



A METHOD FOR EXPANDING THE HUMAN VISUALISING ABILITY: DESIGNING COMPLICATED THREE-DIMENSIONAL GEOMETRICAL SHAPES THROUGH MATHEMATICAL EXTRAPOLATION

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Abstract: This research focuses on the role of technology in creative thinking in design. Human thinking space can be expanded with the help of technology, thereby enabling humans to generate entirely new ideas that are otherwise difficult to imagine. This research aims to generate three-dimensional geometrical shapes with a computer, which are so complicated that they cannot be visualised easily in the human mind but are deemed interesting. This research tries to develop a method for designing three-dimensional geometrical shapes in which the parameters of shapes recorded in a computer are mathematically extrapolated to create more complicated shapes. In an experiment, subjects were asked to create new shapes in accordance with this method. The results indicate that new geometrical shapes generated by mathematical extrapolation, which cannot be visualized by the human mind alone, are considered by the subjects as interesting as those created by themselves.

Keywords: *three-dimensional geometrical shape, design support, mathematical extrapolation*

1. Introduction

This research focuses on the role of technology for human creative thinking in design. Methods for improving design creativity can generally be classified into two types. The first aims to improve the human ability of creative thinking, whereas the second aims to support designers using technology such as artificial intelligence (AI), which has been greatly developed lately. We adopt a method which combines both types, aiming to expand the human thinking space through the support of computers. Thus, humans could generate ideas which they did not have before and their ability of imagination would be improved. A few examples related to this aim, though not from the design domain, are as follows. AlphaGo¹, an AI developed by Google, defeated the world's strongest Go player: the AI defeated the human champion, but as a consequence, Go players from all over the world learned new strategies and increased their knowledge of the game studying the moves of AlphaGo, and as a result, their skills as Go players improved. In addition, Fujii, the youngest Shogi player ever to hold the rank of fourth dan, is improving quickly by studying Shogi with a computer (Brasor, 2017).

¹ <https://deepmind.com/research/alphago/>

Furthermore, in recent years, there is a focus on trying to use technologies in sport challenges. A free-viewpoint video is realized by Flying Eyes, an autonomous flying helicopter (Rekimoto, 2011), which can fly following athletes while they are running and swimming. With this technology, athletes can observe their own movement, improve their technique, and thus train more effectively.

A strategy for the highest probability of success for basketball shots in court was identified by using Big Data (Carter, 1993). The result indicates that the highest probability of success is achieved by a shot from a forty-five degree angle and by aiming at a point eleven inches to the side of the target. Based on this result, new training methods can be proposed and therefore athletic abilities will be improved effectively by Big Data. In fact, Kashino (2016) states that it will be possible to generate new methods in accordance with scientific evidence by continuing to obtain and analyse data.

In addition, new ways of enjoyment can be generated through the support of technology. For example, music that cannot be composed by human beings alone can be generated by Desktop Music (DTM) software. Furthermore, with the help of Special Effects (SFX), movies that contain scenes created artificially can be enjoyed. A landscape that has never been seen by any human being can be generated by iGAN², a tool that generates landscapes automatically by designating colours and drawing lines.

The process in the above-mentioned examples is shown in Figure 1. 1. Human ability is transferred into a computer system. 2. The system analyses and learns from the transferred data, and a new idea is created which is difficult to get by mere human ability. 3. The human being is stimulated. 4. The space of human thinking is expanded and human ability is improved.

In this research, we attempt to develop a method for expanding the human thinking space in the domain of design.

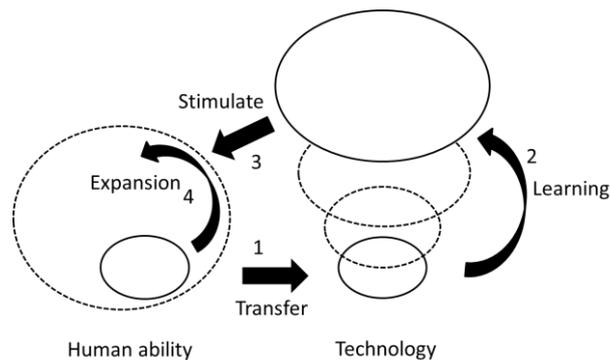


Figure 1. Cycle of expanding thinking space and improving the ability of imagination through the support of computers

2. Purpose and method

This research generates three-dimensional geometrical shapes through the support of the computer, which human beings cannot visualise easily in their minds but that are deemed interesting. The human ability of recognizing a three-dimensional space is limited; if it could be expanded, new shapes could be generated that are as interesting as those created by human beings, but cannot be visualised in their minds due to their complexity. In this research, mathematical extrapolation is used for verifying this hypothesis. Currently, software that supports generation of shapes is developed; thus, people who are not good at designing can represent shapes visualised in their mind through the support of such software. This research generates new shapes with computers that could be as interesting as those created by human beings, by extrapolating parameters of known, less complicated shapes to get more complicated ones (Figure 2).

² <https://github.com/junyanz/iGAN>

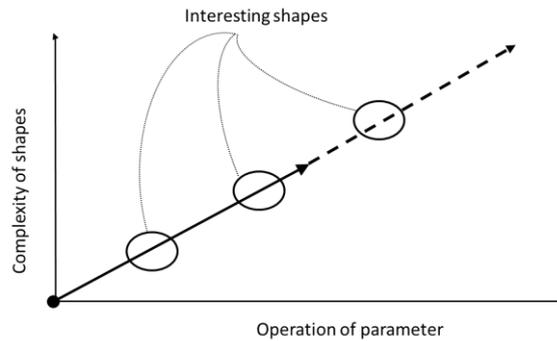


Figure 2. Image of generating new interesting shapes by extrapolation

The process is as follows. First, as a preparation, a method for designing three-dimensional geometrical shapes with computer software is developed. The specific method will be explained in Section 3.1. Second, an experiment is conducted to confirm whether a new idea of shape is generated or not. In the first step of this experiment, subjects are asked to design their favourite geometrical shape in accordance with the design method. In the second step, an experimenter mathematically extrapolates the geometrical shapes designed in the first step. In the third step, subjects are asked to evaluate simultaneously the shapes designed by themselves in the first step as well as the shapes extrapolated in the third step.

For designing geometrical shapes, two software products, Blender³ and Sverchok⁴, are used. Blender is a three-dimensional computer graphics software that can generate geometrical models easily. Sverchok is a parametric tool that generates geometrical shapes added to Blender. It can transform shape models geometrically and can also generate new shapes. For example, it can duplicate a shape, bend a line, and combine two shapes together.

3. Design method

3.1. Development of the design method

The design method we developed is shown in Figure 3. First, a shape such as a cone or cube is chosen as the base of a geometrical shape. Second, the base shapes are arranged on a curved line by operating <iterate>, which is the parameter corresponding to the number of shapes, and the parameters <matrix deform> and <euler matrix>, which are the parameters corresponding to the bending of the line. Third, a polyhedron is chosen. Finally, the shapes which are arranged on the curved line are combined with the polyhedron in perpendicular directions. Geometrical shapes can be designed in accordance with this process.

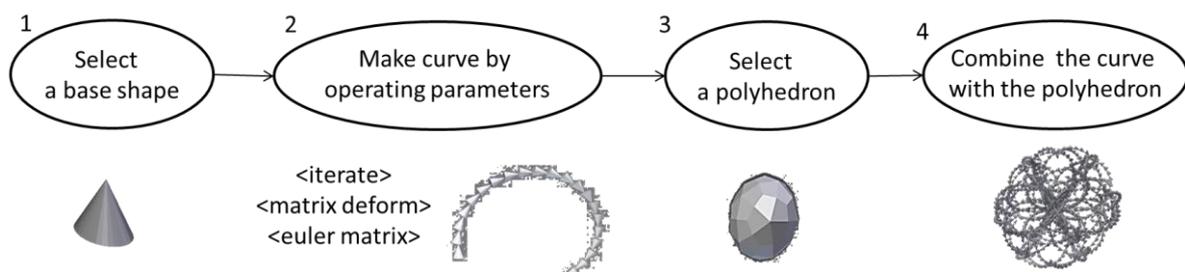


Figure 3. Development process of the design method

³ <https://www.blender.org/download/>

⁴ http://nikitron.cc.ua/sverchok_en.html

3.2. Examples of generated geometrical shapes and their mathematical extrapolation

3.2.1. Example of three-dimensional geometrical shapes designed in accordance with the design method

Figure 4 (a) shows an example of three-dimensional geometrical shapes designed in accordance with the developed design method. First, a cone was chosen as a base shape. Second, <iterate>, the parameter corresponding to the number of shapes, was set to 20. <matrix deform> and <euler matrix>, the parameters corresponding to the bending of the line, were set to (0.06, 0.36, 1.23) and (9.00, 7.86, 1.26), respectively. Cones were arranged on a curved line by operating these three parameters, and the shapes were combined in perpendicular directions to the surfaces of the regular polyhedron <pentakis dodecahedron>. As a result, the three-dimensional geometrical shape, as shown in Figure 4 (a), was created.

3.2.2. Example of the mathematical extrapolation for generating the geometrical shapes

Next, the generated geometrical shape, shown in Figure 4 (a), was extrapolated. The polyhedron <pentakis dodecahedron> that was used to design the shape was changed to the polyhedron <rhombicuboctahedron> and hence the geometrical shape shown in Figure 4 (b) was generated. Moreover, another geometrical shape was designed by operating three parameters: <iterate> was set to 20, <matrix deform> was set to (0.24, 1.46, 1.40), and <euler matrix> was set to (7.05, 12.86, 6.76); then, it was combined with the shape shown in Figure 4 (a). As a result, the three-dimensional geometrical shape (Figure 4 (c)) was generated.

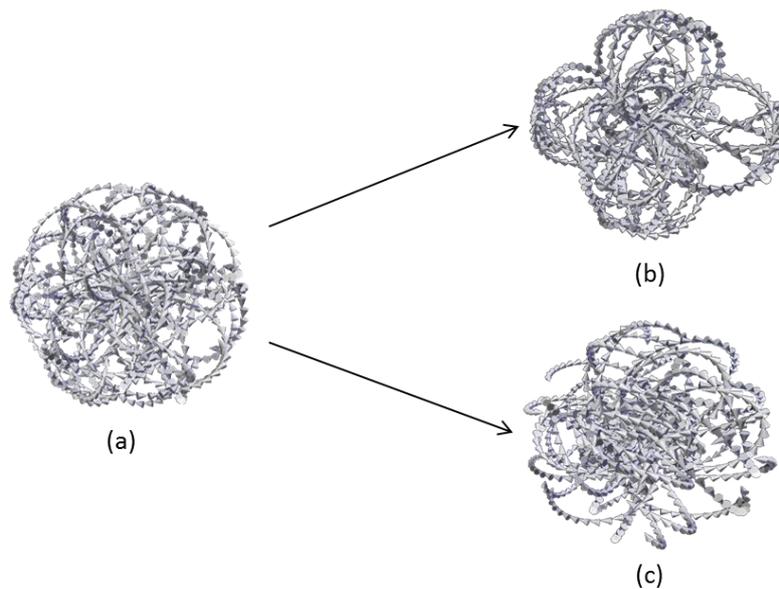


Figure 4. Three-dimensional geometrical shapes before (a) and after extrapolation (b, c)

4. Experiment

4.1. Overview

The experiment was conducted to confirm whether new shapes are as interesting as those designed by the subjects can be generated by the mathematical extrapolation of some starting shapes. In the first step, subjects were asked to design new geometrical shapes in accordance with the design method explained in Section 3.1. The subjects were four individuals who studied art and were interested in design. They participated in the experiment one by one (Figure 5). In the first step, a lampshade was

given as a theme. The direction of extrapolation that attracts the subject's interest most strongly cannot be defined by us, and hence, sixteen shapes for each subject were generated so that the subject could choose the most interesting of those.

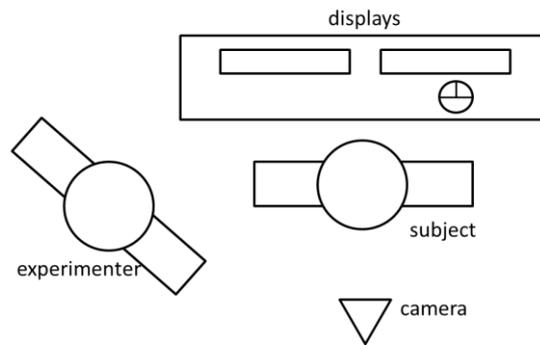


Figure 5. Experimental setup

4.2. Procedure

The first step

First, an experimenter explained the design method to the subjects and made them understand the process. Next, subjects were asked to imagine three-dimensional geometrical shapes for a lampshade and design them on a computer in accordance with the design method. At that time, subjects could revise the shape or they could form different ones until they were satisfied with the result.

The second step

The experimenter extrapolated the geometrical shapes designed in the first step by the subjects and generated sixteen shapes.

The third step

Subjects were shown sixteen geometrical shapes generated in the second step through mathematical extrapolation and they had to choose the most interesting one. In this step, because it seemed difficult to choose directly one single shape from a total of sixteen, we proposed a tournament method as shown in Figure 6. The subjects compared the geometrical shapes in pairs, having 1 min. for each comparison. After the process was repeated fifteen times, the most interesting shape was finally chosen.

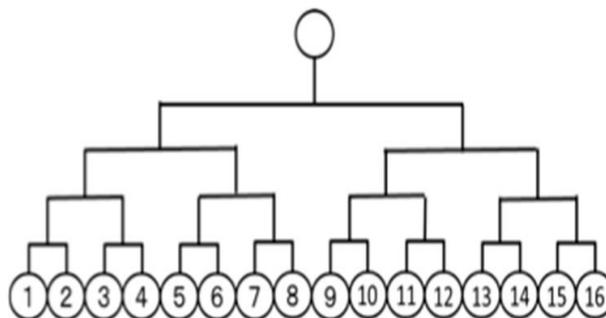


Figure 6. Combination of comparisons

Subsequently, the subjects were asked to evaluate the following questionnaire items (on a scale from 0: Completely disagree, to 100: Completely agree) on both the geometrical shape designed by them in the first step and the mathematically extrapolated one chosen in the third step as the most interesting.

The questionnaire items are as follows.

1. Do you like this shape?
2. Do you think this shape is beautiful?
3. Are you attracted by this shape?
4. Have you seen shapes which looked like this one?

5. Do you think you can sketch this shape clearly?
6. Can you image a complete picture of the shape in your brain?
7. Do you remember the shape in every detail?
8. Do you think you can make the shape by yourself if you were familiar with how to operate the software?
9. Do you think you can make the shape with another tool such as clay?

Items from 1 to 3 are questions about how much subjects are interested in the shape, and items from 4 to 9 are questions about whether the shape can be visualised easily in his or her mind.

4.3. Results

Table 1 illustrates the three-dimensional geometrical shapes designed by the subjects in the first step before the extrapolation process, and the mathematically extrapolated shapes that are chosen as the most interesting ones in the third step. Table 2 shows the subdivision of time spent on each shape, over the total time of 1 min., in the third step. The columns on the left show the numbers of the selected shape and the opponent shape in the tournament as shown in Figure 6. The columns on the right show the time in seconds spent with the selected shape and opponent shape. Figure 7 shows the average value of the questionnaire items 1 to 9 and the error bar indicates the standard deviation. An asterisk indicates that the items have significant difference at a probability of less than 0.05.

In Figure 7, there were no significant differences between the geometrical shapes before and after extrapolation regarding the following three items which evaluate how much the subjects were interested in the shape: item 1 ($F(1) = 0.173, p = 0.6809$); item 2 ($F(1) = 0.343, p = 0.5628$); and item 3 ($F(1) = 0.001, p = 0.9727$). Regarding the questionnaire items which evaluate whether the shapes can be visualised in the subject's mind, we see that the following three items elicited a significantly different response to geometrical shapes before extrapolation versus geometrical shapes after extrapolation: item 4 ($F(1) = 5.825, p = 0.0229$); item 5 ($F(1) = 4.778, p = 0.0377$); and item 8 ($F(1) = 5.690, p = 0.0243$). In these items, the shapes after extrapolation were evaluated as more difficult to visualise in their minds than the shapes before extrapolation. However, there were no significant differences between the geometrical shapes before extrapolation and after extrapolation in the following three items: item 6 ($F(1) = 1.432, p = 0.2418$); item 7 ($F(1) = 0.393, p = 0.5359$); and item 9 ($F(1) = 0.741, p = 0.3970$).

4.4. Discussion

Regarding items 1 to 3, the results indicate that the new geometrical shapes generated by mathematical extrapolation are as interesting as those designed by the subjects. As shown in Table 2, each subject tended to spend more time for the more attractive shapes; this implies that the shape which was finally chosen in the third step was seen by the subjects for more time. Nevertheless, regarding items 4, 5, and 8, the evaluation for the shapes designed by the subjects was higher than the one for the most interesting extrapolated geometrical shapes; this indicates that the geometrical shapes generated by mathematical extrapolation are so complicated that they cannot be visualised easily in their minds.

Table 1. Three-dimensional geometrical shapes before and after extrapolation

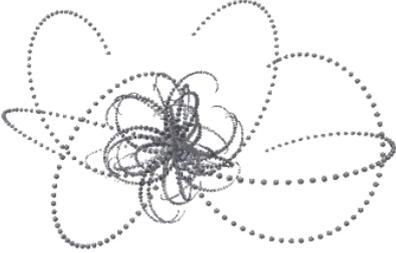
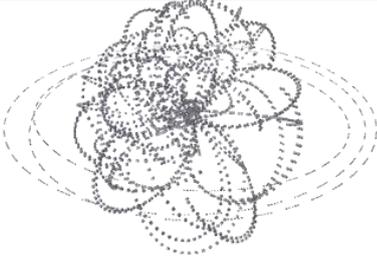
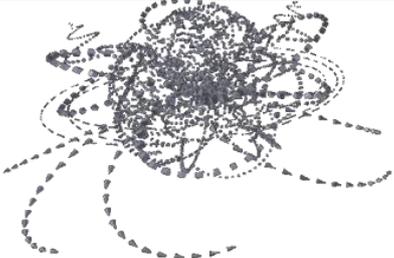
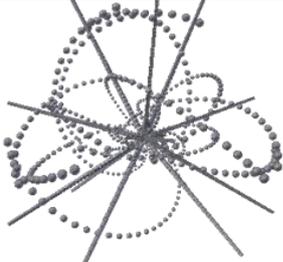
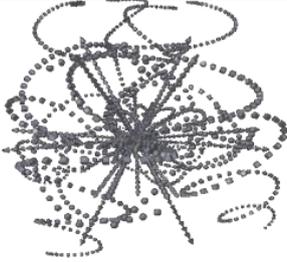
	Before extrapolation	After extrapolation
Subject1		
subject2		
subject3		
subject4		

Table 2. Subdivision of time spent on each shape

subject1		subject2		subject3		subject4	
number of shapes	seconds						
(1-2)	(44-12)	(2-1)	(32-28)	(2-1)	(41-19)	(2-1)	(45-15)
(3-4)	(28-32)	(4-3)	(34-26)	(3-4)	(27-33)	(4-3)	(37-23)
(5-6)	(19-41)	(6-5)	(29-31)	(6-5)	(26-34)	(6-5)	(40-20)
(8-7)	(28-32)	(7-8)	(34-26)	(7-8)	(38-22)	(7-8)	(37-23)
(9-10)	(39-21)	(10-9)	(33-27)	(10-9)	(31-29)	(9-10)	(47-13)
(11-12)	(26-34)	(12-11)	(42-18)	(11-12)	(53-7)	(12-11)	(35-25)
(14-13)	(22-38)	(13-14)	(33-27)	(13-14)	(32-28)	(14-13)	(41-19)
(16-15)	(43-17)	(16-15)	(37-23)	(16-15)	(32-28)	(16-15)	(22-38)
(2-3)	(35-25)	(4-2)	(26-34)	(4-2)	(35-25)	(4-2)	(25-35)
(8-5)	(30-30)	(7-6)	(35-25)	(7-6)	(20-40)	(5-7)	(28-32)
(9-11)	(41-19)	(12-9)	(40-20)	(11-10)	(33-27)	(9-12)	(25-35)
(16-14)	(38-22)	(13-16)	(34-26)	(16-13)	(41-19)	(16-14)	(38-22)
(8-2)	(32-28)	(7-4)	(34-26)	(7-3)	(32-28)	(4-5)	(45-15)
(16-9)	(35-25)	(13-12)	(38-22)	(16-11)	(36-24)	(9-16)	(26-34)
(16-8)	(40-20)	(13-7)	(55-5)	(7-11)	(31-29)	(4-16)	(47-13)

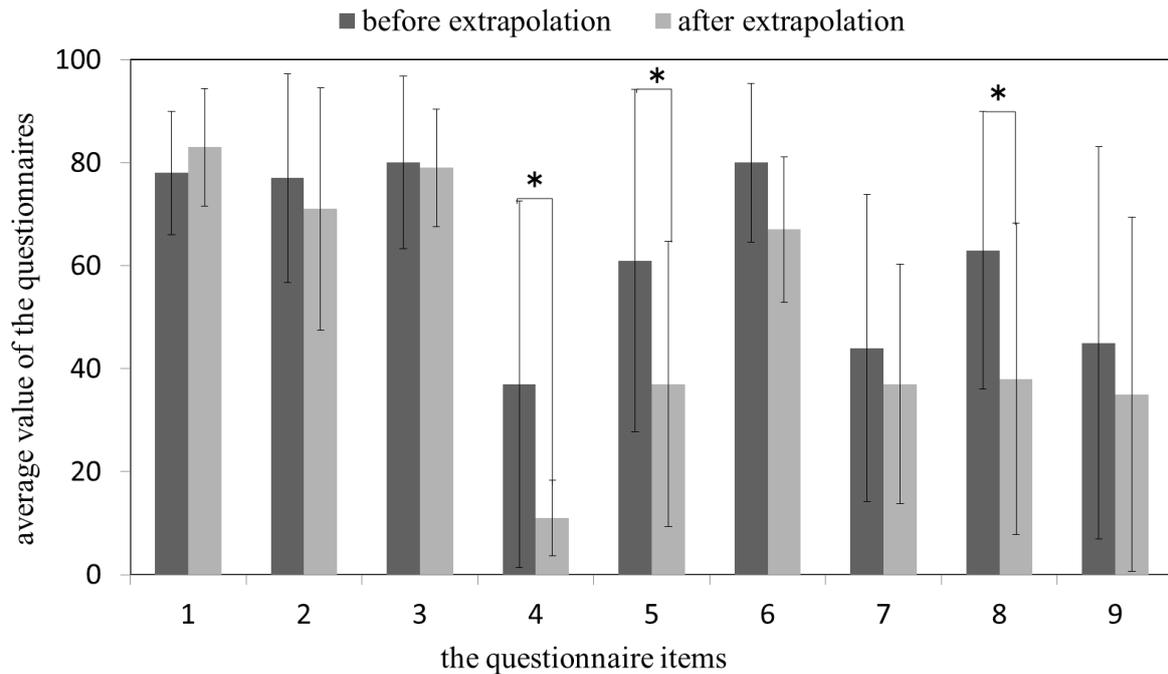


Figure 7. Average value of the questionnaires along with standard deviation

5. Conclusion

The aim of this research was to generate geometrical shapes, through the support of the computer, that are so complicated that they cannot be visualised easily in their minds but that are deemed interesting. The results of the experiment indicated that new geometrical shapes generated by mathematical extrapolation were considered by the subjects as interesting as those created by themselves. It was suggested that the human thinking space can be expanded and new ideas can be generated with the support of the computer. However, the experiment was conducted for four individuals only. In the future, we will attempt to apply this method for subjects with a different major field.

Acknowledgement

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