NordDesign 2018
August 14 – 17, 2018
Linköping, Sweden

3D-printing as a Creative Modelling and Prototyping Tool

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Abstract

3D-printing offers possibilities to quickly and cheaply play with different body shapes, material texture, and the functions of objects as well as to test, compare and judge which of the different iterations to settle on or to combine as a final solution. In the development of new tangible (hardware) products, creative modelling can also be used to obtain retailer, user and customer opinions of new product concepts. To experience using 3D-printing as a modelling tool, we made a strict copy of simple plate product from which we could "play" with different creative solutions.

We found that realizing extended product functionality that gradually emerged in the creative process had been (extremely) expensive and long-lasting using classical modelling and prototyping methods because complicated tools had had to be manufactured and changed before each test iteration. Using 3D-printing, it was easy to make changes, and new ideas could easily be tested, which increased not only the functionality but also other product values.

Keywords: 3D-printing. ideation, modelling, product values, prototyping, testing

1 Introduction

This paper shares some experiences gained from a new product development (NPD) work carried out for which 3D-printing was used as a creative modelling and prototyping tool. The mission was to exchange a simple metal plate cover of a safety belt buckle with a plastic cover that had more functionality and that possibly could be produced with Additive manufacturing or with traditional plastic forming production methods.

Before the work started, the problem was to find a simple product to improve. However, the author had contacts with the Swedish company Careva AB that is acting in the welfare technology sector. One product line of the company is positioning belts. These belts keep disabled passengers in vehicles and wheel chairs in an upright sitting position (see Figure 1). Without the positioning belts, the function of the safety belts in vehicles is poor and dangerous traffic situations can occur. In addition, a problem with the positioning belts is that children can open the locks when being transported. Therefore, the company sells a black-painted metal cover that is pushed over the locks preventing such unwanted unlocking.

Figure 1. An example of positioning belts for disabled passengers in vehicles and wheelchairs (from www.careva.se)

When the metal cover is pushed over the belt locking, the lock can be opened by pushing, for example, a ballpoint pen through the ø5 mm hole that is situated over the pushdown release button (see Figure 2). The hole is small enough to prevent even small fingers to release the release button. The metal cover is heavy and is a rather rough solution, lacking, for example,. a klick sound when the cover is in the right position over the lock. Therefore, the author decided to study the process of developing a new "better" cover using 3D-printing as a mediating tool.

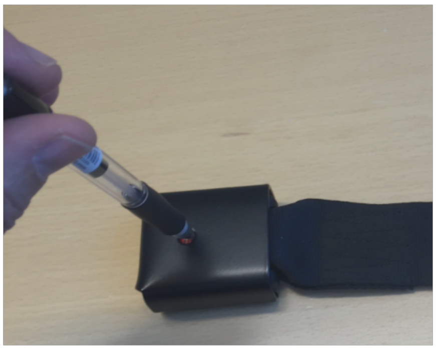

Figure 2: Through the hole in the cover is an opening device – here a ballpoint pen is used to unlock the belt

The initial part of the work was earlier reported as a conference report (Ottosson & Skogsrød 2016).

2 Research Method used

The author acted as project leader and used common Action Research principles (Ottosson 2003) for the scientific part of the work.

3 Definitions

To find and produce new solutions, *creativity* and *improvisation* are needed by the people doing the development work. These two terms can be defined as follows.

> "*Creativity* means shakings things up, both inside ourselves and in the world around us, and constant re-organizing of both cognitive schemata and, to a greater or lesser extent, the domain of the creative person's activity." (Montuori 2003)

> *"Improvisation* is thought of as making the best of things, while awaiting a return to the way things should be done. Improvisation is an exception, something we can 'fall back on' when things don't go the way they should." (Montuori 2003)

In the development of new tangible (hardware) products, creative modelling can be used in the chain from the *ideation* (idea generation) to the testing of user and customer opinions of new product concepts. Practically seen, *creative modelling* means iteratively making and testing models and prototypes so that the end result can be new sustainable innovations that meet a large number of product values.

There are many definitions of the terms "models" and "prototypes". In this paper, a *model* will be a formed solid object that demonstrates the function and/or the shape of the product. The model can also be a part of a product concept used in the further development of a new product. When a model exists, a prototype can be developed, which means to develop a production ready solution is developed. The definition of a *prototype* is "an approximation of the product along one or more dimensions of interest. (Ulrich & Eppinger 2016)". In this study, the development work to make a model is called modelling and the development of a prototype is called prototyping.

Models are important visualization tools for the developers, as well as for managers, users, and customers. When one is able to touch a model, one gets a firmer mental picture to work from than if only a picture or digital mock-ups exist. Thus, models help to provide a better understanding of the priorities and help us to avoid mistakes and misunderstandings.

It is sometimes recommended that the modelling should be simple and rough. The strength of rough modelling with simple materials is that it encourages playing with ideas (Ottosson 2009). Simple materials, such as clay, paper, or wood, ,are quick and easy to change, which is why they preferably should be used before using harder materials. "When a model starts to harden up, so also does the thinking." (Schrage 2000, p 79). Note that modelling with "mock-ups", used in the shaping of new products, do not generally demonstrate the function of the products. Another effect of modelling and prototyping is that both tacit and explicit knowledge is used on an individual and on a collective basis. "Using prototypes and prototyping may hold a monumental potential to better capture and transfer knowledge in product development, thus leveraging existing integration events in engineering as a basis for knowledge transformation" (Erichsen et al 2016).

Although the development work can be based on continuous improvements of an existing product, which is called Lean product development, sometimes – if the developers are creative and can improvise – radical new solutions can occur, providing a possible foundation for radical innovations.

4 Development theory

There are many product development methods to choose from when a New Product Development (NPD) project is to start. As a study of between seven development methods showed that the Dynamic Product Development (DPD™) method was the most versatile method (Vajna & Kittel 2009) and as the author has worked a great deal with that method, DPD™ was used in the development work treated here. It is too far reaching to here go into details of that method (see, for example, Ottosson 2009). However DPD™ states that different product values have to be considered during the development and that the use of Brain Aided

Design (BAD), Pencil Aided Design (PAD), and Model Aided Design (MAD) before doing Benchmarking and Computer Aided Design (CAD) often leads to faster, more creative and useful results.

4.1 Product values

In the classical industrial era of product development and engineering design, almost all efforts have been concentrated on taking care of functional values at Product Development (Ottosson 2016). The DPD™ method proposes that other soft values of mindful content should also be taken into account if new products are to become successful innovations. Seen from a user's point of view, a product can have at least six important values, which can overlap each other (Ottosson 2009).

- *Functional values* are dependent on the technical solutions mostly hidden inside the product. The function can be as simple as just filling in the space (e.g., gas in a balloon or concrete in walls). It can also be advanced with all degrees between simple and advanced, e.g., an engine in a car has simple as well as advanced parts and systems.
- *Existential values* are values that are experienced in extreme environments, such as intensive care units and remand prisons (Torkilsby 2014). The wellbeing in such environments is dependent on the design of the environments.
- *Perceptory/sensorial values* are based on what we experience with our five classic senses (see/hear/taste/touch/smell) from outside and/or in contact with a product. The product semantics is an important part of these values.
- *Image values* are based on the image we get of the product and what we think of it when, for example, closing our eyes. Brand names, patents, the image given on web pages, stories and the expressed experiences of the product by other users, will influence and develop the image we have of a product. The product semantics can influence these values.
- *Emotional values* are the passion/feelings we have for a product. The product semantics can also influence these values.
- *Sustainability values* are a longlasting environmental responsible values for the users, society, and the providers (the business).

Usability is important for achieving good functional values. According to ISO (1998), usability is "the effectiveness, efficiency and satisfaction with which specific users can achieve specified/particular goals in particular environments". On a deeper level, these three terms have the following meanings.

- *Effectiveness:* Is the product considered effective for reaching the goal? Is it possible to implement the findings in real user environments? What is required to make that happen (e.g., education needs, training needs, expert needs, tools acquisition, or organizational change)?
- *Efficiency:* Is the product considered efficient to use? Is it tricky to use? Is it time - resource intensive?
- *Satisfaction:* Will the users find the use of the product more pleasant to use than what they experienced before the implementation? Will the users feel that the outcome is more efficient? Will the use of the new product contribute to a better economical result for the individual or will it reduce failure risks in any aspect?

Another aspect of usability of a product is that it should contribute to a "barrier free world" for different types of (disabled) users. That is called Universal Design (UD), for which seven principles have been proposed (Story et al 2001).

- Equitable Use
- Flexibility in Use
- Simple and Intuitive
- Perceptible Information
- Tolerance for Error
- Low Physical Effort
- Size and Space for Approach and Use

In addition we also can add two more UD principles (Ottosson 2018).

- Comfort in Use – from comfort to discomfort to pain

Joy/pleasure in Use

4.2 BAD, PAD, MAD, CAD

To find a functional design taking into consideration the different usability aspects, the systematics of BAD, PAD, MAD, and CAD has shown to be fruitful in practical work (Ottosson 2009), supported by the use of creativity and improvisation in every new ideation step. Brain Aided Design (BAD) means thinking of different abstract solutions. Pencil Aided Design (PAD) means sketching with an ordinary pen. MAD means making a model. Figure 3 explains the abbreviations as well as indicating that the recommendation to start the work at an abstract and wholeness level and ending up at a detailed and concrete level. Which order the different activities are done is dependent upon what products are to be developed, the newness wanted, and the time limits.

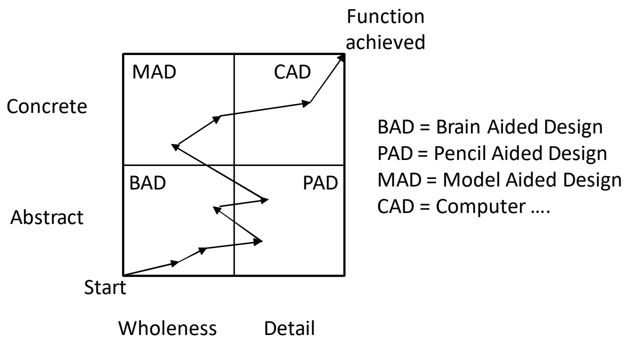

Figure 3: To find a functional solution combination of BAD-PAD-MAD-CAD can be used (Ottosson 2009)

5 From idea to model and prototype

The start of the development work was to make a CAD design that closely related to the metal cover. Then we modelled it to be suited for 3D-pringing in our university machine, which is an EOS P395 machine. (The powder used was PA2200 and the belt buckle was driven by a standard EOS balance parameter.)

Therefore, the first 3D-printed model in our NPD project was a strict copy of the functional metal cover (see Picture 2 in Figure 4). The first creative idea that came to mind was that the product name, protruding 0,5 mm, could be done so that it would add to the image value of the product and company (see Picture 3 with a painted upper surface in Figure 4). Also, the shape of it could be done to closely resemble the lock itself, which would increase the sensorial and image values (see Picture 4 in Figure 4). Picture 5 in Figure 4 is a small change in the shape of the cover to get it look better. With that change, the original design in Picture 1 had been left behind. The next step was to move the hole (Picture 6 in Figure 4) as we realized that by doing so, the release power could be lowered, providing a functional improvement. To lessen the environmental impact and make it a sustainable solution, we shortened the length of the cover (see Picture 7 in Figure 4).

Figure 4: The development chain from the original metal lock to a functional prototype

Then, as a creative idea, we added a thin line protruding 0,2 mm under the lock to ensure that the cover did not unintentionally slide off the locking (see Figure 5). That solution gave an unintended clicking sound indicating that the cover fitted correctly when pushed over the lock. In product value terms, this meant an additional functional as well as the sensorial value to the product.

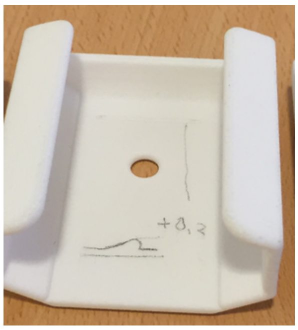

Figure 5: The first idea to add a clicking and holding line under the cover

To change the holding force and to get a higher clicking sound, our tests showed that the line had to protrude 0,5 mm to achieve the desired requirements on the clicking sound and ensuring that the cover did not fall off when the lock was shaken.

One negative effect of using the cover is that children may feel imprisoned or claustrophobic, which can be a problem for the existential design to overcome (Torskildsby 2014). However, in January 2016, when we were planning a lecture in product development, the design professor Kari Øverseth at NTNU in Gjøvik got an impulse to make a quick sketch showing that the cover could be made into a “cat shape” to please children (see left Figure 6). Therefore, we sketched the idea on the cover (see right Figure 6) for the CAD work to be done before we could make next model.

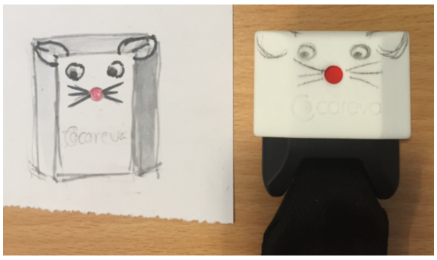

Figure 6: The left sketch was transformed to instructions on how to realize the idea in reality

The addition of the cat on the cover has no functional value, but it can be used in a positive way to take away claustrophobic feelings for small children. For example, parents can say that they will ask the cat if it is OK to lock or release the child. It is worthy of note that the short, functional cover in Figure 6 did not give a pleasant aesthetic look, although the shorter cover meant a more sustainable solution as 35% less material was used. We therefore went back to the original length of the cover. Figure 7 shows the result and how we thought it feasible to let the parents paint the cat with a color they preferred in a simple way.

Figure 7: The end result of the development experiment showing the PAD-draft, the 3D printing outcome and the result after a marker pen had been used to fill in the “ditches”

However, the company (www.careva.se) did not want to prioritize small children with the product shown in Figure 7. The reason was that the most primary users for them are youngsters and adults, for which the product should be as "invisible" as possible. This is why they now expressed that they wanted the product to be black with a soft surface, much like the powder-painted black metal cover in Picture 1 in Figure 4. If possible, they wanted the product to be shown at the Reha Care Fair in Düsseldorf, Germany, in August 2016.

As there was no known firm in Norway that could make black smooth 3D-printings, we asked the Swereco experts in Göteborg (www.swereco.se) for suggestions of serious companies in the field and received a list of contacts in Sweden and Poland. A Swedish company gave us the best impression from their homepage and contacts over telephone. They claimed they could not make black covers, but suggested SLS (Selective Laser Sintering) details in polyamide. In an email from them, they suggested black dyed products, which "are basically white, but dyed black. The staining penetrates a small piece of the material and is more durable than lacquer." They did not want to make a test piece free of charge, but Careva ordered ten pieces on 10 October.

After they had received the order, they sent a message by email stating that "your file must be adjusted so the "Careva" logo will be at least 0.6 mm thick." That sounded a bit strange, as we had had no problem with that in the printing with our university machine. However, we changed the CAD file and they printed, dyed the products black, and delivered them on 27 October 2016 (see Figure 8). However, the result was disappointing with regard to the surface structure. (The machine they used was an EOS P760 and the material used was PA2200.)

Figure 8: The product with a painted C. The surface is like an orange and frosted, which is difficult to see from the photos

When we complained about the color and surface finish, we got an email message on 28 October: "If it is a smooth finish you are after, we would have to putty and polish more, and then I do not think this method would be profitable. Vacuum casting would be a better option as you can get black material from the start." They also told us that they do this type of production.

We had come to a dead end and did not know how to proceed if we did not accept vacuum forming of the products, which would mean that we had capitulated, so the project was put on hold.

On the 8 November 2016 the author attended the weekly meeting of the Öckeröarna Rotary Club, at which a representative of Magicfirm Europe told about their 3D-printing development. He sent around some difficult-to-produce samples of a toy train engine and told us that the company was working on mixing different colors. The smoothness of the surface was considerably better than what we had gotten in Norway and from the Swedish firm. He promised to make a sample free of charge, which arrived on 30 November 2016 (Figure 9).

Figure 9: The first sample from Magicfirm Europe, printed in their machine ZYYX+ 3D Printer

The hole on the sample was not perfect and the surface inside it was not as good as on the outside. We queried this and received their answer on 9 December 2016: "we believe we can improve the surface quality, but we think we would need to make some slight modifications to the model in order to do so. Our machines are capable of printing in multiple colors, and more information on this process can be found at: www.zyyx3Dprinter.com/print-unlimited-colors-and-unlimited-materials-with-your-zyyx-3D-printer/". To do that, they asked for quite a large sum of money without giving any guarantees that the surface demands could be met.

Based on the negative experiences from our struggling to get an Additive Manufacturing solution, Careva decided it was too risky to continue the project and thought the investment in plastic tooling had to be pushed on the future, although the prototype in Picture 7 in Figure 4 and in Figure 5 showed pleasant product values except from the surface smoothness.

6 Discussion

The use of 3D-printing made it possible to satisfy all the product values mentioned in the theory part of the paper, the ISO (1998) demands, the usability demands, and the 7+2 UD-principles. Thus, all the product demands in the Definition section were satisfied in the development of this product.

The development of the new product model was based on an existing solution, which is why BAD-PAD was only used in a limited way. Figure 10 shows the sequences used. That a functional solution existed from the start contributed to the appearance of the so called anchoring (or focalism) effect and delayed the development in the form of more steps that needed to be taken.

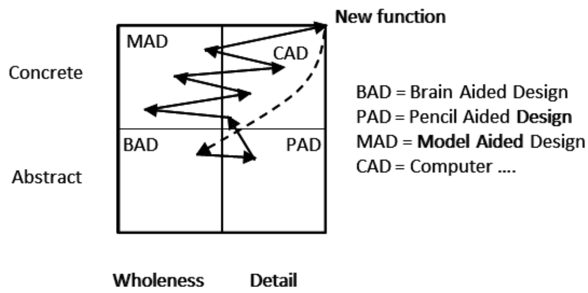

Figure 10: How the design activities were done in the test example

In this case, the creativity was felt to be higher than what could possibly have been the case if 3D-printing had not been used. The main reason for this conclusion is that there were few – if any - limitations as how the product could be designed in terms of interior and exterior shape. Another reason was the easiness in testing new ideas that evolved when each new model had been produced.

The functionality that gradually emerged in the creative process had been (extremely) expensive and long-lasting to realize with classical prototyping methods as in that case, complicated tools had had to be manufactured and changed before each testing iteration.

Using our method, it was easy to make changes, and new ideas could easily be tested, which increased not only the functional but also the other product values.

The surface roughness is at a level that makes Additive Manufacturing not useful for the production of this product. Going to other production machines would require new tests and the functional values might change. Another limitation is that it is not easy to get different colors other than white or grey. Painting did not give an acceptable result in terms of wear, and coloring using chemical bath procedures is questionable from a sustainability point of view. However, if white or grey colors can be accepted, this product demands less material than when it is produced in other ways, which influences the environmental aspect from the cradle to the grave of the product.

In our case, it turned out to be more problematic to go from the 3D-printed prototype to Additive Manufacturing than anticipated, because the production machine could not make the thin lines made by the prototyping machine. Redesign had to be done to meet that demand. The surface roughness meant that the product did not meet the specifications.

One effect of the problems with the transfer from the prototype machine to the production machine was that time to market (TTM) was delayed. Frustration could have been avoided and time could have been gained if we had found out about the surface qualities and minimum line-widths of different production machines in the development stage of the prototype. We had received plate samples with good surface quality and in different colors. We regarded these as samples from the machine, when, in reality, they must have been mass-produced samples, most probably from a plastic granule provider. This can be seen as a miscommunication between us and the provider. A visit with the producer could have revealed this.

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7 Conclusions

From this project, we have learned that modelling and prototyping with 3D-printing is beneficial when many functions are to be fulfilled in NPD. Thus, as a creative modelling and prototyping tool, 3D-printing showed in this case to give useful results and also to give unforeseen positive effects such as the clicking sound.

We have also learned that going from prototype to production was much more difficult than anticipated causing, in the end a dead end, in the project. Because false information from the producer, time to market (TTM) was severely delayed and eventually infinitely long and as the firm lost confidence, that market feedback could not be gained. The earnings disappeared when the whole market introduction was eventually stopped.

It is clear that for similar cases, it is important to find out early about the machine data of different production machines and to visit the company or companies to verify that they can, in fact, deliver the required products.

The 3D-printed covers could have been used to get dealer, user and customer feed-back. However, for an eventual production, the surface roughness is not good enough, which is why other plastic manufacturing methods have to be considered.

The DPD™ method was shown to be useful, but the BAD-PAD-MAD-CAD model needs an adjustment when modelling is based on an existing solution.

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