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USING IDEA MATERIALIZATION TO ENHANCE DESIGN CREATIVITY

Georgiev, Georgi V.; Taura, Toshiharu
Kobe University, Japan

Abstract

In this paper, we focused on the advantages of 3D printers to build new creative designs and to make it possible to enhance physical interactions with the design idea that may be able to expand the feelings of the designers and users of the designs. We proposed a general method focused on intentional theoretical expansion of concept space and materialization of design ideas. In an exploratory example, we investigated generation of design ideas and materialization of creative ideas for shapes. Interaction with the materialized ideas, and expansion of concept space results in the generation of new features, uses, functions, or contexts of the design idea and these can be reflected into a new idea. This suggests that interaction with materialized idea and expansion of concept space, and further rapid iterations of this cycle, can contribute to the expansion of human feelings evoked by the design, through this, contributing to design creativity.

Keywords: Creativity, Design methods, Early design phases, Expansion of concept space, Materialization of design ideas

Contact:
Dr. Georgi V. Georgiev
Kobe University
Organization of Advanced Science and Technology
Japan
georgiev@mech.kobe-u.ac.jp

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1 INTRODUCTION

In this paper, we focus on the possibility of using advanced technologies to enhance design creativity. Advanced technologies, such as three-dimensional printing (3D printing), allow for the production of various shapes that are difficult or impossible to produce using traditional technologies. A particular advantage is that such advanced technologies make it possible to build new creative designs that may be able to expand the feelings and sensitivity of the designers and users of the designs. An example of such expansion with regard to 3D printing can be found in the creation and sharing of new designs for 3D printing that has become very popular (Strickland, 2013).

In particular, this exploratory paper *aims* to propose and outline a method for materialization-enhanced design creativity. The particular problem we wish to solve is how to realize such a method and apply it to enhance creativity. The proposed method consists of 3D printing-based materialization of an initial design concept and interaction with this materialization to generate new and creative design ideas. These ideas can then be used for further enhancement in next iterations of additional new and creative design ideas.

The *characteristics* of the proposed method are as follows:

- Use 3D printing for *materialization* and then interaction with the actual object created from the design idea.
- Intentional theoretical expansion of *concept space* (space in which a new design idea is generated), based on mathematical and parametric approaches.

We use this method to expand the concept space, and then interact with the actual object created with 3D printing. Overall, the iteration of this cycle between expansion and interaction is intended to enhance the design creativity.

To address the aforementioned aim, we first investigate previous research work conducted for materialization and material-inspired (material prototype-inspired) design creativity. Second, we determine steps to inspire design creativity using materialization of ideas. Third, we discuss a method for materialization-enhanced design creativity. Finally, we discuss a preliminary example case to which we apply the proposed method.

We conclude that through interaction with the materialized ideas and expansion of the concept space, new features, uses, functions, or contexts for the design concept can be generated and incorporated into the next iteration. This suggests that interaction with materialized ideas and theoretical expansion of the concept space, and further rapid iterations of this cycle can contribute to the expansion of human feelings evoked from the design and enhance design creativity.

2 BACKGROUND

2.1 Idea Generation and Design Creativity

Design creativity is critical for the development of new products (Taura and Nagai, 2012). Generation of ideas for a product at an early stage of design is fundamental for design creativity. It is essential to understand and further enhance the generation of creative ideas at this stage of design, particularly concepts inspired from existing products and creative ideas for new products.

We focus not only on the so called “engineering design”; however, we capture the design from a broader viewpoint, as the creation of a product that is beneficial for humans and that tackles human feelings (for example, such as products of emotional design) instead of focusing solely on function.

The most important aspects of design creativity are not only the originality and novelty of the shape or function of a product, but also how the product may influence what a human imagines and feels towards it. For example, a truly creative product *expands feelings* in humans (Taura, 2015) (e.g. contemporary electronic products such as products utilizing virtual reality technology or interactive digital art). Such products evoke feelings such as excitement, enthusiasm, and engagement in humans that interact with them. Furthermore, such creative products cause people to think about the product, recall interactions with the product, and trigger imagination regarding the product.

Human feelings are not inherent as they are in the human mind. For example, in the case of music, humans receive strong impressions from the music, however, music is phenomenon that does not exist in nature and its sound is very complex. In consequence, we feel an artificial phenomenon, and conversely, our feelings are expanded by that artificial phenomenon. Respectively, in the context of technology, for example, if a human sees a visualization of a product that does not yet exist, the human generates deep feelings and impressions of that newly created product. Thus, the essence of a new creative product is characterized by the new feelings and impressions that it creates in a person, thus, expanding the feelings of that person (Taura, 2015; Taura and Nagai, 2012).

In order to gain understating of how to enhance feelings, in this research, we focus on expanding the possibility of designing creative shapes. The particular approach we adopt for this is to *materialize the generated ideas* and *interact* with the materialized (idea for a) product. We think this interaction is essential to understand and further put forward new creative ideas for products.

Often, creative ideas generated in the early stage of design are never materialized due to issues such as effort, cost, or time. However, if these creative ideas are materialized into a product prototype, they have a chance to be developed further or, more importantly, serve as a basis or inspiration for new creative design ideas.

2.2 Materialization through 3D Printing

The main aim of such materialization is for the ideas to be materialized with ease, which makes the approach less limiting. Particularly, *3D printing* offers one such means of materialization. 3D printing saves time and cost, as well as contributes for other technical characteristics (e.g. geometrical complexity) of the materialized models (Kroll and Artzi, 2011).

Consequently, the main merit of 3D printing is that it facilitates easy materialization of objects of shapes that are otherwise difficult to produce; hence, it can expand possibility of production of creative shapes and products. This study is based on the theoretical propositions of materialization in previous research (Sass and Oxman, 2006), and our ongoing practical research on materializations of new design ideas (Imada et al., 2014). In this research, we focus on the application of 3D printing as a tool to enhance the feelings that are evoked by the 3D-printed product.

Thus far, the characteristics of 3D printing have been focused on from the viewpoint of efficiency (similar to the focus on the characteristics of additive manufacturing processes and rapid prototyping) (Sass and Oxman, 2006; Rosen, 2014).

3D printing and additive manufacturing processes represent a tremendous opportunity for improved *concept generation and exploration*, particularly in the context of combining industrial design practices with engineering design methods (Rosen, 2014).

Pursuing *many materialized* prototypes in the earliest phases of the design process is regarded very beneficial for learning (Neeley et al., 2013); further, it may be beneficial for creativity as well (Gonçalves et al., 2014; Toh and Miller, 2014).

Some studies focus on the integration of generative computing and rapid prototyping into one process (Sass and Oxman, 2006). The approach proposed by Sass and Oxman supports a process to generate *diverse* candidate artefacts as solutions to design problems. Here, diversity can be sought as an important characteristic related to design creativity.

The representation modalities can serve as cues to creativity, and the 3D representations (such as prototypes) may be regarded as potentially inspirational stimuli; moreover, the use of 3D representations as inspirational *stimuli* is highly rated by the design professionals in the study conducted by Gonçalves et al. (2014). Thus, 3D materialization itself has a better inspirational and creative potential than other representations utilized in the design process.

Interaction and how the representation of a product is viewed have been connected with the evaluation of a product (Georgiev et al., 2014), and through further evaluation these can be linked with the feelings evoked in the designer or user.

However, the underlying factors that influence physical interactions and have impact on design creativity have not been investigated (Toh and Miller, 2014). Thus, our focus is on the advantages provided by 3D printers that can easily create shapes that were difficult to create previously, and use this advantage to enhance physical interactions with the design concept and have a further positive impact on design creativity.

This study is not one on general prototyping, but focuses on the specific advantages of 3D printing. The specific advantages of 3D printing among the prototyping methods for design creativity in practice can be articulated as follows:

- Advantage of time (allowing quick materializations)
- Advantage of process continuity (allowing the designer’s feelings to be maintained throughout the design process)

Human feelings cannot be described, for that purpose we use 3D printing (as a kind of “media” for human feelings). Furthermore, an important point for design creativity is that designers should keep feelings in mind. However, in practice, it is difficult to maintain the designer’s feelings in his/her mind for long periods of time, therefore the shortening of the design prototyping time is useful. Using 3D printing, it is easy to materialize complex shapes in a short time. With other methods, prototypes of complex shapes can take a long time to create.

In fact, the exploration process of *generation and materialization* is essential for creativity (Figure 1).

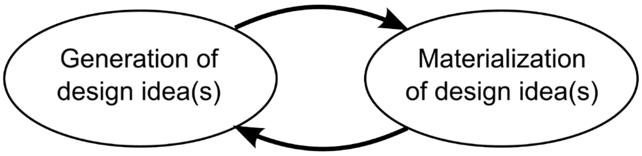

Figure 1. Exploration through generation and materialization of design idea(s)

Such exploration is connected with creative cognition (Finke et al., 1992). The interaction between generation and materialization of a design idea enables the generation of greater numbers of potentially more useful and novel ideas (on the basis of an application, function, or context foreseen from interaction with the material prototype).

In such a way, 3D printing can be seen enabling (or allowing for) imagination of new applications, functions, or contexts. This is made possible by the material interaction itself, the way the material prototype is viewed, or how its form/shape is understood.

We focus on the enhancement of design creativity using 3D printing for implementing generated creative ideas for design in material product prototypes. Furthermore, a case where creativity is possibly interwoven with materialization is discussed.

3 METHOD

To understand how materialized creative design ideas can be used for enhancement and improvement of further generation of creative design ideas, we propose a general method (or approach) (Figure 2). We use this method to *intentionally expand the concept space* and then *interact* with the actual object by using 3D printing. Overall, iterating this cycle seeks to enhance the design creativity. Concept space is the space in which a new design idea is generated.

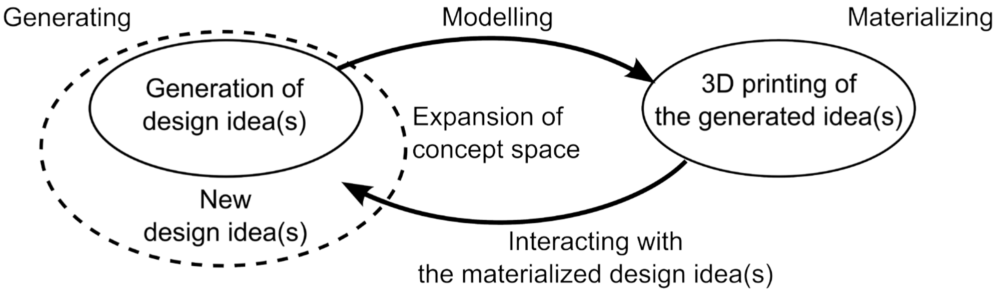

Figure 2. Method for expansion of concept space and interaction with materialized design idea(s)

The following are the steps of the method (Figure 2):

- Generating: Generation of design idea(s) (e.g. using sketches)
- Modelling: 3D modelling of generated idea(s) (e.g. using 3D modelling software)
- Expanding: Intentional expansion of concept space
- Materializing: 3D printing of generated idea(s) (using 3D printing)
- Interacting: Interaction with the materialized (3D printed) design idea(s) and using the idea(s) to enhance the generation of new idea(s)

In particular, the proposed approach has the characteristics of combining simplified modelling and 3D printing, which is beneficial for the focus on enhancement of idea generation.

Furthermore, in the step of modelling, which may be time-consuming, we focus on the application of theoretical approaches to expansion of concept space and the generation of a shape, for example, alter the shapes' order and increase the complexity of the shapes (Figure 3).

Additionally, using parameters to theoretically expand the image of a shape can also be used to fulfil aims of our proposed method. Parametric generation of shapes has already been connected with creativity (Lee et al., 2015; Oxman, 2015).

As mentioned, the step of materialization focuses on simplified 3D printing. The focus of the last interaction step is on expansion of feelings.

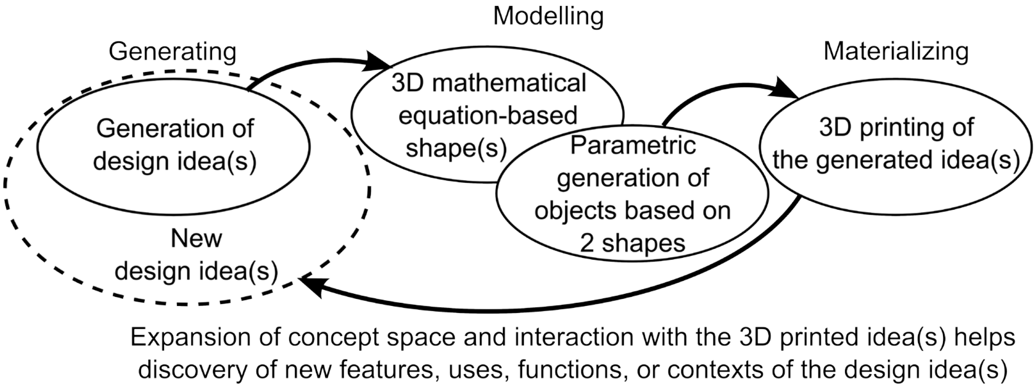

Figure 3. Idea generation process

4 EXAMPLE

4.1 Objective and setting

With the objective to implement the proposed method in an actual case, we discuss the following example. The underlying hypothesis of this implementation is that new features, uses, functions, or contexts for the design concept can be uncovered with the proposed method.

We focus on an open-ended case that is not representative of real-world design situations (e.g. not a situation with constraints). This is in order to reduce the limitations on design creativity. Moreover, it is from a broader viewpoint that is the design of a product that is beneficial for humans and tackles human feelings. We considered that any constraints in this case, for example, would limit the expansion of the concept space in terms of constraining features, uses, or envisioned functions.

In the discussed open-ended case, we selected a shape that allows for easy modification (a mathematical equation-based shape). Thus, the possible limitation of 3D modelling as a time-consuming and skill-challenging process would not have a considerable effect on design creativity.

The example is based on the details of the idea generation process outlined in Figure 3. The aforementioned method was applied in the following exploratory example of design idea generation by one designer with an engineering background.

The setting for this example uses current 3D modelling software with add-ons for equation-based modelling and an add-on for parametric-based modelling (Blender (2014), version 2.72b, with add-ons Add 3D Function Surface (2014), version 0.3.6, and Sverchok (2014), version 0.2.7). This setting allows for diverse possibilities in generating and manipulating shapes.

4.2 Idea generation process

The following description of an idea generation process for a shape is open-ended, without a particular design target. The idea generation process can be described as follows:

- Modelling: on the basis of generation of a mathematical equation-based shape (concave hyperbolic octahedron) and sketches (Equations (1) to (3), see Add 3D Function Surface (2014), and Figure 4).
- Generation of a common multifaceted shape (called IcoSphere in Blender).
- Parametric generation of a 3D object consisting of placement of multiple mathematical equation-based shapes on the facets on the multifaceted shape (Figures 5 and 6).

- 3D printing of the object (Figure 5).
- Use of the 3D printed object in the generation of new ideas. The object may trigger generation of new ideas.

$$x = (\cos v)^3 (\cos u)^3 \tag{1}$$

$$y = (\sin u)^3 \tag{2}$$

$$z = (\sin v)^3 (\cos u)^3 \tag{3}$$

for $-\frac{\pi}{2} < u < \frac{\pi}{2}$ and $0 < v < 2\pi$

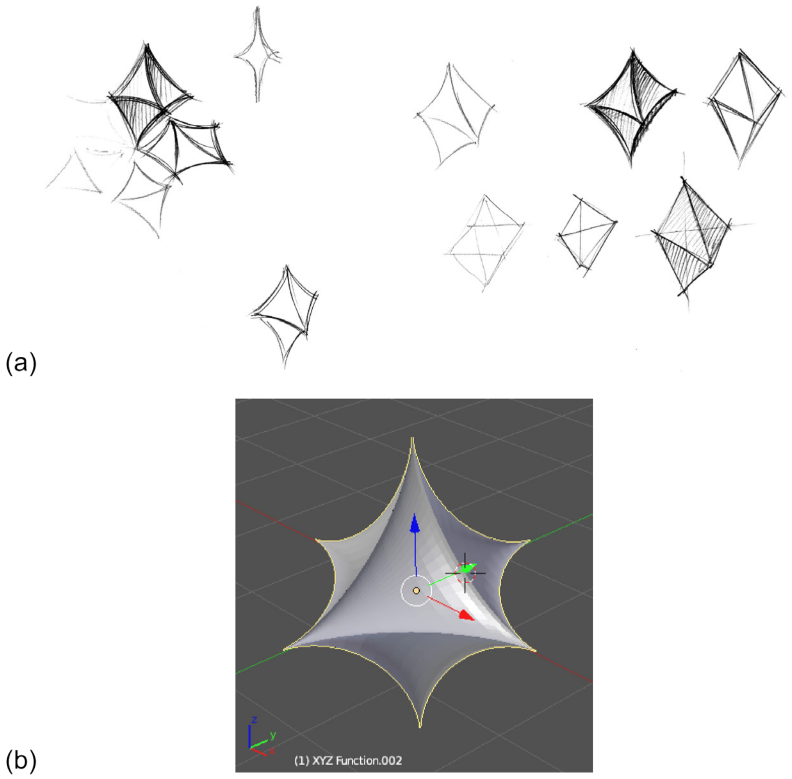

Figure 4. Idea generation sketches (a) and mathematical equation-based shape (b) (shape created in Blender (2014) with add-on Add 3D Function Surface (2014))

A 3D object generated with the help of parametric generation is complex and difficult to produce with technologies other than 3D printing.

The open-ended approach actively elaborates upon the mathematical equation-based and parametric generation, which allow for unrestricted changes of the concept for the designed shape. To illustrate this, Figure 4 shows an example of the initial idea that is extended to the difficult-to-produce model (Figure 5) and leads to materialization of a more comprehensive design idea, which is possibly more creative.

Mathematical transformations were performed by the designer (freely elaborating parametric procedure elements). The parametric procedure illustrated in Figure 6 consists of two input shapes (objects on the left side) transformed by placing multiple instances of the mathematical equation-based shape on the facets of the multifaceted shape (taken as a matrix and rotated as vectors normal to the surfaces of the facets). The final object is consolidated from multiple instances of the initial object.

In this way, focusing on expansion of the concept space and creativity, it is possible to produce a complex and possibly original design in a short time-frame.

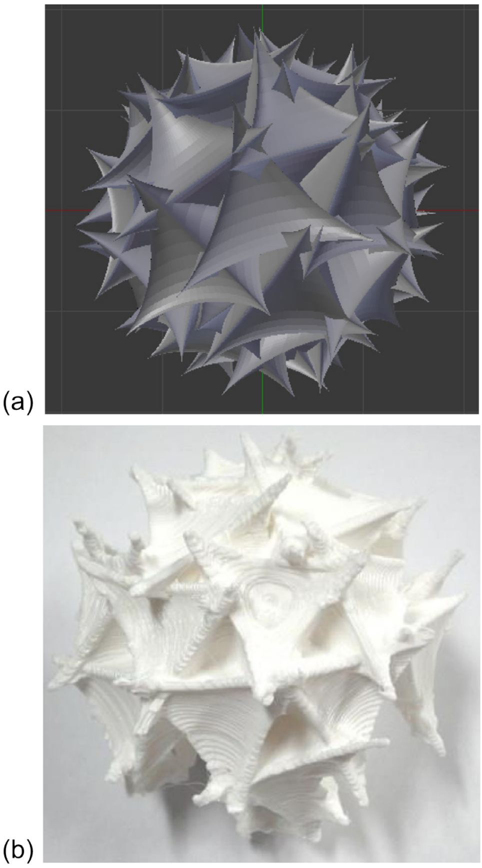

Figure 5. Sample 3D model (a) and its 3D print (b)

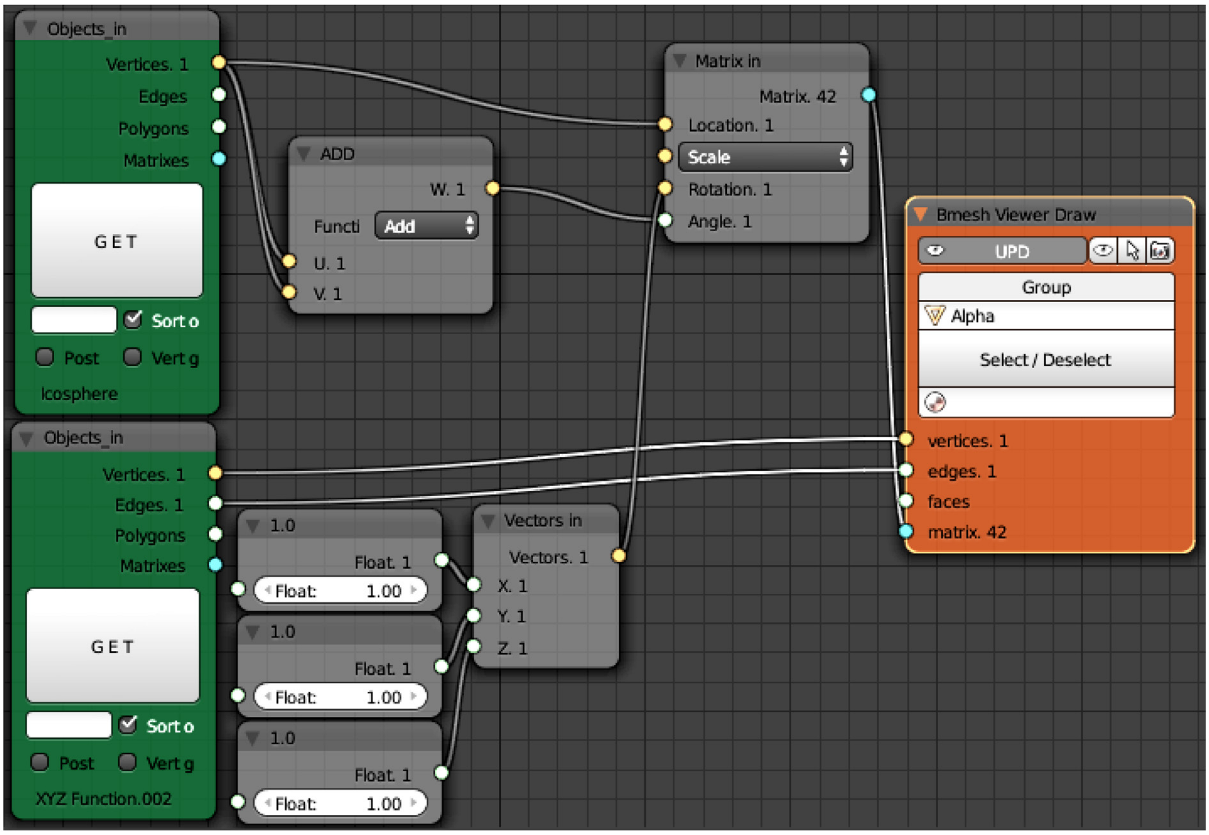

Figure 6. Parametric procedure for generation of the sample 3D model and its print (procedure implemented in Blender (2014) with add-on Sverchok (2014))

4.3 Outcomes

Interaction with the 3D printed concept has a role in generation of new design ideas in terms of the following:

- Discovery of new features, uses, functions, or contexts for the design concept and incorporation into the next idea (for example, for the complex shape in Figure 5, design ideas for “high friction object”, “object that prevents touching”, “object that reflects sound” can be generated; these ideas were not present before interaction with the 3D printed object).
- Complexity of the materialized design idea may further trigger inspiration (for example, changing the initial shape into the complex shape in Figure 5, or modifying the parameters of the procedure in Figure 6 may lead to another design idea).

Particular ideas introduced during the presence of and interaction with the 3D printed object were the ideas of a “high friction object” and “object that reflects sound”, which can be interpreted as new use or function. Consequently, the second of these ideas (“object that reflects sound”) led to a changed shape and a regenerated 3D model, on the basis of Catenoid instead of IcoSphere (Figure 7).

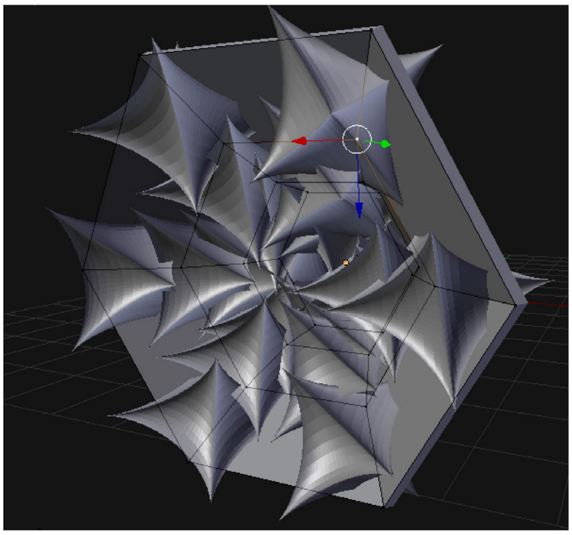

Figure 7. Regenerated 3D model

5 DISCUSSION

5.1 General Discussion

The proposed general method for materializing design ideas and using them for further generation of new original design ideas emphasises the expansion of the concept space and interaction with the 3D printed concept to stimulate the imagination for new idea generation.

In the presented exploratory example, we investigated the potential for enhancement of creative design idea generation using the materialization of creative design. We have not yet conducted an objective evaluation and the provided example is subjective one. Although the example serves a demonstrative purpose for materialization-enhanced new design ideas; it does not identify the underlying factors and particular roles of materialized creative design ideas in creative idea generation.

Humans cannot capture all the characteristics of a modelled product in the virtual world. So far, the role of 3D printing and prototyping has been pointed out as a process that has more than just physical effects (Sass and Oxman, 2006; Kroll and Artzi, 2011), it also affects human feelings for the object from the viewpoint of scale, realistically. Real-world recognition and the act of looking at the product in the physical world are very important points for enhancing designers’ creativity. On the basis of the discovery of new features, uses, functions, or contexts for the design concept and its incorporation into the next idea, we can speculate that interaction with a materialized idea can contribute to the expansion of human feelings evoked by the design and also the enhancement of design creativity.

We assume that in this interaction with materialized ideas, natural human characteristics such as curiosity (e.g. curiosity about shape and its space configuration or about characteristics of the surfaces) and imagination (e.g. perception-triggered cognition and affect with regard to the 3D printed shape) facilitate the discovery of new features, uses, functions, or contexts. The interaction with materialized ideas can enhance creativity through such characteristics. Further expansion can be sought by applying theoretical approaches for shapes' order and complexity – the example uses mathematical equation-based shapes and parametric generation, which allow unrestricted revisions of the idea for the designed shape. These approaches aid creativity, which is in accordance with previous research on creativity and parametric generation (Lee et al., 2015; Oxman 2015).

We expect such a method to be beneficial for enhancement of design creativity using 3D printing. The results will be relevant to the early conceptual stage of design (i.e. generation of design ideas). The expected achievements will be beneficial for enhancing design creativity in educational and practical settings.

5.2 Limitations

There are many limitations of this study. The first limitation is connected to the study's exploratory characteristics in terms of implementation. The second limitation is due to a single preliminary study used to exemplify the proposed method and approach. The final limitation of the approach presented in this paper is that it is an open-ended generative approach for the design of shapes because of which much of the output may not be found to be practical.

5.3 Future Work

Future work will be focused on experimental investigation of the influence of expanded concept space and materialization of creative design ideas into prototype shapes or products on further creative design idea generation. The expansion of the concept space can be evaluated with the method of measuring the distance between nouns used to describe the initial idea and new idea (Taura and Nagai, 2012, pp. 67-69).

Particularly, it will be focused on obtaining data from practical materialization of multiple creative design ideas into prototype shapes or products. An experiment will be designed to use these materialized ideas as stimuli, prior to or during the concept generation stage of consequent ideas. We expect that these stimuli will provide clues on the role of these materialized ideas. General analysis of creativity of ideas and their materialization will be conducted through ratings on originality and practicality of the ideas (based on a method in previous work (Finke et al., 1992)). Further, observation will be made on new feature discovery and how inspiration is triggered.

In this way, we can gain an understanding of what role the materialization of creative design ideas plays in the design process and how this affects designers' work.

6 CONCLUSION

In this paper, we focused on the advantages of 3D printers that can easily produce forms that were previously difficult to make, and use this advantage to enhance physical interactions with the design idea and have a positive impact on design creativity. To understand how materialized creative design ideas can be used for further enhancement of the generated creative design ideas, we proposed a general method consisting of iterative generation, modelling, and materialization steps. In an exploratory example, we investigated generation of design ideas and materialization of creative design ideas for shapes. Interaction with the materialized ideas, and expansion of concept space results in the generation of new features, uses, functions, or contexts of the design idea and these can be reflected into a new idea. This suggests that interaction with materialized idea and expansion of concept space, and further rapid iterations of this cycle, can contribute to the expansion of human feelings evoked by the design. Hence, this method contributes to design creativity.

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