Experimental Research in Applying Generative Design and 3D Printers in User Participating Design

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Abstract. This research applied an open structure of generative design in order to provide parametric sliders for users to adjust a digital model under the designer's plan. Moreover, the design outcome can be printed immediately using 3D printing technology, to experiment with users' preferences and see the effects of generative design in modifying pattern, regular/irregular and detail transformations on a product. Three types of feature modification on i-phone4 case were chosen as simulations by 3 design experts. Five experienced and five young designers were asked to manipulate a digital generative design model as they want. Then 2D rendering images and 3D printed mockups were presented for subjects to compare with their original design. The result demonstrated that experienced and young designers both can recognized their work in 3D print mockups. Experienced designers can use the limited tool to make distinct outcomes for more satisfaction form tan subjects. Young designers expected to obtain 3D printed mockup to help their design decision in design process.

Keywords: Generative design, Design process, Grasshopper.

1 Introduction

As aided tool, s computer and software help designers rapidly verify ideas through 2D or 3D models rapidly. Nowadays minimalism has becomes a representation of Apple's style and the imitation of followers has led products to look the same. Customers tend to focus on accessories to add personality in their product shapes. The trend of 3D printing such as MakerBot's thingiverse(www.makerbot.com) free platform, it has opened a door for users to make almost anything themselves and share their creations with others in open space. Many hardware and software companies in different industries are aware of the trend, from the auto industry's BMW to the mobile industry's Nokia both of whom have announced that they will develop open source component and data for customers to make parts of their own. As a leading software company, Autodesk kept developing free and easy to use 3D software app, the 123D series, on pad devices in order to satisfy non-the demands of users without a design background. This trend could contribute to 3D print and generative design related software support. In the design profession, the rises of cheap 3D printers in recent years have led designers to be able to make design decisions through real models in the early stages of the design process. Furthermore, generative design

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offers the user an excellent pattern design tool. However, has the new developed tool and interface been accepted by designers? Could it fulfill the demands of design job? These are the concerns of this research.

1.1 Background

In a previous study, Cooperative Generative Design Method (CGDM) was proposed. It demonstrated that industrial designers and generative designers working together could help each other focus on what they are good at. An industrial designer could concentrate on shape grammar definition and think about what kind of shape or style they like to add to products. On the other hand, the generative designer's duty is to define the solution space given current conditions, such as electronic and engineering demands, then considering shape grammar to build up digital parametric models on Rhino software as platform and Grasshopper plugin as interface. Then the industrial designer could manipulate sliders or input parameters to control the digital model to acquire the perfect shape that they want. The results got many positive feedbacks. This research is based on it to explore more advanced experiments.

1.2 Purpose

3D printer rapid prototype technique was used in this research to explore the accuracy of representation in 2D rendering pictures and 3D printing models when a designer is dealing with shape thinking and expression. Moreover, patterns on the back surface of handset cover were defined as design details. Computer generated random calculated patterns and human controlled pattern generative models were proposed to test out of computer random calculated shapes or human controlled shapes which one was suitable to represent designers' idea.

2 Related Works

2.1 Mass Customization and User Participation

Mass customization and user participation related researches had achieved a lot in the B2C field by management scholars. Piller, F. and Walcher, D., 2004, used Toolkit software to allow hundreds of customers to participate in choosing watch styles. Users could follow steps to select many kinds of dial plates, indicators, belts, colors, textures and materials. They used quantitative research and statistical methods to prove that target groups would pay more for purchasing their participated results. However, the process was still featured on a computer screen where the groups would select a designed module and combine the parts together. There was still a question whether the final product and screenshot were the same as the customer's imagination while they are using Toolkit. This research invited users to participate in a real design process to discover the users' though process when they were manipulating generative digital models and compared 2D rendering and 3D printing outcomes to know which one is close to users' imagination. The current question in customization is that when users have a chance to choose their own design does the meaning and story of the design though process from designer remain?

2.2 CGRM

Dav, Singh V. and Gu, N. 2012, compared Cellular automata, Genetic algorithms, Shape grammars, Lindenmayer systems and Swarm intelligence through background technique, design point of view and system constructive factors. They proposed an integrated generative design structure, according to Dav, Singh V., because conceptual demands are different in varied design situations, from up to down or from down to up, a flexible generative technique can be used to get better results. The point of view is similar to this research.

Hsiao S.W., 2010, Hsiao, K.A. and Chen, L.L., 2006, Chen, K.S. 2006, Lin, M.H, 2003, inspected shape structure through genetic algorithm, components, morphing and Kansei engineering individually. Their stimulations are rough 2D or 3D components database. Subjects could not adjust details as real as design jobs. However, generative design tools offered designers a chance to check shape changes directly. It made research and experiments closer to real design situations. This research proposed an agent-based model that generative designer following design experts' shape grammar to build up generative digital models for industrial designers to manipulate. Currently, CGDM is more suitable for applying in shape refine processes for routine design job. For concept extend process of non-routine design jobs, CGDM process needs to be reorganized and test.

2.3 3D Printer

3D printing is not new technique, there were some scholars and engineers devoted to computer-aided manufacturing who used digital models to produce real objects directly while computer aided design was still in its early stage. Consequently, the rapid prototype technique has been developing to this today, many companies developed their own material and methods to produce things, such as Stereolithography apparatus (SLA), Selective laser sintering (SLS), Fused deposition modeling (FDM) and so on. Most of the technique patents were held by companies. Yan. X. and Gu. P. 1996, indicated that in early stages 3D printers meant those machines which contain special powders and nozzles that went through slice paths layer by layer from digital models to eject special glue for bounding to become object. Due to expensive components and patents of materials, only few large companies and specific industries such as the automotive and toy industries were able to afford RP equipment. In recent years, FDM technique patents have expired, moreover, open source has incited users to make a machine themselves through internet opened components lists to reduce the cost. 3D printing has become a symbol to realize the dream of ordinary family.

3 Case Study-CGDM for iPhone4 Cover

This research executed two experiments by applying Grasshopper to construct two kinds of generative digital models in different iPhone4 cover shape for subjects who could adjust the parameters according to their preference. In order to analyze the feedback differences between individual subjects individually, while they were adjusting the structural and irregular texture details and comparing 2D rendering and 3D print results. Further, the aesthetic feel of random computer generated design and human manipulation between the different groups of subjects were discovered through experiments.

3.1 iPhone4 Cover Shape Grammar

This research invited three design experts with 10 years of experience each to participate. They discussed the design process of the main body and detail refinement and chose the iPhone cover as a suitable example to conduct the experiment. The shape grammar and solution space of the iPhone cover which drives the generative model to assemble with iPhone were defined at the same time. After that, the generative designer followed the definitions to construct generative digital models and leave wide range parameters to control shapes. The generative models then were delivered to design experts to setup appropriate parameters and restraint.

The iPhone shape continued Apple's style of taking a rounded square as its basic feature. Design experts all agreed that parametric adjustments of width, length and corner radius are fundamental in main body control. Then other conditions were added such as raised or indented (convex or concave) curves, symmetry or asymmetry. After three design experts manipulated the generative digital model, back surface adjustments were added in. As a result three generative digital models can be described as:

a. Main body structure-
   1. Three parameters controlling width, length and depth
   2. Three parameters became a group to control upper curves for adjusting raised/indent, symmetry/asymmetry, the other three parameters are the same, controlling the curve on the right side.
   3. The curvature of the corner was manipulated by 2 parameters.
   4. The back surface was constructed using three curves: left, middle and right curve. Each curve contained three parameters to adjust the height of the upper, middle and lower point of the curve.

b. Random pattern details
   1. Hollow patterns were constructed by vonoroi function in Grasshopper.
   2. The number (1-30) of holes could be adjusted by parametric slider.
   3. The shapes of holes are randomly calculated by computer algorithm.
   4. The width and thickness of the wire frame could be adjusted while the shape and numbers of holes are changed.
   5. The radius of the hole corner can be controlled by parametric slider.

c. Human controlled patterns-
   1. Users can set up the number (1-30) and position of points as they want.
   2. The coverage of holes can be controlled by parametric slider.
   3. The width and thickness of the wire frame can be adjusted while shape and numbers of holes are changed.
   4. The degree of hole curve can be adjusted by parametric slider.

3.2 Solution Space Definition

This research separated the iPhone cover features into main body and details. The iPhone handset had to be fit into the cover seamlessly and generative models must be able to be used by an iPhone4 and iPhone5. The situation is similar with the inside-out design in the previous CGDM study. Therefore, the iPhone handset digital model was first build up as reverse engineering process. Then following with shape grammar, (See 3.1), the generative designer built up a generative model which width, length and corner radius could be adjusted by parametric sliders. After that, 3D digital models were translated to a 3D printer to produce a real model for ensuring that the virtual models' size was real. (See Figure 01-03)

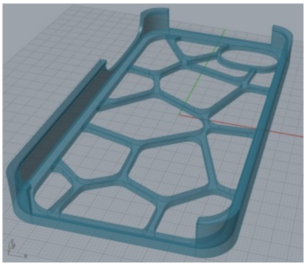


Fig. 1.

Fig. 2.

Fig. 3.

2D digital model and 3D Printed mockup for i-phone case

3.3 CGDM Example Modeling

According to the definitions shape grammar from design experts (see 3.1), the generative designer built up the iPhone cover digital model which was controlled by three groups of parametric sliders, upper length, right width and corner round. (See Figure 04) L and W sliders controlled the total length and width. L1, L2 and L3 sliders decided the shape of the left, middle and right at top of the cover. The same as W1, W2 and W3, the right side shape was controlled by these 3 sliders. R1 and R2 controlled the shape of the corner. The top and bottom, right and left shapes were symmetry in this case. Because Grasshopper is Rhino plugin sliders cannot be shown on digital models directly. All parametric sliders were placed on their relative position for users to understand the location of the shape they were adjusting.

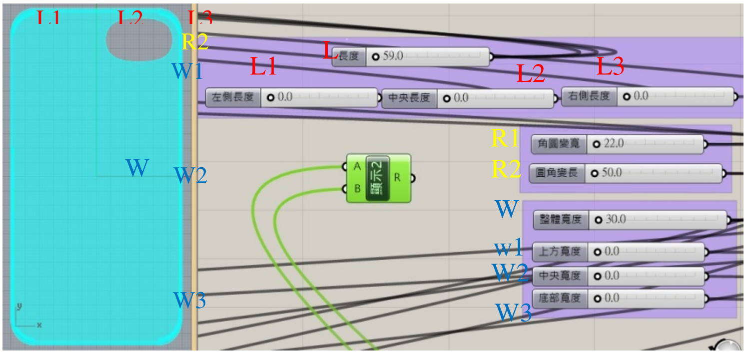


Fig. 4. Interface of i-phone case digital generative model

The back surface shape was structured using 3 curves through 9 points. (See Figure 05). Adjusting La, Lb, Lc, Ma, Mb, Mc and Ra, Rb, Rc sliders the height of the left, middle and right curves on the back surface would be changed. They also had been placed in relative position.

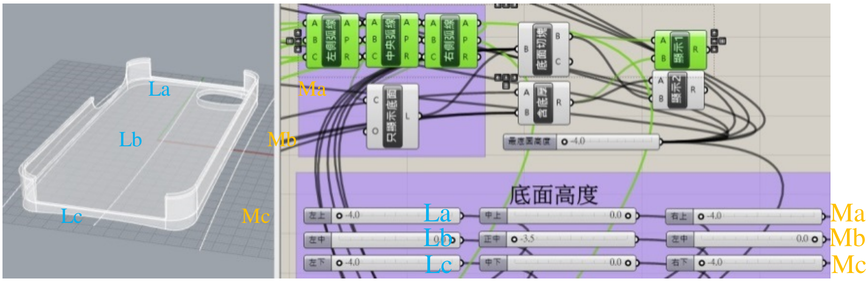
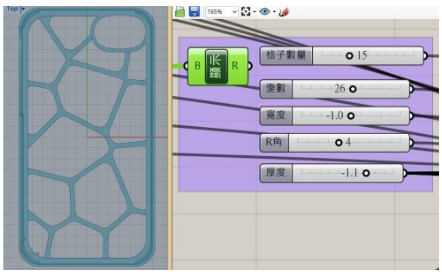


Fig. 5. Back surface interface of CGDM digital model



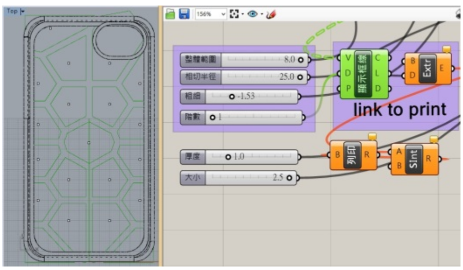


Fig. 6. Details adjusted details UI

Fig. 7. Human controlled details UI

Details adjustments were controlled by two kinds of generative models. The first model was the random parametric inputs model. (See Figure 06). Users could decide the number of holes, the width and thickness of the wire frame, then drag the slider to adjust the random number to choose a shape they want. The other human controlled model required users to move, add or delete points in Rhino. (See pic.07). Then effect range of voronoi, width and thickness of wire frame had to be decided. In these cases, the numbers of parametric sliders were limited in five to six for observing subjects' thinking process easily.

3.4 Stimulus

Three digital models were provided: model A could adjust mail body shape variation for subjects to become familiar with the operation method. Three to five parametric sliders as a group were provided with the procedure in three views to vary the ratio of length, width and thickness, also straight line or curve in the restrained area. Model B1 could select pattern shapes from random computer calculations, using five parametric sliders to choose the numbers of patterns, random shape types, wire frame width and thickness and radius of pattern corners. Model B2 required subjects to add, delete or move points in Rhino program in order to decide the numbers of patterns and its location by human control, then a Grasshopper generated pattern would surfaces immediately.

3.5 Equipment

Software-Rhino was used as a platform, Grasshopper was the operation interface. The operation processes were arranged with three views and the number of parametric sliders was limited to five in each view to decrease the complexity of the operation. Furthermore, Camtasia Studio was used as screen record tool.

Hardware- An Notebook computer was used as the Grasshopper operation interface and another 15-inch monitor was used as extend screen showing Rhino model. While the experiment was executed Camtasia program and camera ran at the same time to record the subjects' actions. After all experiments had been done, the outcomes results were printed by both 2D and 3D printers under the same condition, then the results were compared.

3.6 Subjects

Five forth-year design students with basic Rhino training (two males and three females, age 20-22) and five designer with more than five years of experience (three males and two females, age 33-38) were invited. iPhone4 users were preferred but not the required, in order to realize how the feedback difference between computer simulation and real object effect design decision. Moreover, through questionnaires and interviews this research explored the recognition and acceptance between random computer generated and human manipulated shapes, also offering suggestions for further studies.

3.7 Experiment Process

First demonstrated the mission, explained the interface and model construction theorem for five minutes, then the subjects based on three provided digital prototype adjusted main body variation and two different details for iPhone covers in ten minutes. In that period, subjects could suspend the time to ask questions anytime, then after explanation, the experiment continued. If the experiment duration were over or less than 10 minutes, the experiment kept going until the subject was satisfied with the outcome then the time was recorded. An interview was held for 10-15 minutes after the end or the experiment. After all 10 subjects finished the experiments, the 2D and 3D rendering was printed out by KeyShot and RealFun3D printers respectively under same conditions. After one week, thirty rendered pictures and real models were provided separately to the 10 subjects, they were asked to choose the one they liked and find out their own design. Also the differences among shape imagination, 2D simulation and physical product in design process were discussed.

4 Results

The two groups both agreed the main body generative model could easily help check rough shapes, and the interface was quite easy to understand. Comparing the 2D rendered and 3D printed outcomes, the two groups both admitted that the real model could help to make design decision accurately in the concept stage if it was provided earlier. Some design students expressed that the 2D render plus the 3D print was enough to demonstrate and check their ideas. If they could have their real design models immediately after the experiment, they might change their design again. Most experienced designers understood that concept idea, 2D rendered picture and 3D printed model have gaps because their purposes are different. Although the source digital model of 2D render and 3D print was the same, they usually spent more time in materials, lighting, reflection …etc. effects to make the pictures "overly realistic" on purpose. They treated it as a kind of advertisement to attract the clients' eyeball.

Comparing the two groups of more than five years experienced designers and four years design training students, the design though process and difference in purpose made the outcomes totally different, although the generative model had restrained the shape variation in a limited solution space. Experienced designers tend to think about how to manipulate the digital model to create the shape they want, even though sometimes the system revealed unexpected shapes. Most of the subjects tried the unexpected shape and checked the outcome then went back to their original ideas. Furthermore, many experienced designers submitted demands to add more parameters in order to make the shape have different shape grammar. It demonstrated that if industrial designers were involved in the early shape grammar stage, this system would be extended in a large scale containing varied kinds of shape styles.

4.1 Generative Model Experiments Results

The average main body generative model adjustment time of the five experienced designers was eight minutes and thirty seconds, the five design students' average time was six minutes and thirty seconds. All subjects manipulated parametric sliders from the top view to check the shape then went to perspective view to confirm details.

In the random computer pattern generative model experiment, the designers and design students spent seven minutes and thirty seconds, and eight minutes and five seconds in average time on adjusting models respectively. Many designers focused on hiding the camera wire frame or assimilating it with patterns. On the other hand, most design students focused on the aesthetic of the pattern to adjust the shape and size of holes. In the human controlled pattern experiment, the average operational time of the designers were six minutes and ten seconds, the students was thirty minutes five seconds. All the designers spent most of their time on moving, adding or deleting points to confirm the direction of the shape. Most of them chose to deviate from the original shape. However, the students tended to spent more time on shape details, sometimes they restarted again because they were unsatisfied the outcome.

The two groups both expressed that the interface was easy to use and suitable for basic shape variations during interviews after the experiments. There were subjects in both groups that suggested adding more parametric sliders to change shape grammar because it was difficult to produce regular geometry shape in current generative model. Moreover, the cover shape grammar became three or five points grabbed the handset, or some irregular blocks extruded out of the cover.

4.2 2D Rendering Interview Results

Because the back surface possessed features of the main body and was difficult to be displayed on picture, the front view and other different perspective rendering were printed to assist the interview. All designers recognized their own design, however, there were two students' whose results looked similar. Figure 8 and 9, both from the designer group, displayed the most popular curve surface main body shape. They both got 5 votes in ten subjects. Figure 10, from the student group, was the best of the random computer generated design. Figure 11, from the designer group, shows the favorite human controlled generative model of ten subjects. Subjects indicated that comparing the aesthetic of texture shapes or the propotion, a specific shape from random variations of handset covers could be recognized easily.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

Most popular main body shapes

Most popular rendom design from students and human controled design from designer

4.3 3D Print Interview Results

Figure 12 displays some results from 3D printer. Figure 13 shows the front and back of the favorite iPhone covers, all from the group of designer, produced by three generative models. All subjects could recognize their own design immediately from 3D printed models. And they confessed that the back curve surface and two side curves made the main body model looked outstanding and easy to hold. That was the reason they chose it. On the other hand, the back surface thickness and the special circle texture made those two get more votes from the irregular pattern generative models.

Fig. 12. 3D printed results

Fig. 13. Favorite iPhone covers

5 Discussions and Suggestions

This research utilized practical methods to explore generative design combined with 3D print techniques for applying it to specific shape details of product design operative process. It compared the design decision difference from simulated and real design representation tools between different levels of designers. The results demonstrated that current interface and function of submitted generative models are suitable for basic design shape variations. If there were appropriate platform or data transfer methods the experiment could be executed by ordinary users. As a touchstone, this research did evoke the designers' interest in shape grammar and proposed more demands on shape variations. Although the design students did not reveal requirement of shape grammar, they expressed that combining 2D rendered pictures and 3D print models could help to present ideas accurately and efficiently, even though the 3D print model quality was poor. Moreover, 3D print models rapidly fixed the gap between imagined shapes and 2D renderings to young designers. It helped them deal with uncertain shape details to make design decisions before they waste time and money in CNC procedure to produce the final model.

Different level of designers revealed different idea in to applying 2D rendering and 3D printing. Design students believed rapid real model could help with idea presentation and confirmation of rough concepts. Though designers were interested in 3D printing and had the urge to buy their own design produced by a3D printer, a designer manager expressed that the generative design application and process this research proposed could be applied inside design departments to reach agreements rapidly. However, if an unfinished concept was produced using rough 3D printing and handed to non-design departments it might cause misunderstanding and disturb the design direction.

This research combined the advantages of 3D print and CGDM, with the help of generative designer, industrial designer could focus on the meanings and variations of shapes then demonstrate the idea and usability. However, the platform is currently limited to specific professional programs. Users must learn Rhino manipulation first, it would be even better if designers could understand Grasshopper programming principles. It would help in working with generative designer seamlessly. Also, generative designers must communicate with industrial designer frequently during the CGDM process in order to understand the real and potential demands.

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