· holding the standard content volume (180ml)
· visualizing a quantity of remaining sake with some tilting degrees and staying stable at rest in a single

inclination for each particular quantity of sake
· tilting with moderate motion not to pour out the sake in *tokuri* nor break itself by impact

In order to simultaneously meet these complex requirements, a numerical evaluation is necessary on geometry and statics for a tentatively determined configuration at every tilting position followed by a modification to a better result.
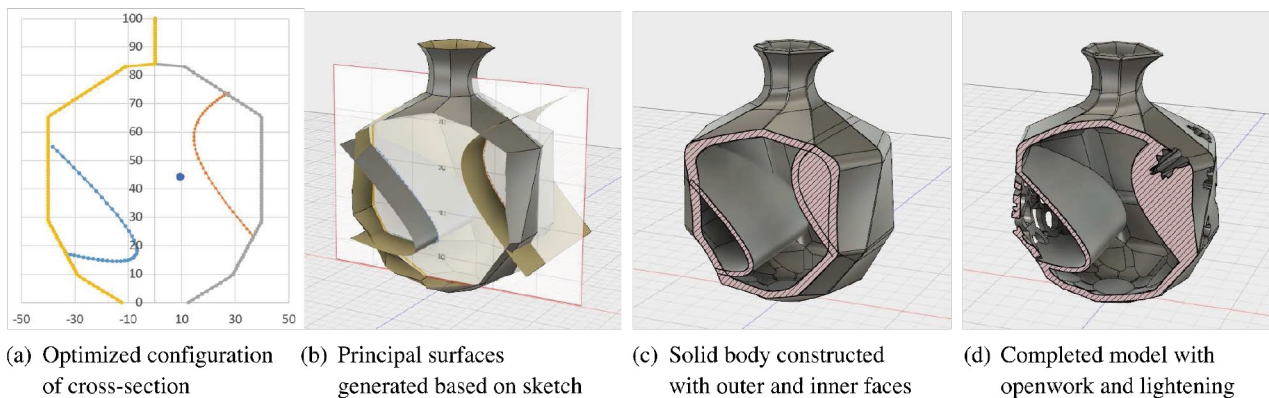

(a) Optimized configuration of cross-section
(b) Principal surfaces generated based on sketch
(c) Solid body constructed with outer and inner faces
(d) Completed model with openwork and lightening

Figure 1: Modeling process of *OJIGI TOKURI*

(a) Basic solid pattern
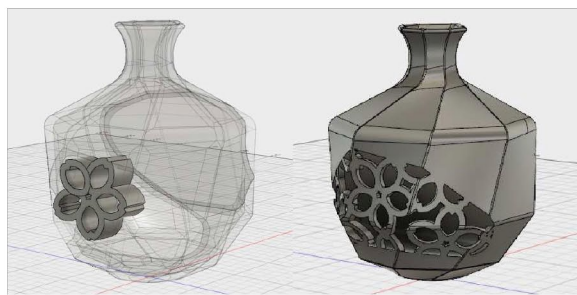(b) Completed openwork

Figure 2: Openwork by use of Boolean operation

Figure 3: Fabricated prototypes for performance confirmation

20

3 Modeling environment and procedure

As design of such a novel product is a creative work, successive modification and even introduction of addtional requirements and constraints found out in the process will be required. To handle such process, the configuration of *tokuri*, cross-section of outer and inner surfaces, was evaluated and optimized by use of spreadsheet, not special CAE tools nor a programing languages that require special knowledge and skills to users. Furthermore, as shown in Fig.1(a), the users can confirm calculated results by instantly illustrated outline of the *tokuri* and the position of center of gravity at each tilting position as 2D plots.

Digital 3D modeling of the *tokuri* was carries out on Fusion 360: 2D sketch was drawn by tracing the profiles determined based on calculation on spreadsheet, and 3D surfaces in Fig.1(b) were generated based on the sketch. Its outer and inner surfaces were then joined into a solid body in Fig.1(c). Finally, openwork and lightening in Fig.1(d) were added for better performance of *tokuri*.

The openwork is partly for a better performance by making fine adjustment, and also for disclosing the existence of inner partition, impressing the mechanism of generating its interesting behavior. In the modeling of the openwork, Boolean operation was applied with a basic solid pattern shown in Fig.2(a) and arranged on the shell of hollowed area in Fig.2(b).

4 Final model of *OJIGI TOKURI*

The final model is shown at the top of the first page and in Fig.2(b). The behavior has been improved through the five prototypes fabricated with FDM 3D printer as shown in Fig.3 from the left to the right.

The five prototypes are constructed with an axially symmetrical outer surface or combination of ruled surface; the final model is constructed with small curved surface patches. The patches are generated by connecting regular octagons by use of loft surface, one of the most fundamental functions of 3D CAD, octagons which are storied along *tokuri*'s centerline with a relative revolution between the neighboring two polygons. Such curved surface patches seem to be effective to give *OJIGI TOKURI* a moderate tilting motion to a feasible direction, being expected to avoid *tokuri* rolling off the table and being damaged by the impact. To control its tilting behavior, an appropriate fillet size is chosen for each edge of patches.

The contour of the bottom face is a circle for a smooth start of tilting. Surface cut with a truncated circular cone is applied for the connection between the circular bottom face and the octagonal section.

Also to implicitly show the existence of solid weight opposite to the hollow partition, the other mechanism of the tilting behavior, rather deep extrude cuts having a contour of flower are added.

Capricious Hearts

Kokichi Sugihara
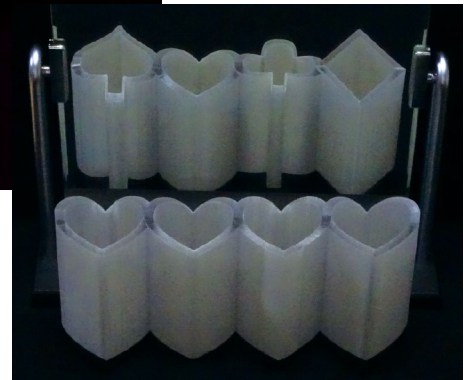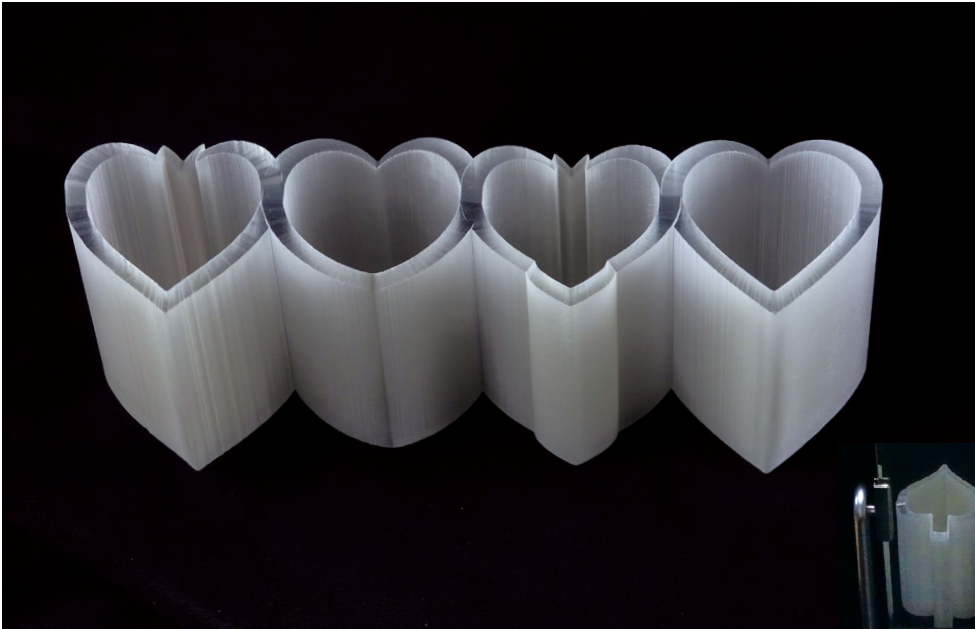
Kokichi Sugihara "Capricious Hearts" 2017, Material: RGD720, Size: 249.6W x 74.4D x 127.2H (mm)

The object appears to be four hearts in a line when we see it directly, but the reflection in a vertical mirror behind the object appears to be the set of all four suits of the trump, i.e., diamond, club, heart and spade. We know that the shape of an object and its mirror image are mirror symmetric to each other, and hence heart cannot change to diamond, etc., in a mirror; the behavior of this object seems impossible. However, this is possible because our perception is subject to optical illusion.

Keywords: ambiguous cylinder, impossible object, optical illusion

1 Behavior of the Object

From a special viewpoint it appears to be four hearts in a line, but if we rotate it around the vertical axis by 180 degrees, it appears to be the set of all four suits of the trump, i.e., diamond, club, heart and spade. These two appearances will be enjoyed at the same time if we place a vertical mirror behind the object and look at the object and its mirror image simultaneously.

We know that the shape of an object and its mirror image are mirror symmetric to each other, and hence heart cannot change to diamond, for example, in a mirror; the behavior of this object seems impossible. However, this is possible because our perception is subject to optical illusion.

2 Production Process

I found a systematic method for creating a new class of impossible objects, which I named "ambiguous cylinders." This class of objects generates optical illusion in the sense that their appearances change drastically in a mirror [1]. The ambiguous cylinders are based on two observations, one is physical and the other is psychological.

Physically, a single image of a 3D object does not have information about depth, and consequently there are infinitely many possible 3D objects that yield the same 2D image [2]. Hence, we can generate a 3D object that has two desired 2D appearances when seen from two special viewpoints, if the pair of appearances satisfies a certain condition.

Psychologically, on the other hand, our vision systems have a strong preference for rectangularity in the sense that we are

apt to interpret 2D images as 3D objects with as many rectangles as possible [3]. Hence, if we present cylindrical shape with a constant height, we usually interpret the edge curve of the cylinder as a plane curve perpendicular to the axis of the cylinder, even if it is a space curve.

Combining these two observations, we can construct ambiguous cylinders. This is the basic idea for ambiguous cylinders. I applied this method to four pairs of shapes, one is heart and the other is one of the four suits of the trump, and thus generated four ambiguous cylinders. Finally I joined them to the present object

3 Software & System

With my original program written in Fortran, I computed the shape of four objects corresponding to the four suits, and then generated their STL data. Finally, using the commercialized modeling tools Rhinoceros version 5.0, I merged them into one final object.

References

[1] Sugihara, K., Ambiguous cylinders: A new class of impossible objects. *Computer Aided Drafting, Design and Manufacturing*, Vol.25, No.3, pp.19-25, 2015.

[2] Sugihara, K., *Machine Interpretation of Line Drawings*. MIT Press, Cambridge, Massachusetts, 1986.

[3] Perkins, D. N., Visual discrimination between rectangular and nonrectangular parallelopipeds. *Perception and Psychophysics*, Vol.12, pp.293–331, 1972.

3D PRINTED MODEL AS AUGMENTED REALITY MARKER

Petar Pejic, Sakan Srdjan, Sonja Krasic
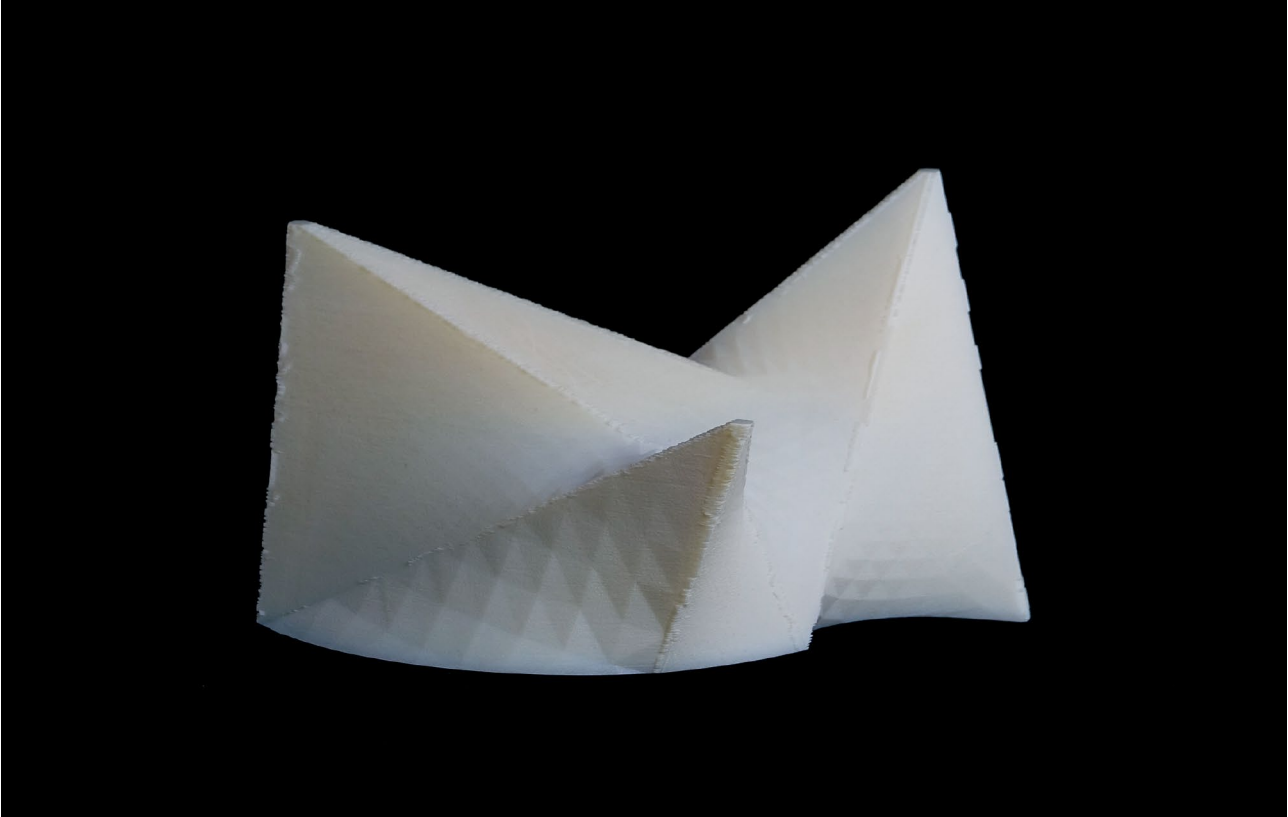
Petar Pejic, Sakan Srdjan, Sonja Krasic "3D PRINTED MODEL AS AUGMENTED REALITY MARKER" 2017, Material: VeroWhite, Size: 198W x 107D x 138H (mm)

Virtual 3D model of the complex architectural object, which contain 9 hyperbolic paraboloid is created. 3D model is printed and used as a marker for visual Augmented Reality tracking. For purposes of this research, we develop android application based on Augmented Reality technology, which provide additional information on the top of printed 3D model in the form of virtual 3D geometry, sound and links to additional web resources.

Keywords: Complex Geometric surfaces, Architecture, Augmented Reality
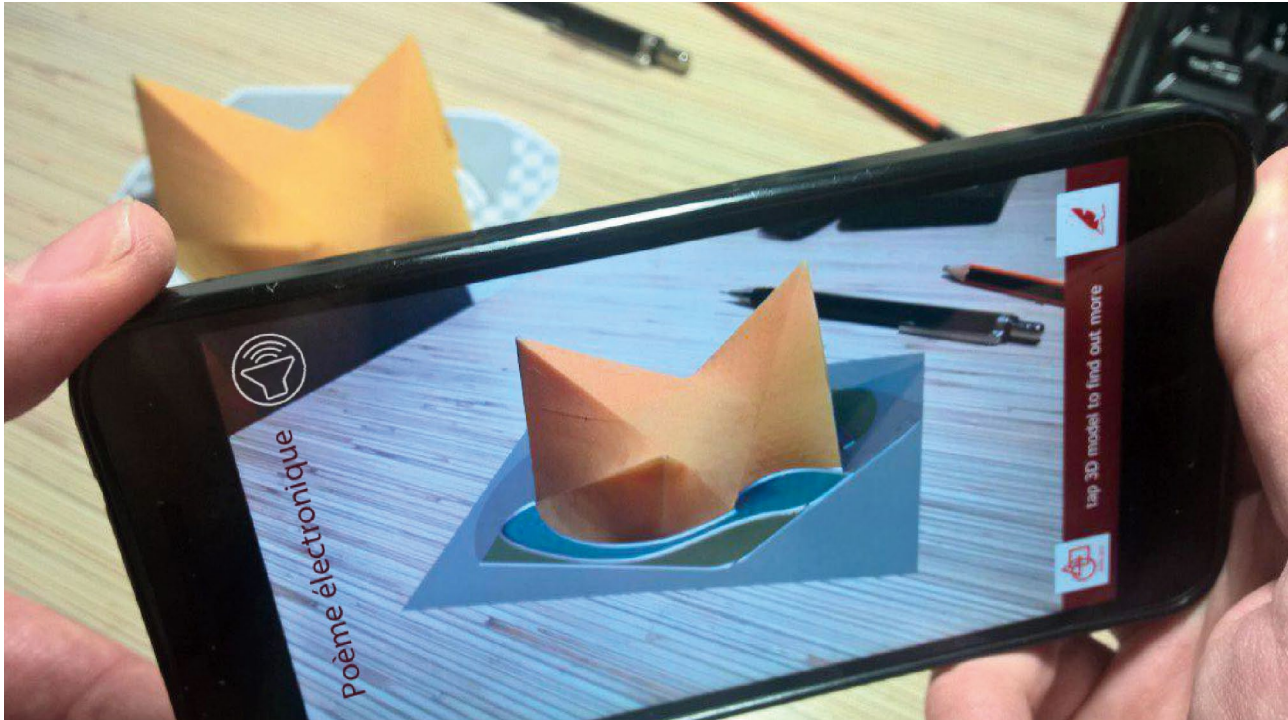
1 Abstract

In this research, we create a virtual 3D model of the complex architectural object, which contain 9 hyperbolic paraboloid. 3D model is printed and used as a marker for visual Augmented Reality tracking. For purposes of this research, we develop android application based on Augmented Reality technology, which provide additional information in the form of virtual 3D geometry, sound and links to web resources.

2 Model idea

3D printing, also known as additive manufacturing, has become an established technology in many industry sectors for the fabrication of three-dimensional (3D) objects [1]. Some complex geometric shapes of architectural objects, such as buildings made of hyperbolic paraboloids are really hard to produce. The traditional construction method assumes use of complex temporary supporting structures, which usually cost more than the rest of the building [2].

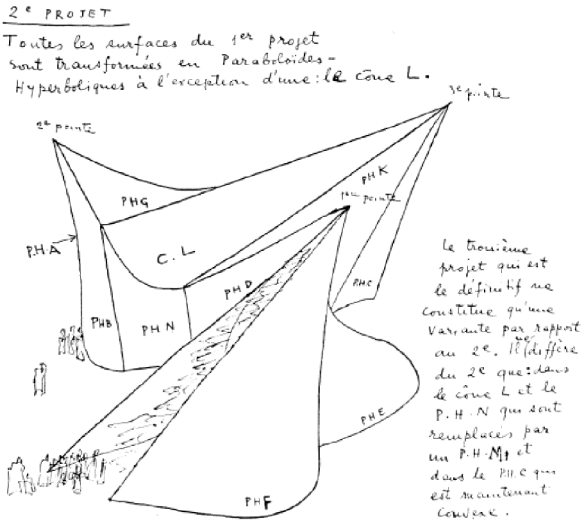The main inspiration for 3D model was The Philips Pavilion

Figure 1: Original sketch of Philips Pavilion

Figure 2: SketchUp – 3D model

Figure 3: Printed 3D model

designed for Expo '58 in Brussels by the office of Le Corbusier (Figure 1). The pavilion was designed to house a multimedia spectacle that celebrated technological progress. It is a cluster of nine hyperbolic paraboloids in which music, Edgar Varèse's Poème électronique, was spatialized by sound projectionists using telephone dials [3].

3 3D model production process

A 3D model is created on the basis of existing sketch and images [4] using SketchUp [5] software package. A structure is created from 9 Hyperbolic paraboloids. Some are only parts, created by cutting them with ground horizontal plane (Figure 2).

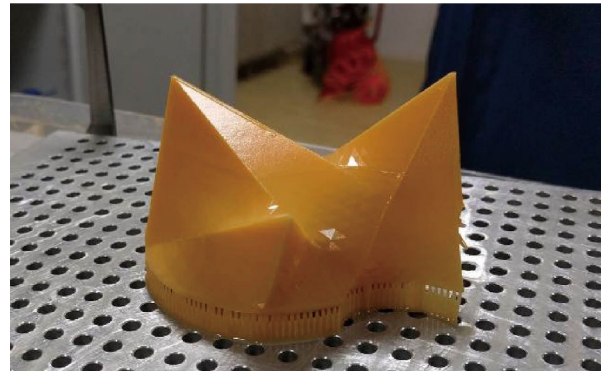Created 3D model is exported as *STL file and printed using Ultra 3SP printer [6] (Figure 3).

4 Augmented Reality

For purposes of this research android based Augmented Reality, mobile application is developed [7], [8]. The application uses previously printed 3D model as a marker in order to connect and display virtual data inside real surroundings.
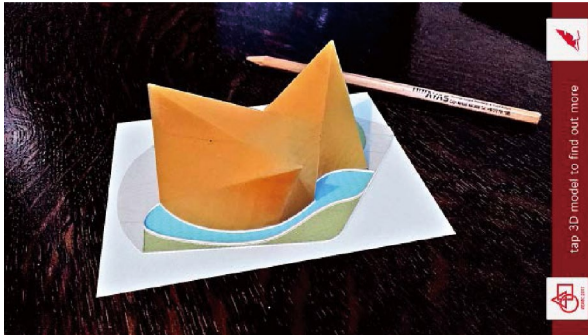
26

Figure 4: Mobile application screenshot

After starting the application, the device camera records real surrounding, while the application is searching for predefined 3D model. When the application detects and recognise 3D model, on the device display and speakers additional information is provided.

Detection of 3D model by application activates the original song "Poème électronique", composed by Edgard Varèse and performed inside the Philips Pavilion.

On the basis of pictures from World's Fair - Expo '58 held in Brussels virtual 3D model of the building surrounding is created and presented in same scale as printed 3D model. Moving the marker will cause a joint move of both the marker and the additional digital content on the device display (Figure 4).

Taping on printed 3D model inside application provide additional information about the Philips Pavilion available on the web. While buttons at bottom of the screen provides links to ADMC 2017 conference and additional information about authors.

References

[1] Teizer, J., Blickle, A., King, T., Leitzbach, O. and Guenther, D., Large Scale 3D Printing of Complex Geometric Shapes in Construction, 33rd International Symposium on Automation and Robotics in Construction (ISARC 2016), 2016.

[2] Veljković M., Krasić S., Pejić P.: Use of the torus in the design of modern architectural structures, The 5th International Scientific Conference on Geometry and Graphics, moNGeometrija 2016., June 23-26, 2016, Belgrade, Serbia, pp.445-453, 2016.

[3] https://en.wikipedia.org/wiki/Philips_Pavilion

[4] http://www.cirma.unito.it

[5] https://www.sketchup.com/

[6] https://envisiontec.com/3d-printers/industrial- 3d-printers/ultra-3sp/

[7] Pejić P., Krasić S., Veljković M., Sakan S., Rizov T.: Augmented and Virtual Reality application in traditional architectural project presentation - case study of "MH Petra" house, FME Transactions, Volume 45, No 2, pp. 227-231,2017.

[8] Pejić P., Krasić S., Petković D., Veljković M.: Application of augmented reality in façade redesign presentation, Journal of industrial Design and Engineering Graphics, number 10, ICEGD 2015, SORGING, Romania, ISSN 1843-3766, pp.45-49, 2015.

Design by Spheres – A Project for Museum
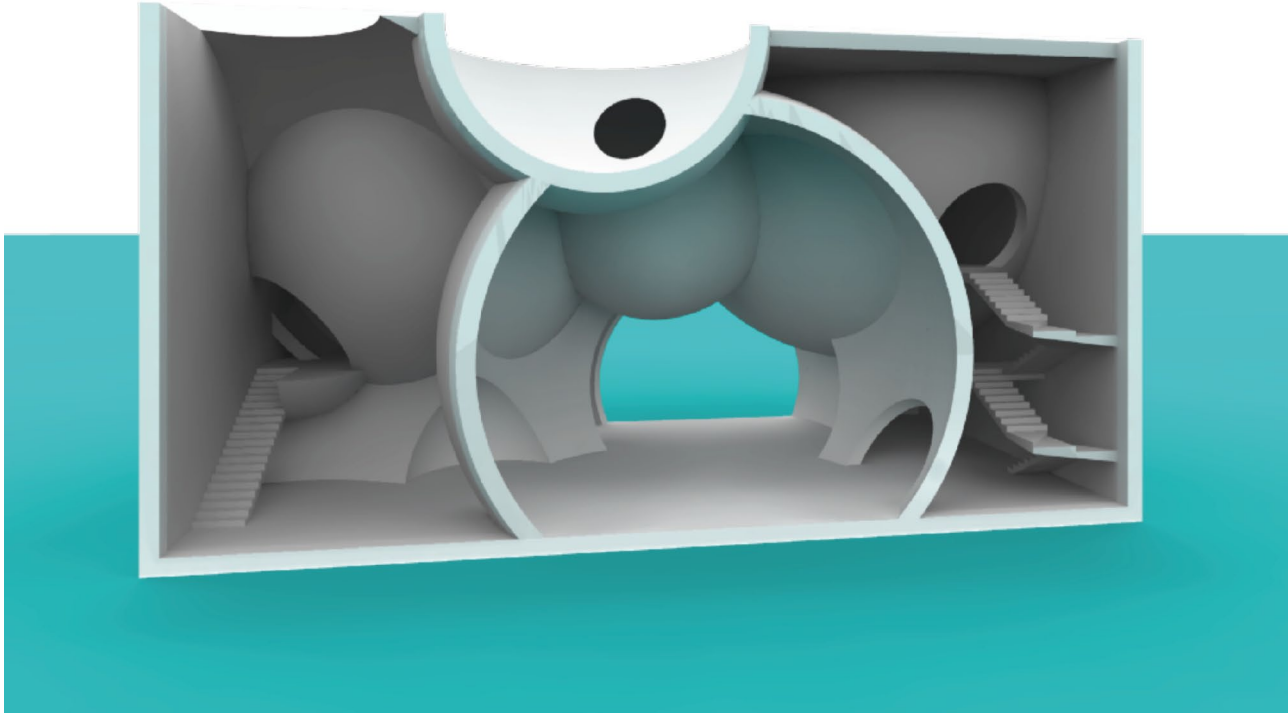
Naomi Ando
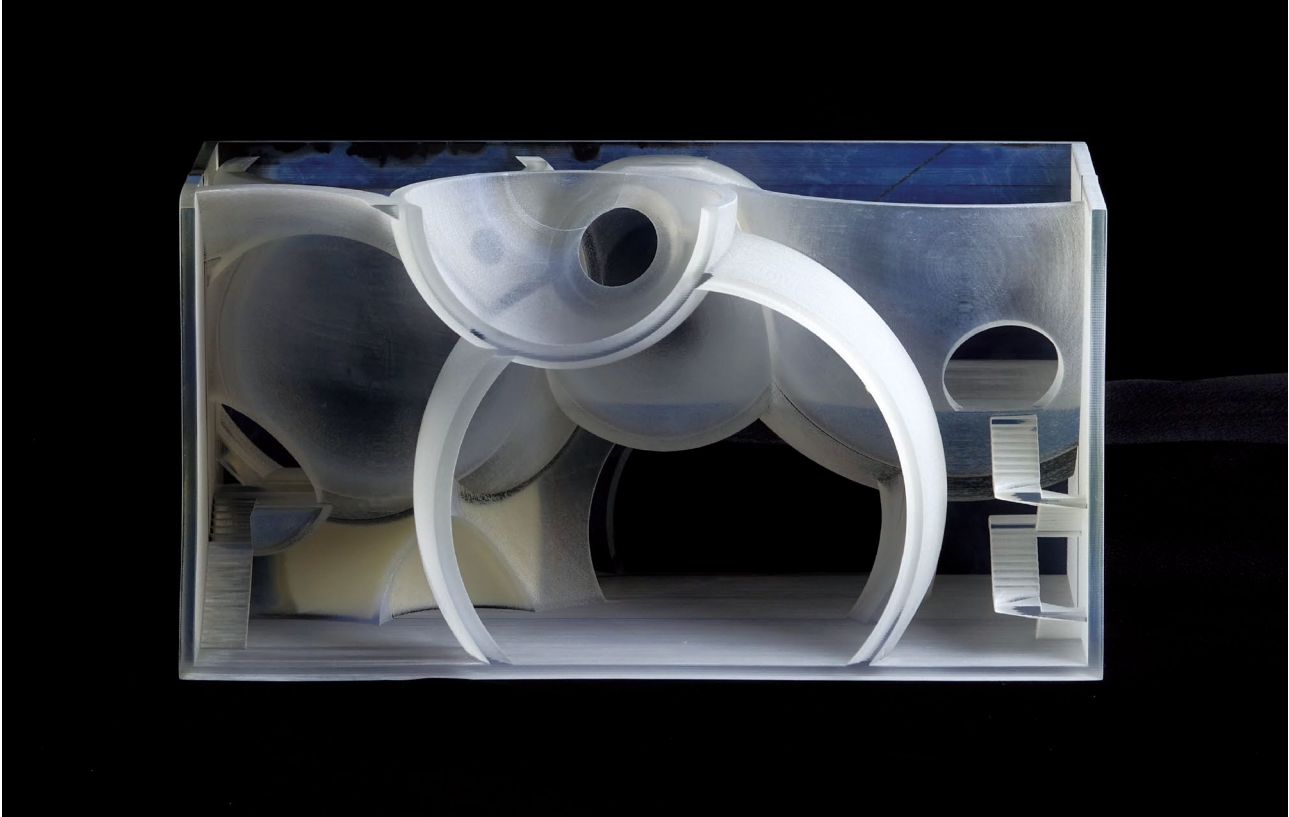
Naomi Ando "Design by Spheres – A Project for Museum" 2017, Material: VeroClear, Size: 180W x 90D x 93H (mm)

"Design by Spheres – A Project for Museum" is a prototype of a small museum. A total of 12 spheres of varied diameters from 3.2 m to 16 m were arranged inside a volume space that was 24 m wide, 12 m deep, and 12 m high. Dynamic spaces with spatial fluctuations were realized by the algorithm to generate spheres with random diameters in random positions. Individual functions, such as an entrance hall, a lobby, exhibition halls, a terrace, and storages, were given to each sphere, and architectural elements such as stairways and floors were added. The structure of this museum was assumed to be constructed with reinforced concrete shells of 20 cm to 40 cm thick.

Keywords: Sphere, Architecture, Algorithmic Design

1 Design by Spheres

Spheres, with centripetal spaces inside, have been used as a motif in various architectural designs, from the Pantheon (ancient Roman architecture) to modern architecture. "Design by Spheres – A Project for Museum" is a prototype of a small museum.

A total of 12 spheres of varied diameters from 3.2 m to 16 m were arranged inside a volume space that was 24 m wide, 12 m deep, and 12 m high. Dynamic spaces with spatial fluctuations were realized by the algorithm to generate spheres with random diameters in random positions.

Individual functions, such as an entrance hall, a lobby, exhibition halls, a terrace, and storages, were given to each sphere, and architectural elements such as stairways and floors were added, as shown is Figure 1. The structure of this museum was assumed to be constructed with reinforced concrete shells of 20 cm to 40 cm thick.

2 Production Process

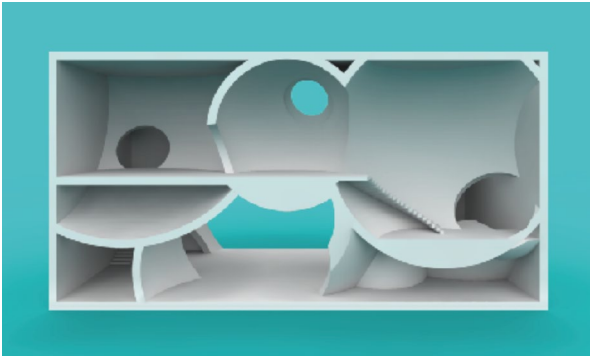Besides the random values for the diameter and positions of
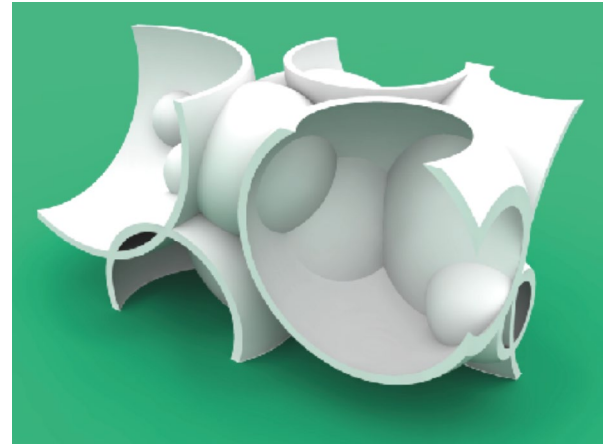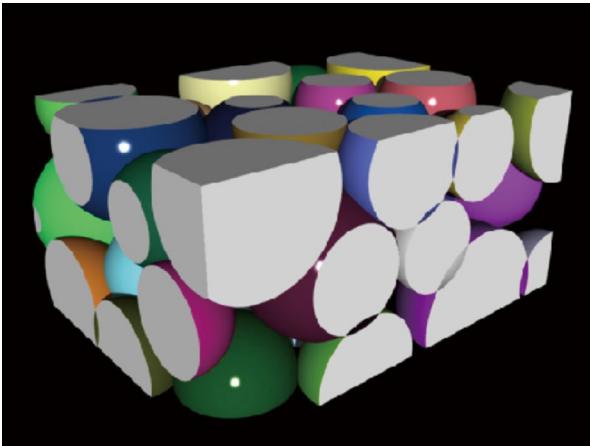
Figure 1: Section of Exhibition Halls

Figure 2: Arrangement of Spheres

Figure 3: Framework

Figure 4: Exploded Diagram

the generated spheres, tangency or overlapping of spheres was controlled, as shown in Figure 2. The algorithm was described by VB (Visual Basic) component of Grasshopper(1), which is a plug-in for Rhinoceros(2). By this method, spheres were arranged randomly with the following conditions: [N] number of spheres were generated;
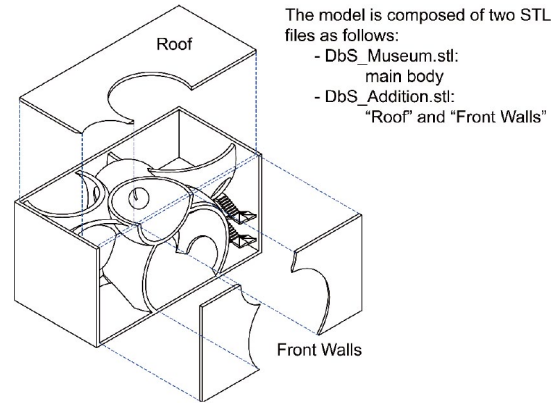
the center points were in the [X-Y- Z] region; the radius of the spheres varied from [R0] to [R0+R1]; overlapping of the spheres was allowed if it was smaller than [B]. This method of the "Design by Spheres" was firstly presented at AFGS 2015[1].

Through a number of trials and errors in the automatic gener-
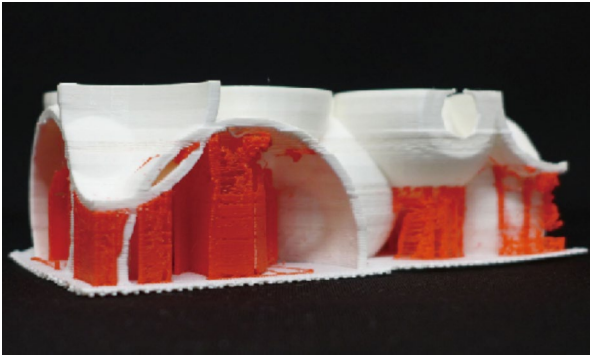
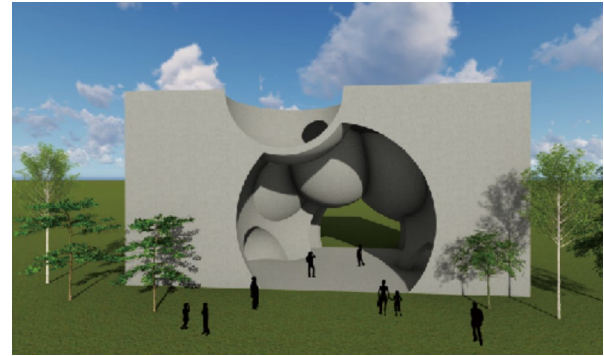Figure 5: Trial Model (support materials are not removed)

Figure 6: Exterior View

Figure 7: Interior Views of the Exhibition Halls

ations, a framework of the model, as shown in Figures 3 and 4, was determined. Trial model was fabricated by 3D printer, as shown is Figure 5. Then, some modifications for the structural rationality and planning efficiency were added for architectural design, as shown in Figures 6 and 7.

3 Software & System

(1) Rhinoceros: http://www.rhino3d.com/

(2) Grasshopper: http://www.grasshopper3d.com/

References

[1] Ando, N. Ishii, S., "Design by Spheres - A Computer Graphic Material for Architectural Design Education", Proceedings of the Asian Forum on Graphic Science, P.8 (USB), 2015.

Design lamp shade

Kimihiro Miura

Kimihiro Miura "Design lamp shade" 2017, Material: VeroClear, Size: 260W x 260D x 310H (mm)

This work is a lamp shade which has a rotation mechanism. The inside and the outside of the model rotate separately. By this mechanism, we can enjoy the change of light volume and shadow of the shade. Because the basis and the main body are separated, it is easy to replace or extend the body to a new design. The size, height, and material etc. may be changed according to the room where the lamb shade is placed. The users can design and adjust for their own life. From the idea of this work, I hope that lamp shade created by 3d printer will be further developed and spread.
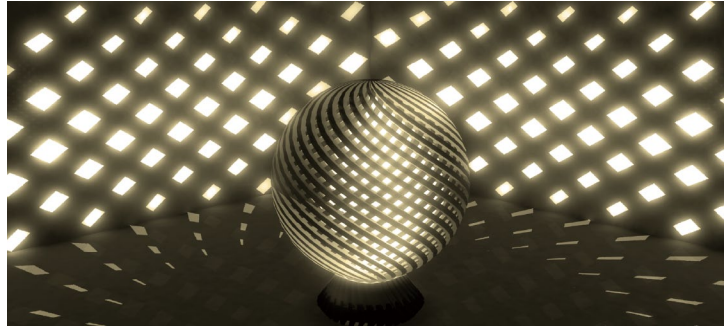
1 Concept

With the internal and external rotating mechanism, you can enjoy the shadow change, I aimed to be able to use it according to situations and uses.

It also intended to change the brightness depending on the type of material of the 30 printer.

The reason why we did not make the base of the lower part integral is that we have expandability (height, design etc.).

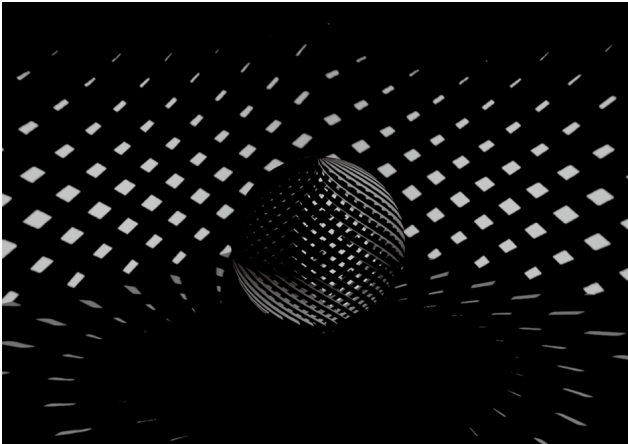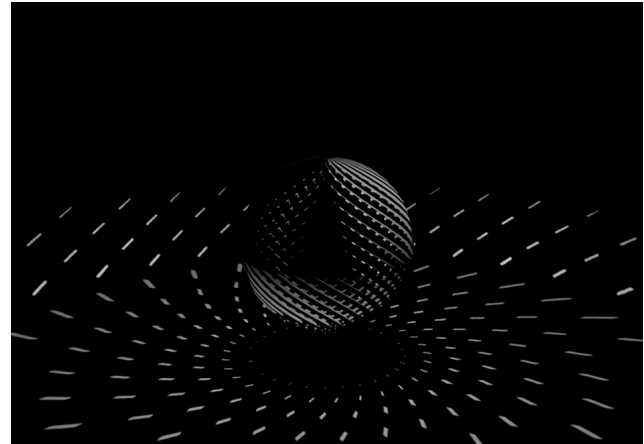It is imagining that it can be newly added depending on the application.

2 Images
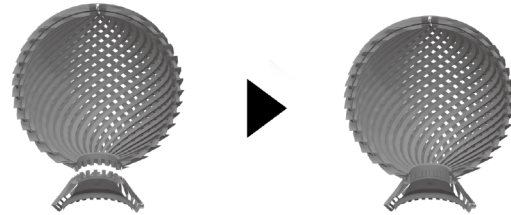
attach image

3 Softwer

3ds max2016, photoshop cs6

rotation image
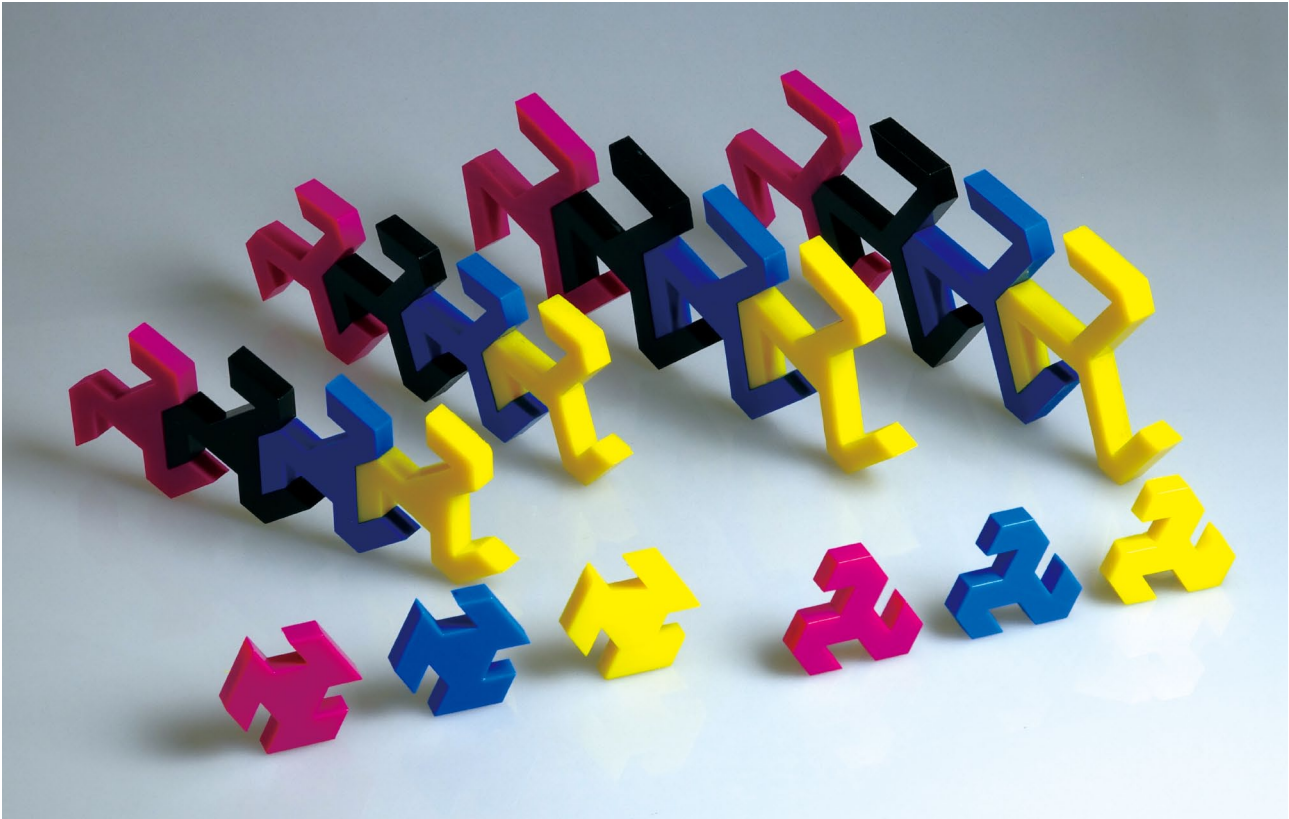
Triskelion Blocks

Akihiro Matsuura, Hiroshi Shirane

Akihiro Matsuura, Hiroshi Shirane "Triskelion Blocks" 2017, Material: VeroCyan,VeroMagenta,VeroYellow, Size: 75W x 60D x 9H (mm)

A triskelion is an iconographic pattern that consists of three legs (or spirals) having three-fold rotational symmetry. We make use of this strange but intriguing figure as a motif of our new construction toy. We present two families of triskelion blocks with/without a central equilateral triangle, where one block is connected to another at its concave parts in three directions. Such connection with some tiling properties can be effectively used in constructing various shapes using the blocks. One can also enjoy "balancing play" of physically standing constructed shapes on the ground which reminds us of coordinated group gymnastics.

Keywords: triskelion, construction toy, rotational symmetry
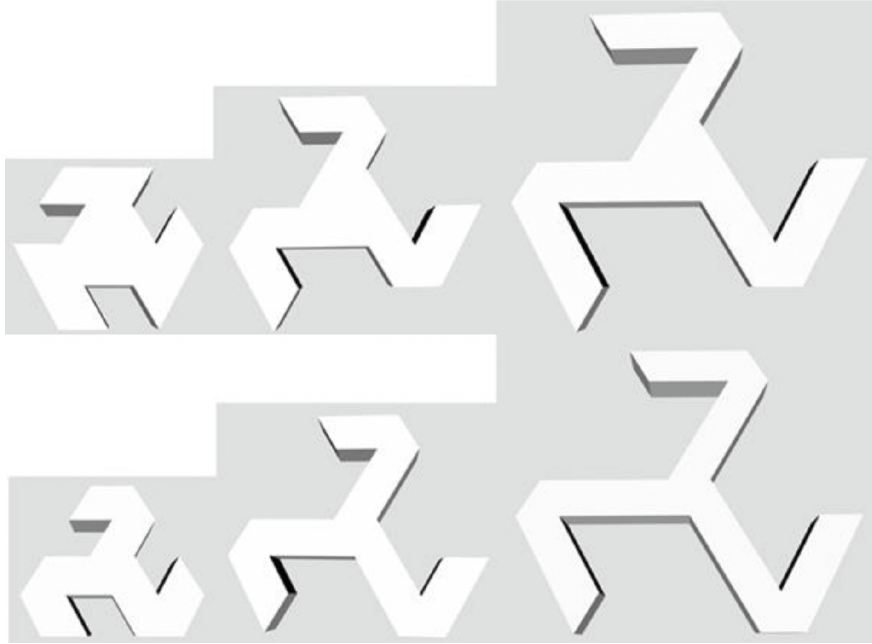
1 Basic Ideas & Figures

A *triskelion* or *triskele* is a classical iconographic pattern that consists of three spirals placed with three-fold rotational symmetry. It is frequently used with a representation of three bent human legs, which are seen for example in the flags of Sicily and the Isle of Man [1] shown in Figure 1.

We make use of this strange but fascinating figure of three legs as motif for our new construction toy. Two basic plane figures we use are shown in Figure 2 (let us call them figures T_1 and T_2). Both figures have three legs with distinct (RGB) colors, where the left one has no center triangle but the right one has, i.e., the yellow equilateral triangle.
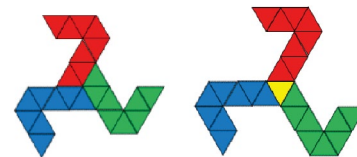

Figure 1: The flag of the Isle of Man

Figure 2: Two triskelion-like figures T_1 and T_2.
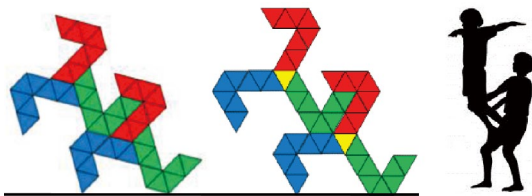
Figure 3: Connections of T_1's or T_2's and the gymnastic pose.

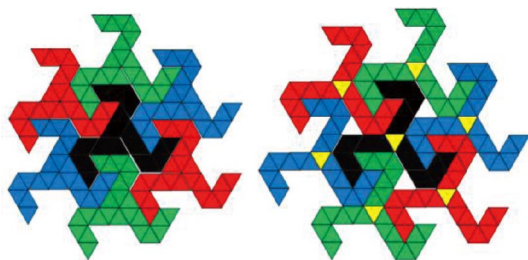Figure 6: The family of figures for T_1 (leg length = 1, 2, 3).

Figure 4: Circular connection of T_1's and T_2's.
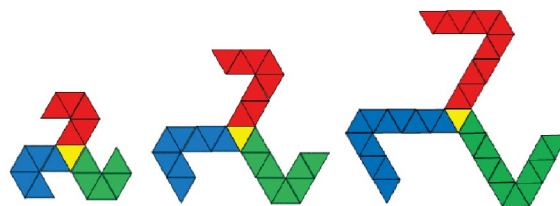
Figure 7: The family of figures for T_2 (leg length = 1, 2, 3).

Figure 5: The slilding property of T_1 and T_2.
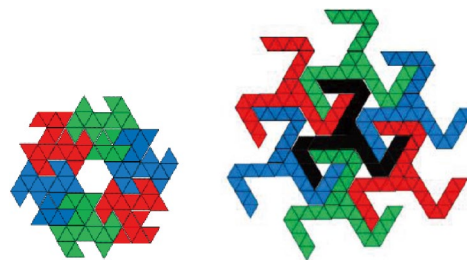
Figure 8: Circular connections for T_1-family (leg length = 1,3).

The common property of these figures desirable for a construction toy is that a leg can be connected to the concave part between two legs of another piece as shown in Figure 3, left. This makes the figures to connect in three directions and helps to create a variety of shapes. We also emphasize that the connected figures are just like the gymnastic pose of physically-balanced two persons, which will make the play more entertaining and imaginative. Furthermore, these triskelion-like figures have some beautiful geometric properties on tiling. Namely, six T_1's and six T_2's can be connected in a circular way as shown in Figure 4 and these connections are extended infinitely in a recursive way. Espe-

Figure 9: Circular connections for T_2-family (leg length = 1,3).

Figure 10: Some constructions.

cially on T_1, the central black part is again the shape of T_1 and T_1's radially tile the whole plane.

The final typical property of T_1 and T_2 that we figured out after prototyping and playing around with the pieces is that when we try to disconnect the three pieces from the interlocking situation in Figure 5, left, we can succeed it by just sliding two of the pieces, say, green and blue ones since then the remaining red piece slides out rather automatically without direct manipulation.

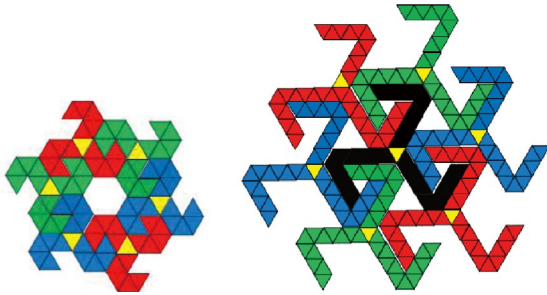Now, we show families of triskelion figures for T_1 and T_2 that preserve the properties of leg connection and recursive tiling. First, we illustrate the family for T_1 with leg length 1, 2, and 3 in Figure 6 and the family for T_2 in Figure 7. (The figures of leg length 1 are rather exceptional but since they also have the required geometric condition, here we include them).

2 Software & System

3D models were made by adding a constant depth to the figures in Section 1. When the length of unit triangle is 1, the depth is set to be half of 3 squared, i.e., 0.86 (rounded off) since then the depth parts can be inserted to blocks vertically and construction can be 3-dimensional. All the models were designed using the 3D CAD system 123D Design of Autodesk and output in the STL format. The six models are shown in Page 1.

3 Prototyping & Some Constructions

We made prototypes of the blocks using PLA resin and the 3D printer Replicator 2. Here we show some of the constructions using the prototypes in Figure 10.

The circular connections for the figures in Figures 6 and 7 are shown in Figures 8 and 9, respectively.

References

[1] Triskelion, http://en.wikipedia.org/wiki/Triskelion

Natalie's Ramonda pavilion

Biljana Jović, Komnenov Mirjana
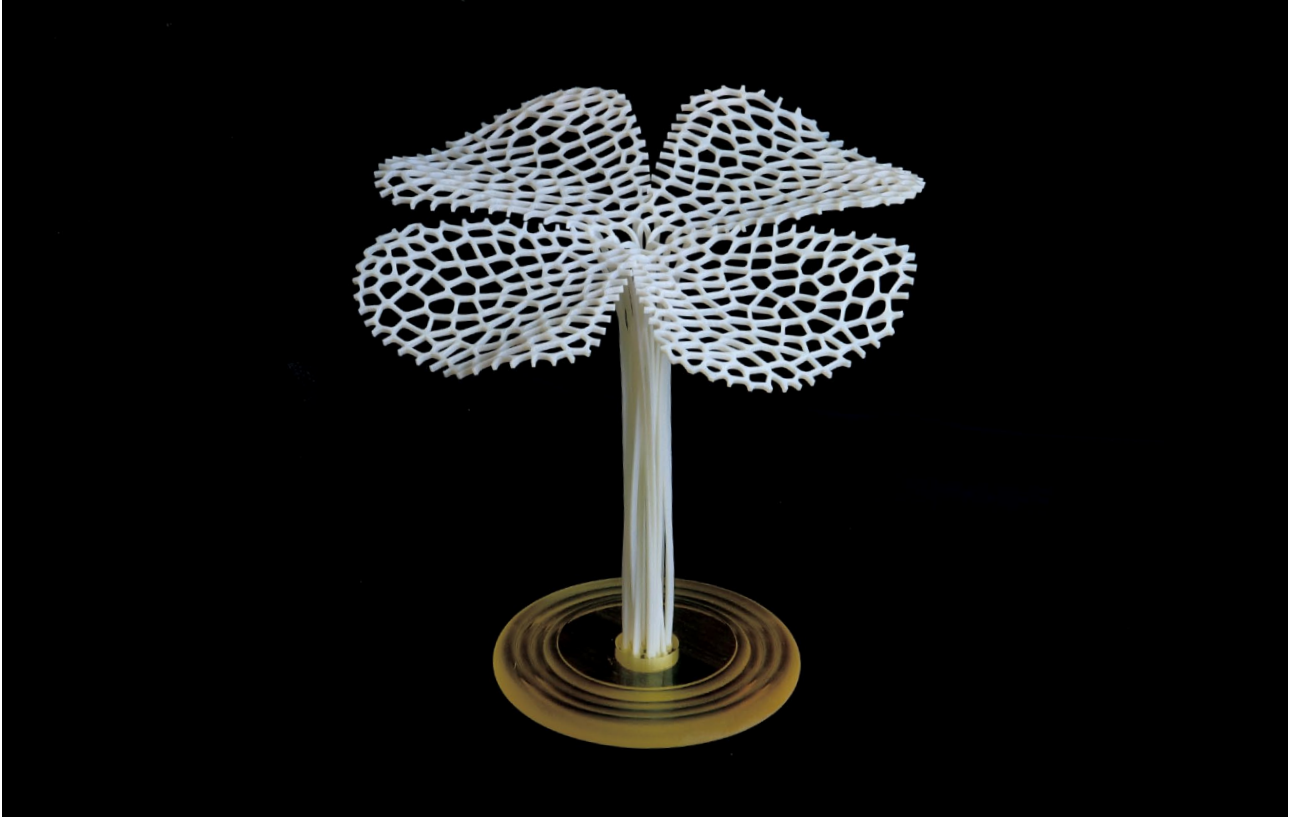
Biljana Jović, Komnenov Mirjana "Natalie's Ramonda pavilion" 2017, Material: VeroWhite, Size: 188W x 188D x 172H (mm)

Natural shapes are increasingly used as inspiration for design. Flower forms stand out because of their beauty, so we find them inspiring. The species of choice for us is Ramonda nathaliae P. et P., characterized by unusual traits of poikilohidry and limited range. Its flower shape is simple and consistent, and therefore a suitable basis for the extraction of the form to be used for generative modeling. We transformed the surface of flower petals into the Voronoi pattern, generated them using software tools, and developed them in the model of the Natalie's Ramonda pavilion.

Keywords: *Ramonda nathaliae* P. et P., Voronoi, pavilion
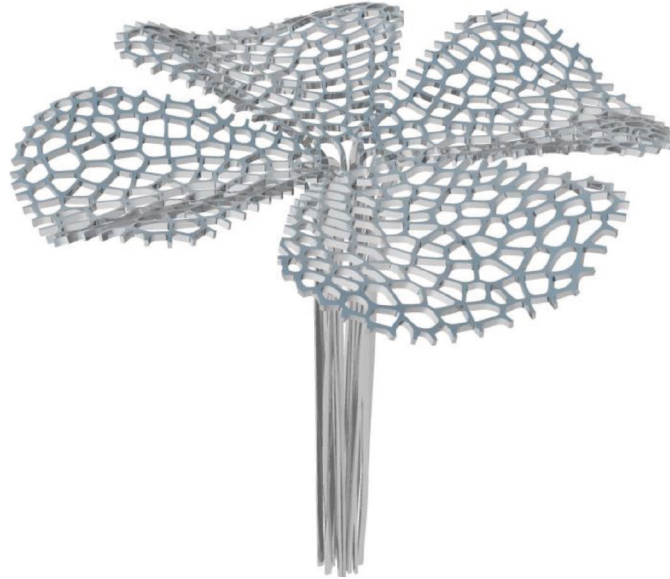
1 *Ramonda nathaliae* P. et P. as inspiration

More often natural forms are used in the design, whether through inspiration or literally because of its quality, whether they are singled out in the structure, function or beauty of form. The possibility of implementing biomimetic principles in spatial design, provides an opportunity for the development of different generative model based on parameters that originate from nature, and whose configuration is adapted to the requirements of spatial structures [1]. The development of biomimetics and digital technology has found its synthesis in the generative design, which is driven to a realistic level by digital fabrication. Implementation of natural forms through the design and spatial structure has so far been limited imitation of organic forms, however generative design offers unlimited range of

obtaining a form and therefore transcends that problem [2,3]. Starting from the viewpoint that plants are the most perfect living organisms, our interest is aimed in their direction. Among the plants and their organs, there are many variations in shape, but generally flower stands out as organ that varies the least in its form and function, yet because of its beauty

Figure 1: Ramonda nathaliae P. et P. flower

attracts the most attention [4]. Precisely for these reasons we determinated this part of the plant as the basis of our ideas, and we find inspiration in the flower species *Ramonda nathaliae* P. et P.. *Ramonda nathaliae* Pančić et Petrović is species of unusual characteristics having in mind that it is characterized by traits poikilohidry and limited range, since is endemic species in Serbia and Macedonia. Among people it is also known as the Phoenix flower, because of its features that allows her to survive in state hibernate in unfavorable conditions and suspend its flowering until favorable conditions occurs. It was named after Serbian Queen Natalija Obrenovic. This is a perennial plant whose flower stalks usually carries 1-3 flower. Diameter of each flower is 3-3.5 cm and is characterized by actinomorphic (radial) symmetry. The flower is made of 4-5 calyx and 4 articulated flower petals (exceptionally 5) [5].

Flower build is simple and consistent, and therefore suitable basis for extraction in the form that will be used to carry out generative model form. In the process we streamed surface of the flower petal into the Voronoi pattern, then generate it by using software tools, and developed in the model of a pavilion.

2 Method

To start, the surface of petals we imagined as a Voronoi grid. In the process we used a photograph of the flower [6]. Based on the photo and nervs of the flower petals of *Ramonda nathaliae* P.etP., characteristic starting points are positioned as a basis for the future pattern, respectively the centers of cells of Voronoi diagram. Comprehensive Voronoi structure is derived by applying software Rhinoceros and it plug-in Grasshopper by linking appropriate components with the
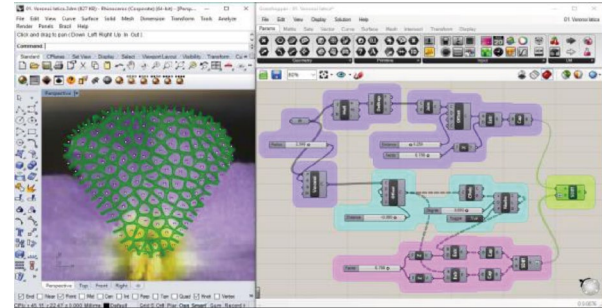

Figure 2: Rhinoceros - Grasshopper configuration

parameters. In this way the arrangement of nerves is translated into a form whose structure corresponds to the surface of the flower petal.

This structure is flat, and the further procedure of generating model comes down to bending model surface to obtain a wavy shape of the petal. The basic design tools within the software package allows us to manipulate this object as part of the design process through which is made a modification that affects on the spread of the model, the morphological characteristics of form and proportion, changes that manifest themselves visually and directly on the model, until the desired result is achived.

In a further process, the petal has served us as a design pattern. The application of natural form in the framework of generative design identical to the role of designers who directs his creative energy in the experiment with a design that offers plenty of opportunities as an outcome of this process [7].

Translation parameters, which has set itself the nature and use them in the experiment search form, it is possible to perform the objects that in essence contains the basic pattern flower petal, to obtain a concrete model. In a further stage of

Figure 3: Pavilion implemented in the space

searching a suitable form so that we can take advantage of the resulting Voronoi pattern we have come to pavilion model. Voronoi structure is limited by the edge of the petal of a flower. Petal of the flower is basically presented as a single wing of pavilion and edges of Voronoi petal witch match the center of the flower is continuing smoothly into the pillars. In this way, the structural differences between the petals and pillar are invisible crossed. Modeling of the object is basically derived by generating surface of wing-petals and pillars obtained by sweep command based on the rail represented by manually defined curve. In order to obtain a final solution, or to set the thickness of the structure, surfaces are offset to a specific thickness. The final model of pavilion that corresponds to a structure of the flower, was obtained by petals that are repeated 4 times in a circular arrangement. The resulting model is designed as a landscape-architectural installations in the space.

3 Software & System

The model is done in system with performances of 2.4 GHz i5 Intel Core x64-based processor and 6 GB of RAM. In a process we used Rhinoceros software with Grasshopper plug-in.

References

[1] Milošević J., Nestorović M., *Bio-interfaces, Studies in Bionics and Space Structure Design*, 4th International Scientific Conference on Geometry and Graphics, moNGeometrija, Vlasina, Vol.1, pp.90-99, 2014.

[2] Pearson M., *Generative Art*, Mannig, 2011.

[3] Kolarević B., *Half Cadence: Towards Integrative Design*, Proceedings of CAADence in Architecture, University of Techology and Economics, Budapest, pp.27-31, 2016.

[4] Čučaković A., Jović B., Komnenov M., *Biometic Geometric Approach to Generative Design*, Periodica Polytechnica Architecture, University of Techology and Economics, Budapest, pp.70-74, 2016.

[5] Šilić Č., *Endemične biljke*, Svjetlost - Zavod za udžbenikei nastana sredstva, 1987.

[6] Jović B., Tripković M., Čučaković A., *Geometric correlation of cultural landscape patterns and Prunus Domestica L.*, Glasnik Šumarskog Fakulteta, Šumarski Fakultet, Vol.104, pp.29-40, 2011.

[7] Leopold C., *Folding structures*, A hermit's cabin, Erasmus intensive programme Kaiserslautern, Structural Architectures – Geometry, Code and design II, Technische Universitat Kaiserslautern, pp.18-20, 2013.

3D-Materials for Mechanical Design and Drawing Education
--Technical Assistance Through Experience

Tsutomu Araki
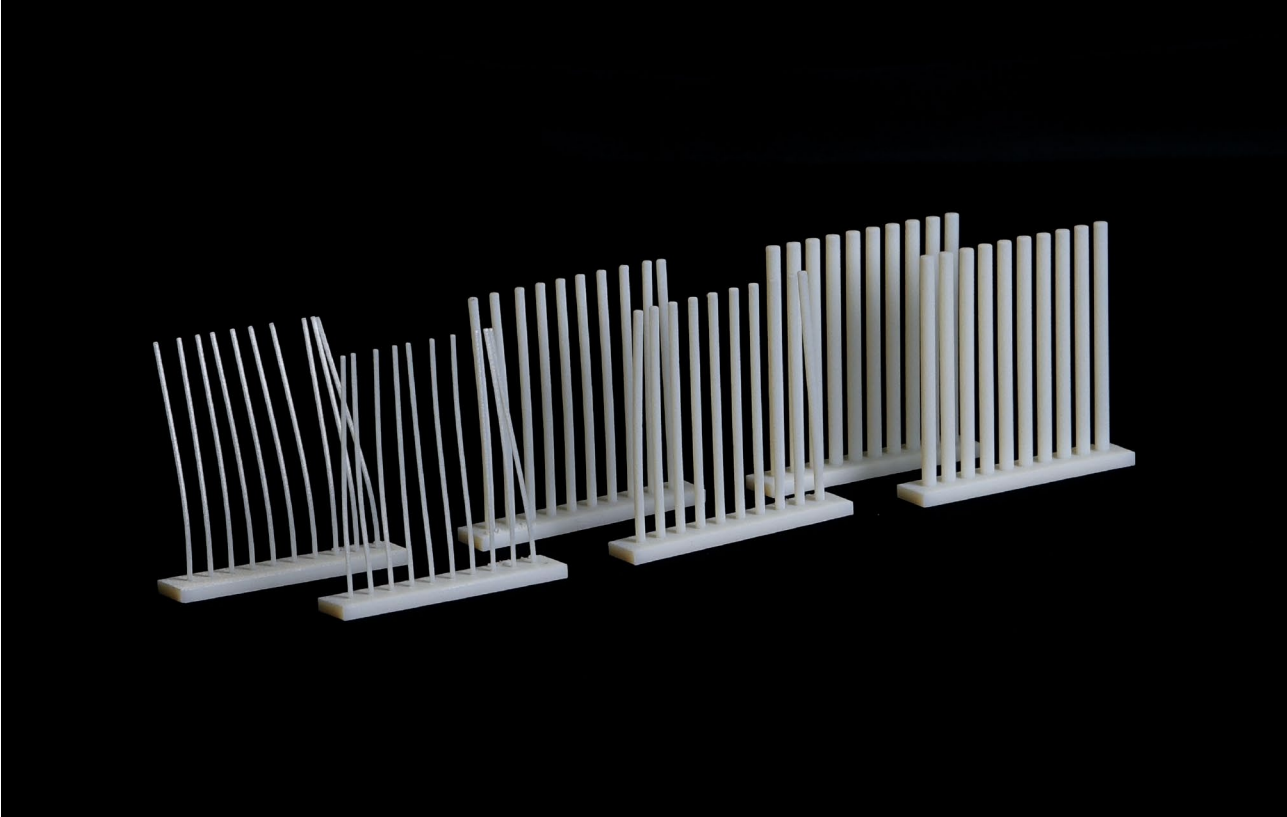
Tsutomu Araki "3D-Materials for Mechanical Design and Drawing Education --Technical Assistance Through Experience" 2017, Material: VeroWhite, Size: 55W x 53D x 10H (mm)

This is a collection of teaching materials for mechanical modeling, intended to deepen the students' thinking, encourage critical assessment, and enhance their capabilities in creating the best products through the educational application of machine designing/ drawing and computer-aided design. We encourage our students to comprehensively experience and be educated by use of these materials for learning technical drawing, through user experience evaluation of student-designed shapes and functions, and trial production of blocks to learn about the processing accuracy or characteristics of 3D modeling machines. These are selected examples of our methods for supporting design and drafting education at our university.

Keywords: Teaching materials, Materials for drawing method, Hands-on experiences, Consciousness of modeling accuracy, Hints for 3D-modeling, Optimization

1 Materials for students to deepen their thought through hands-on experiences

Tsukuba University of Technology (NTUT) is the only higher educational institute for the hearing or visually impaired in Japan. In the Mechanical Engineering Course, we educate hearing-impaired students. And we educate with emphasis on Mechanical Design and Drawing because students with an engineering education typically go on to join a company where they are involved in design and CAD. Tsukuba University of Technology (NTUT) introduced an inkjet type 3D-modeling machine in 2007. Since then, we have been using the machine for the education of design drawing, and collecting data on experience and knowhow for effective use. Utilization of 3D-CAD and 3D-modeling at our university is a means of motivation and communication for high quality design and drafting education for hearing-impaired students. The model introduced here is part of the teaching materials for the development of education.

2 Works of 3D-model as teaching materials

2-1 Handle lever: Teaching material of function of lever
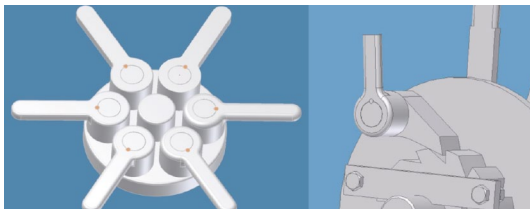
Figure 1: Aseenbled handle levers FILLET R0, R1, R2, R3, R4, R5 on a Exhibition stand (Left side), Usage of a handle lever for Ratchet wheel of Hand winch (Right side)
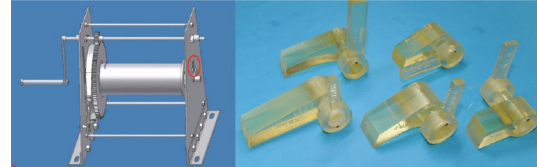
Figure 2: Hand winch's handle lever (Left, in a red circle), Students' design for hand winch's Ratchet wheel (Right)

Figure 3: Handle lever R1 model, Exhibition stand and pin

grip condition of each fillet.

Teaching materials to try and feel in one's own hands. Students will be able to optimize their mechanical design. One of the small stacks to improve one's own sense of design.

2-2 M20 Teaching materials of Bolt screw: 3D-model for Exercises on Machine Design Drawing and Practice of Manufacturing Processes as a Teaching material.
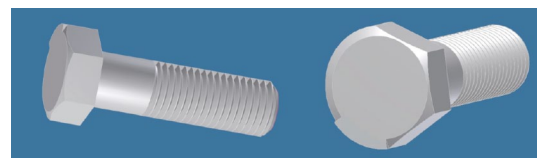
Figure 4: M20 Bolt as a Teaching Material

When producing with a 3D-modeling machine output at 200%.

2-3 Projection teaching material: projection drawing method

Teaching material for explanation of projection method. Made with transparent material. You can see the same explanatory symbol as in the textbook on each side.
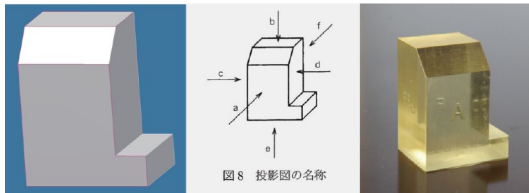
Figure 5: 3D-CAD data, Size: 40W x 30D x 50H (mm) and 3D-modeling (Right side), Figure from textbook (middle side)
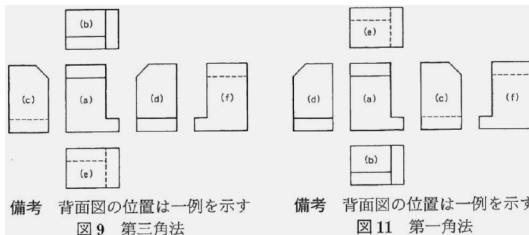
Figure 6: Figure from textbook
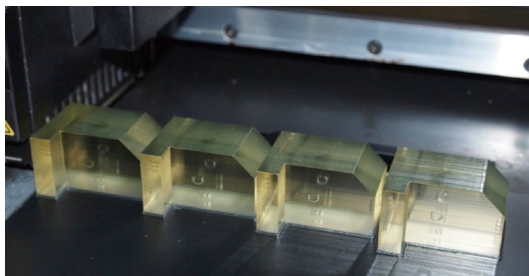
Figure 7: Easy to produce by 3D Printer

2-4 Materials for teaching of drawing: Teaching materials to show how to draw in the same form as the diagrams of textbooks and to gain a better understanding.

Produced as a model to use for explanation of drawing.
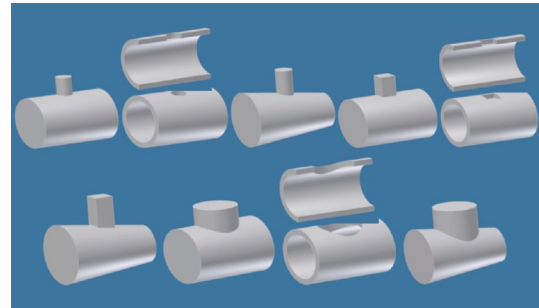
Figure 8: Teaching materials 3D-CAD data for simplified drawing example of intersection same as text book
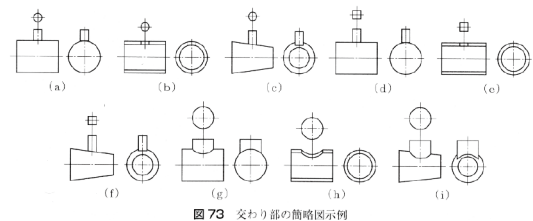
Figure 9: Simplified drawing example of intersection, figure from textbook
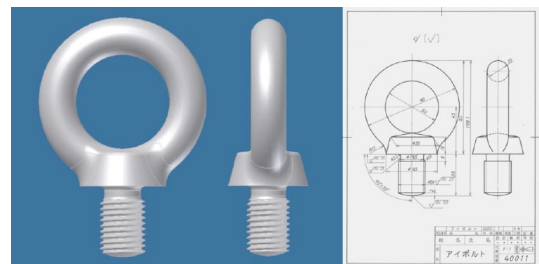
Figure 10: Eyebolt, 3D-CAD data and figure from textbook

44
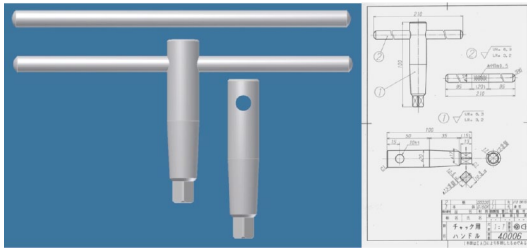
Figure 11: Chuck Handle, 3D-CAD data (assembled data and parts) and figure from textbook

A model for showing the same shape as the drafting sample of the textbook.

Even if the real standard of the same standard exists in the factory, it is often different from the form of the drawing model of the drawing textbook.

For example; "Eyebolt", "Chuck Handle".

2-5 Assembling on the 3D-CAD monitor / Assembling real parts by 3D-modeling machine: Experiencing assembling on a monitor of 3D-CAD and assembling real parts which are made by 3D-modeling machine.

Insert a shaft of diameter 10 mm into a diameter 10 mm hole.

Although parts can be assembled on the monitor of 3D-CAD, the producted axis by this size does not enter the hole in the real model of this size. Please try it.

You will be able to recognize that it is necessary to think about dimensional tolerance for the machine design.

2-6 Considering that it is made with a 3D-modeling machine according to 3D-CAD drawing data: Test pieces for effective useage of 3D printer features

Awareness of processing.

Consciousness of modeling accuracy.

a. Models for consciousness of modeling accuracy of 3D-modeling machines

Shafts and bearings are often used for precision mechanism models. Regarding to the dimensional accuracy: It is important to compare the dimensions of the drawing data of length, width and height with the actual size of the height, width and height of the 3D-model, and to know the machining accuracy of the 3D-machine. When manufacturing a cylinder (shaft) or a perfect circle (bearing) by 3D-modeling machine, check the machining dimensional accuracy of the 3D-machine by horizontal placement and vertical placement.

These are models for consciousness of modeling accuracy of 3D-modeling machines.
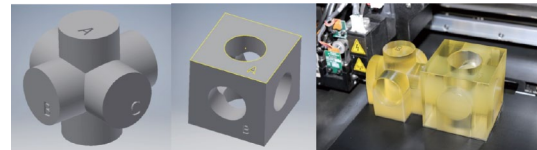

Figure 12: Test pieces by 3D-CAD data and 3D-modeling $\phi25$ x 50W x 50D x 50H (mm)

b. Model for the possibility of shaping --Performance check: Precise forming for 3D-machine and Deforming for materials ($\phi1$, $\phi2$, $\phi3$, 50mm(H))

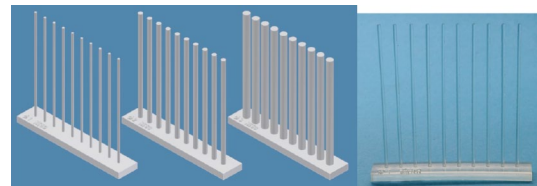Whether precise shaping is possible at a height of 50 mm

Figure 13: $\phi1$, $\phi2$, $\phi3$ x 50H(mm), $\phi1$_3D-modeling

with a diameter of 1 mm. It may be deformed with the passage of time due to the shaped material. For our 3D modeling machine and materials, we can shape them. However, in the case of a 1 mm diameter pillar, it bent after making it.

2-7 A model offers the possibility of manufacturing as an industrial product, even though it can be made with a 3D- modeling machine
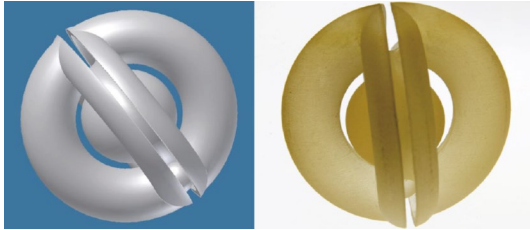
Figure 14: 3D-CAD data (L) and 3D inkjet modeling figure (R)

2-8 A model that allows you to think about devising when making with 3D-modeling (a model that makes you think of the necessity of ingenuity)

Good model for PR-Car use.
Precise model as one sample of 3D-modeling for it can be cheap.
--- Scale: Output size 10% of 3D-CAD modeling data (make it easy to draw output with the desired percentage size).
Make a slit to remove support agent with jet water stream at

Figure 15: Good model for PR-Car use; tire axle also rotate
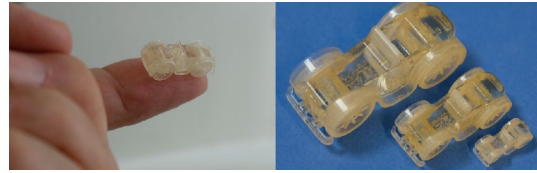
Figure 16: Size 10%: 22W x 10D x 9H (mm), (Left side) Size 30%, 20%, 10% model, (Right side)

the bottom of the car that is under the shaft.
Devices for removing support agent that fills the gap for turning the axle and hole tire with jet water stream.
Precise model of one sample of small 3D-modeling; it can be low cost material and therefore easy to share.

3 Usage of the New Method to Make Specimen for Photoelastic Test

It was found that a 3D-modeling machine can easily produce specimens for photoelastic tests. Any shapes of specimens can be produced based on a 3D-CAD drawing, as if they were printed by a printer. This enabled us to implement photoelastic tests without difficulty. The apparatus used here is a simplified one made of a tracing stand furnished with LED plate illumination of white light shining on the specimen from behind. As students got more familiar with tests, the items they need to consider in design increased
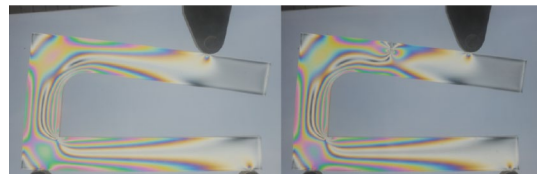
Figure 17: 3D-modeling machine can easily produce specimens for photoelastic tests. With notch at the upper part and stress concentration can be seen (Right side), none (Left side)
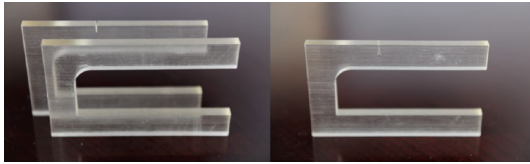
Figure 18: Photoelastic tests with notch and none (Left side), With notch inside the photoelastic test (Right side)

much more. We expect to have further opportunities to develop new areas of the utilization of CAE including 3D-CAD and 3D-modeling.

Various shapes and notches can be made freely. I believe that the scope of further utilization will expand as a teaching Modeling Machine which offers a chance to think and try doing by ourselves.

4 The first 3D-CAD experience teaching material at our university

--Making a mini-hanko (personal stamp): Basic 3D-CAD operations and 3D RP modeling

Manipulation of 3D-CAD and production of 3D-model using mini-stick teaching materials. As a teaching material to make sense of modeling experience in one class period "Making a mini-hanko". Hanko means one's own name stamp.

Through the making of a mini-hanko by 3D-CAD and 3D RP modeling, students can learn about the basic operations of 3D-CAD, as well as the development flow from data drawing to manufacture. Of course, using and trying is real modeling. Production costs are low, production time is short. The production of a strapped mini-hanko that students can actually use afterwards serves as a summary of the basics of CAD.

By guiding students through a production process of their
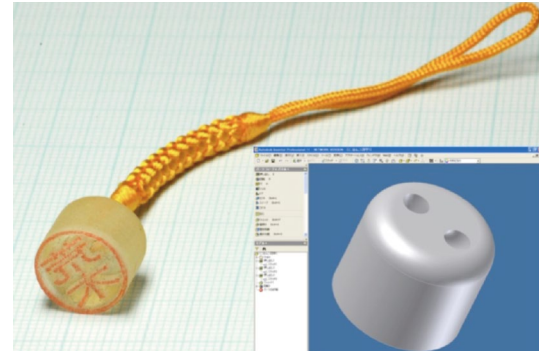
Figure 19: As a teaching material to make sense of modeling experience in one class period "Making a mini-hanko"

own interest, we hope students can get a hold of the techniques of technical design drawing and CAD usage positively.

5 Software & System

Software: Autodesk Inventor

Modeling machine: Objet EDEN260, inkjet modeling machine

References

[1] Araki, T., Nakamura, N., Honma, I., *Educational Assistance Through Modeling in Tsukuba University of Technology--Professional Education for the Hearing or Visually Impaired*, Computer Aided Drafting, Design and Manufacturing (CADDM), China Graphics Society, Vol.25, No.4, pp.58-65, 2015.

[2] Araki, T., Hirano, S., *Development of cooperative education and basic engineering education: aided by 3D CAD and 3D RP modelling*, Int. J. Computer Applications in Technology, Vol.51, No.1, pp.80-85, 2015

Report on How to Construct 3D Models for 3D Printing

Report on How to Construct 3D Models for 3D Printing

Misako Nishii, Yoshiaki Machida

1. Foreword

This report discusses digital modeling methods for printing data analyzed in past Digital Modeling Contests using 3D printers.

Each year, the works entered into the Digital Modeling Contest held since 2008 become more and more elaborate. To construct such elaborate models, applicants are required to submit high quality model data appropriate for the modeling machine to be used in the contest. In order to enhance the quality of the model data submitted, the sponsor provides information on the characteristics of the specified modeling machine and how to use the machine in the contest. Since the applicant and sponsor need to mutually understand the importance of data quality, the sponsor verifies whether the data of works entered is suitable for printing, and informs the results to the applicants. During the verification, the executive committee and members repeatedly verifyies various issues with the cooperation of the manufacturers of 3D printers.

For digital modeling data that needs to be output using 3D printers, there are three important steps in the modeling process. They are "3D shape modeling", "data conversion", and "output". The keypoints of each step are as follows.

2. Keypoints in 3D Shape Modeling

The intermediate file format most commonly used when printing 3D model data with 3D printers is STL (stereolithography). When using the STL format for printing "polygon models" which consist of continuous triangular shapes (called polygons or faces), the model must be a polyhedron with one space.

If the 3D model data to be printed is one of the following polygons, error will result in most cases and the data cannot be printed, although it may differ according to the mechanism of the 3D printer used. Such data must therefore be corrected first. Some modeling software are provided with functions to check the quality of 3D model data or correct errors automatically. These functions can resolve errors to a certain extent, but when these functions are not available, generally editing software for STL data are used.

There are also methods for correcting errors by hand, but they can only be applied if the user understands the errors correctly and have the skills to carry out the appropriate procedure. Again, these methods are complicated and take a long time. Based on the results of data verification functions and data analyses obtained to date, possible causes of errors and preventive measures are discussed in the following.

(1) 3D model data must be a polyhedron with one closed space
<Causes of errors>
· Presence of thin polygon
· Presence of hole (opening)
· Part of polygon is protruded

For the first cause for error above which is the presence of thin polygons, this may occur when modeling software generally called "polygon modeler" is used in CG production. This modeler is able to create three-dimensional

shapes by joining polygons. Polygons are not thick. If all polygons are connected, they form a state with no thickness like a piece of paper. This state with no thickness does not influence the CG production, but causes errors when printed with 3D printers (fig.1). For example, when modeling figures, even areas which do not require thickness in CG such as hairstyle, sleeve and hem of clothing, etc., need to be given thickness when modeled and printed with 3D printers.

The same applies for numerical visualization techniques and informatics. Spatial curved surfaces automatically generated by software programs must also be given thick geometries in the same way. Without thickness, there will first be a need to import the data to a modeling software to add the thickness. One method of resolving this would be to use the extrusion method when dealing with simple free-form surfaces. However, when dealing with an integrated geometry consisting of multiple free-form surfaces intersecting each other, it is not easy to add thickness to the intersecting areas. There would be a need to import each independent object to the modeling software, add thickness
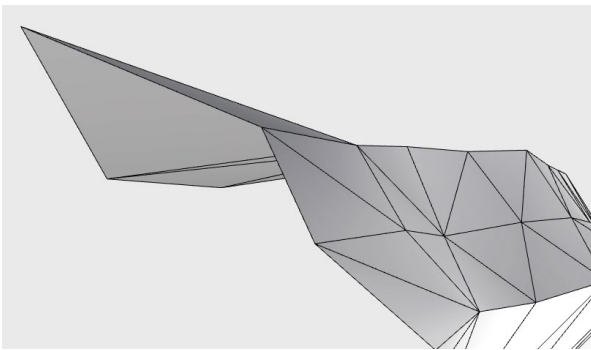
Figure 1: Presence of thin polygon

to each object, and integrate the multiple free-form surfaces with thickness.

The second cause of error is the lack of polygon (fig.2) or the normal direction of the polygon is facing the opposite direction if there are holes (openings). There must be no holes at all in the data. First, there is a need to see if the problem can be resolved by setting the normal of all polygons to the same direction using the modeling software repair tool. If holes remain, they have to be closed. Some software programs have functions which automatically close the holes. The names of these programs are not disclosed here as they can only be used in limited environments.
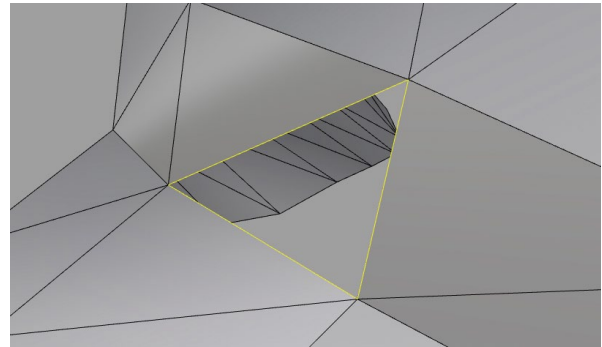
Figure 2: Presence of hole (opening)

The third cause of error is difficult to correct by automatic correction for polygons with ridges that are protruded (fig.3). There is a need to edit the object by hand while checking the shape.

(2) Boolean combination
<Causes of errors>
When polyhedron 1 and polyhedron 2 overlap, a third

Figure 3: Part of polygon is protruded
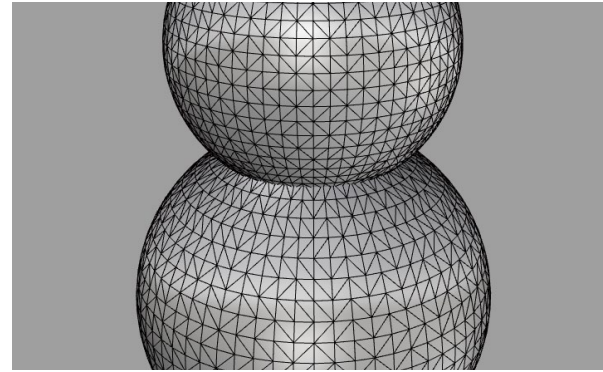
Figure 4: Two polygon objects

polyhedron 3 is formed in the STL data (Fig.4) .

Errors tend to occur easily when some polygons are overlapping (interfering) in structures made up of multiple polyhedrons. The first cause of error is geometries composed of balls piled above balls like a snowman. The existence of multiple divided spaces in areas that are overlapping, is not allowed in data (Fig.5). Polyhedrons need to be single structures called "shell" by using Boolean connection to join multiple polygons (Fig.6). In the case of the snowman, this process removes the partition between the two balls to become one snowman-like polyhedron.

(3) Duplicate operation of objects to be appropriate for 3D printers.
<Causes of errors>

In this case, parts are continuously copied to create the 3D model data. But STL data does not support copied geometries. In modeling, parts are sometimes copied and used. In some cases, to lighten the data, the geometry of the
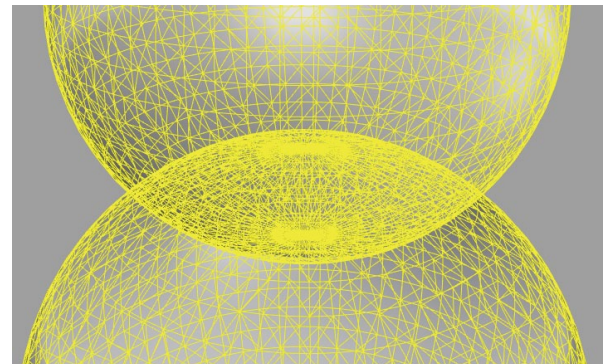
Figure 5: An overlapping area exists in two objects.
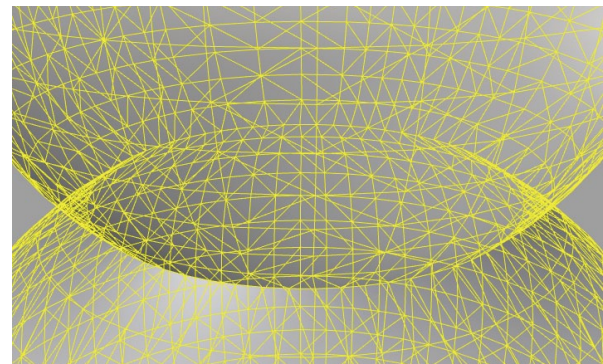
Figure 6: Using Boolean connection to join multiple polygons

parts itself is not copied, but models of parts are copied by a method called "instance". When data is copied, it is substantial and tangible, however in the case of the instance method, because the original object itself is not copied but only referenced, the data is not substantial. When such data is directly written to STL, geometry information will not be reflected in the instance. Thus, there is a need to first convert instance to actual object before writing.

(4) Degree to which object surface is divided.

When modeling by CG production and rendering is carried out, the geometry is made smooth by this rendering, and not by using polygons. When printing with 3D printers, as the data is printed based on the number of divisions of the polygon models, in order to convert it to the STL format, there is a need to increase the number of divisions of the surface as required.

(5) Adjustment of clearance by part
<Causes of errors>
· Some models can be printed out in the assembled state, but cannot be moved because the clearance is too tight.
· The model data of some models created by parts expansion can be output, but the fitted part is narrow and parts cannot be assembled.

In the design of the mechanisms of industrial products, there is a need to design the clearance according to the characteristics of the resin used and the shape of the product modeled. Even if a data has been printed out before, that clearance is often inappropriate on a different 3D printer and needs to be adjusted each time it is printed. Instead of printing out the data directly, there is a need to test some parts of the shape.

This contest provides information on the type of 3D printer used and clearance specifications at the time entries are invited based on past results.

(6) Object tolerance (Deviation)
<Causes of errors>
· When tolerance is large, the modeled geometry is rough.
· When tolerance setting is inappropriate between the two systems used, error occurs.
· When tolerance is too small, the STL data file size is excessively large.

As mentioned earlier, there are various 3D CAD data formats. In order to carry out laminate molding using 3D printers, data must first be rewritten to a triangular aggregate, and printed in the STL format. At this time, there is a need to specify how many polygons to divide the 3D model data into. This is called "tolerance". There are several kinds of tolerance, here we will introduce caution points in CAD.

Tolerance is proportional to the distance between triangular vertices. The smaller this value, the more detailed will the geometry be, On the other hand, the larger this value, the rougher will the geometry be. Tolerance is set not only using the data converted, but on all systems handling the 3D data such as laminating machines. When the data value and value of the settings on the laminating machine differ considerably, error may occur. Thus, there is a need to set the data and laminating machine setting to more or less the same value. In this contest, entries are recommended to set the tolerance to 0.005 mm to 0.01 mm.

The following are example, how to set tolerance by converting CAD file to STL format when using Stratasys™ 3D printing system.

These sentences are quoted from Objet260 user guide DOC-37004 Rev. E[1].

The following instructions generally apply for this printer.

This procedure may vary slightly depending on the CAD software used.

To convert a file to STL format (in a CAD program):

1. *From the File menu, select Save As.*
2. *In the Save As dialog box, open the Save As pull-down menu and select Save As. "STL".*
3. *Click Options and set the following parameters:*
   Total Quality- approximately 0.01 mm (deviation tolerance / linear-dimension tolerance)
   Detail Quality- approximately 5° (angle tolerance)
   Note: Lowering these values produces more accurate models, but results in larger files and longer loading and processing times. For this reason, it is generally not recommended that you use lower values.
4. *In the file format option, choose binary or ASCII. (Both binary and ASCII formats can be used in Objet Studio. However, binary files are smaller, so this option is recommended.)*
5. *Click OK or Save.*
   After converting the model files, it is recommended that you check them for defects in an STL-repair application (such as Magics™, by Materialise®)
   before opening them in Objet Studio and producing the model.
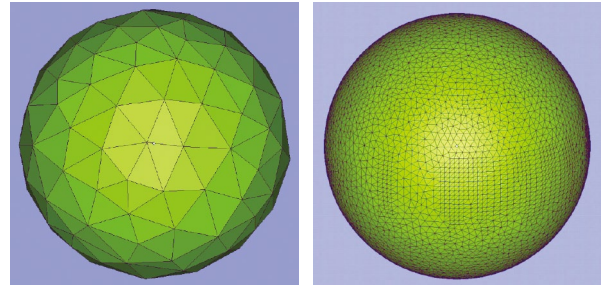
When value is large Geometry is rough   When value is small Geometry is fine

Next, an example of a typical error is shown. For instance, when there is data in which the tolerance is set to a large value(for example 0.5 mm), and the laminating machine is set to a high precision (for example 0.005 mm), increasing the numerical precision of 3D data will also increase the data volume, therefore attempts are made to set the tolerance to a large value. This means that a large value has to be set for the reference (threshold) for judging the error between surfaces. By reading this data on a system set to strict error judgment settings, an enormous number of errors will occur. If the tolerance is set to 0.005 mm for instance, as long as the distance between the surfaces composing the polyhedron is large, it is judged that the surfaces are apart from each other. Consequently, this is judged as a hole, and error results. This error occurred with a laminating system set to a high precision (for instance 0.005 mm) and will not occur with laminating machines set to loose settings. This means when attempts are made to find and correct errors in data created on one's own PC (loose settings) in another similar environment set to the same loose settings, they cannot be

found. To correct such errors, the tolerance at the laminating machine should be set loosely (for example 0.5 mm). But this method is not ideal as the data quality drops significantly, resulting in the modeling of rough geometries.

One method of resolving errors without sacrificing data quality would be to use the "stitch" function for joining surfaces. This function is provided with editing software and presently used mainly for correcting STL data.

(7) Model size is very small after conversion to STL data

Units are not inherited in STL format. As a result, the overall size of the model may become very small, below 1mm. In this case, it can be changed to the appropriate size with the software of the 3D printer. However, if the object is composed of several parts, the appropriate clearance in the magnified state will not be known. In CG production, size is not given significant attention, but due to such problem occurring, the user needs to take into account the size and unit of the model data.

3. Data Conversion

The main modeling software type differs according to the field used in: CG production and design. In some cases, the techniques for configuring geometries created using different software programs differ. Intermediate file formats often used and the areas in which they are used are introduced below.

Format	Type of main geometry	Remarks	Field in which this file format is mainly used
OBJ	Polygon	May be included in formats which can be read by 3D printers	3D CG
STL	Polygon	Standard intermediate file format for 3D printers	3D CAD,3D CG
IGES	Surface	File format for CAD data exchange created by the American National Standards Institute(ANSI).	3D CAD,3D CG
STEP	Solid	File format for CAD data created by the International Organization for Standardization(ISO).	3D CAD
XVL	Polygon/Surface/Solid	Lightweight 3D file format developed by Lattice Technology Co., Ltd.. 3D data is used for design, manufacturing, parts procurement service, etc.	WEB 3D,3D CAD
DXF	Surface/Polygon	2D intermediate file format is the most known intermediate film format. But there also exists intermediate file formats for 3D modeling. 3DCAD data may be used for reading.	3D CAD

4. Reviews Issues when Printing with 3D Printers

4.1. Relation between Modeling Time Efficiency and Output Model

(1) Geometries which can be improved by dividing and assembling

By dividing the geometry and printing it, the printing time can be reduced.

Figures 6 and 7 show a model designed by mathematical modeling being divided at a uniform height, modeled, and assembled. Normally, modeling is carried out in the assembled state, but with models that are tall and have volume, modeling time and material costs will increase and become costly.

In this case, the model is divided horizontally, parts are overlapped and modeled as shown in Figure 6 As a result, the height could be reduced to one-sixth, the volume of the
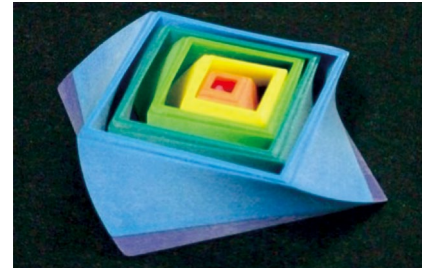
Figure 6: When modeling
Original Object data: Kiyoe Fuchigami

supporter to one-third, and modeling costs to 1/3.

Figure 8 shows an example of a model constructed from design data already assembled. Assembly is not carried out after modeling. Only post-processing such as removal of the supporter etc. is carried out. The 12 gears incorporated in the

Figure 7: When assembling
Original Object data: Kiyoe Fuchigami

Figure 8: Assembled model
Object data: Stratasys Ltd

model could all engage with each other and move.

The base, frame, and gear are built separately, and assembled at last. This is the same procedure as conventional modeling methods, but because the assembly is done by hand, it takes considerable time and efforts. The model in Figure 8 does not require any efforts at all to assemble.

4.2. Problem of Removing Support in Modeling

The work for removing the support is also an important step, and precautions to be taken in the removal are described below using some examples.

As new 3D printers continue to be released one after the other, laminated molding (additive manufacturing) can now be carried out in detail. On the contrary, this has made it increasingly difficult to remove the support without breaking the laminated model.

For example, thin lines (cylindrical columns) of about 0.1 mm in thickness can be output for ink jet (polijet) machines, but because the water used for removing the support is injected out at high pressure, the molded model may be deformed by shredding, etc.

Of the 11 finalist works of this contest, all the faces of one of them were about 0.2 mm thick. At some areas of the structure, the thickness was less than 0.1 mm thick. The results of data verification confirmed that the structure can be molded by normal methods. Faces which are about 0.2mm thick are thought to break easily when the support is removed. For such shapes, water soluble supports may be used to remove them without applying high pressure water currents. The support material of the molded model absorbs water and expands, and this may cause the problem of the molded model becoming deformed according to the shape.

With this work, removal of the support was thought to be difficult, so we asked the creator of the work to correct the thickness of the face to about 2mm.

Most of the other entries were elaborate and easy to break. Many used supports which could be removed by chemicals. Still it was difficult to remove the supports safely, and some of the 11 finalist works had to be remolded due to failure to remove the supports. In this way, the safe removal of supports is a common problem shared by manufacturers. Manufacturers are therefore presently developing various types of support materials, and users are still in the midst of finding appropriate support materials. Understanding the characteristics of these materials and learning how to remove supports safely and accurately will continue to be a challenge in the future.

5. Instructions on Preparation of Entries and Precautions in Data Creation

In ADMC2017 and Digital Modeling Contests until now, "Instructions on Preparation of Entries and Precautions on Data Creation" were provided for the preparation of models using the modeling machine "Eden260VS". Specifications are shown below.

6. Type of Resin Used, Amount Used, and Printing Time in Printing of Entries

The following shows the resin amount used and printing time of a finalist entry of this contest using the 3D printer "Eden260VS".

As the support material is disposed after printing, it is preferable that the amount of material used is small. For cases where the support material used is considerably more

	Entry	Resin for modeling		Support resin		Output time (h)
		Type	Amount (g)	Type	Amount (g)	
1	Duality	VeroWhite	257	SUP707	2,465	17:49
2	Chladni Towers	VeroWhite	421	SUP707	897	8:56
3	Pre-programmed deformable material	VeroWhite	162	SUP707	206	1:31
4	Capricious Hearts	RGD720	874	SUP705	1,166	8:10
5	3D PRINTED MODEL AS AUGMENTED REALITY MARKER	VeroWhite	2,174	SUP707	2,696	27:26
6	Design by Spheres – A Project for Museum	VeroClear	1,993	SUP707	2,194	18:01
7	OJIGI TOKURI (Self-Tilting Sake Bottle)	VeroWhite	186	SUP707	585	7:21
8	Design lamp shade	VeroClear	804	SUP707	1,644	14:53
9	Triskelion Blocks	VeroCyan VeroMagenta VeroYellow	138 359 372	SUP705	94	6:30
10	Natalie's Ramonda pavilion	VeroWhite	454	SUP707	1,289	21:05
11	3D-Materials for Mechanical Design and Drawing Education--Technical Assistance Through Experience	VeroWhite	15	SUP707	25	0:40

3D printing partner company: ALTECH Co., Ltd., (2,3,4,5,10,11), Stratasys Japan Co.,Ltd., (1,6,7,8,9)

than the amount of resin used for the model, there is a need to consider printing methods which can reduce the amount of support material used by dividing the model and building it.

Reference

[1] Stratasys Ltd. "Objet260 User Guide DOC-37004 Rev. E", p3-9.

ADMC 2017