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Some Experiences from Using 3D-printing in the Modelling of a New Product

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Abstract

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 to iteratively make and test models – and prototypes - so that the result in the end can be new sustainable innovations that meet a large number of product values. For the development of new complicated and/or complex products, 3D-printing or Additive Manufacturing offer especially useful modelling alternatives.

To test modelling with 3D-printing, this paper describes the development of a welfare product for disabled children. The test contained ideation in different loops until a ready product fulfilling different product values was reached.

Some conclusions are that, in this case, the creativity was boosted by the 3D-realization possibilities as there were few limitations in how the product could be designed to meet different demands. The functionality that gradually emerged had been (extremely) expensive and long-lasting to realize with classical prototyping methods as complicated tools in that case had had to be manufactured. With 3D-printing it was easy to make changes for the printing of new models, meaning easiness to change the CAD-model for new 3D-printings. Many iterations meant that a more complete end result was reached. As the surface roughness is not regarded to be good enough for this product, another production method must be used if the product is to be produced and sold.

Keywords: Additive Manufacturing, Modelling, New Product Development, Product Demands, 3D-Printing, User demands

1 Introduction

A Swedish company Careva AB 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 will be poor and dangerous traffic situations may occur. However, one 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 un-lockings. The product functions well, but in principle that is the only good thing that can be said about it.

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 e.g. a ball-pen through the ø5 mm hole that is situated over the pushdown release button (see figure 2).

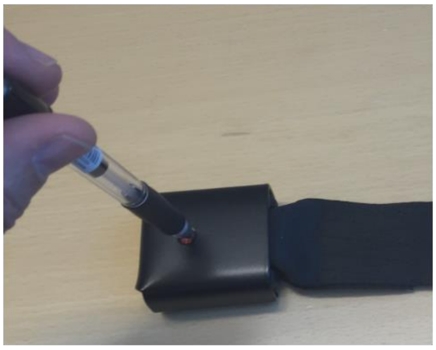

Figure 2: Through the hole in the cover an opening device – here a ball pen – is used to unlock the belt

As the metal cover is not a perfect solution, there was an opportunity to try make a better one, which would satisfy more product demands. That opportunity was used to find out what benefits and disadvantages there could be in making a new complete solution based on creative modelling using 3D-printing as a modelling tool.

2 Research

The development was done as a low cost Participating Action Research (Ottosson 2003) project. Then, based on the experiences from the work, three research questions were formulated:

RQ 1: To what degree can creative thinking be boosted using 3D-printing as a realization vessel compared to when traditional methods are used?

RQ 2: Can different product values be better taken care of using 3D-printing in the modelling process compared to when traditional methods are used?

RQ 3: What kind of limitations would it be going from a functional 3D-printed model to a sustainable innovation impose?

3 Product development fundamentals

Traditionally, product development was, and still often is, seen as an activity to give businesses sustainable profits for a long period of time. Therefore the design work was focused mainly on the manufacturing and assembly of new products. Then, in the middle of the 1990's, User Centred Design and Design for Usability began to be seen as the most important missions for product developers. The reason was that without satisfied users there will be no sustainable business. From about 2005 also Design for Environment and Sustainable Design have also been added as important aspects of product development, the reason being that unless the society demands for sustainable (green) products are satisfied there will be no sustainable business. Thus, today, successful product development must satisfy demands from users, society and business.

The project leader of a new product development process and the product development team will strongly influence the environmental impact during the whole Product Life Cycle of the product and the supplementary products that the primary product may need to function as intended. Figure 3 shows the recommended actions to develop a sustainable product solution. The numbers in the figure refer to:

1. Based on the intended user and the use of the product, seek to enhance safety and quality of life from the use of the product.
2. Decrease the resource utilization and the costs throughout the whole PLC depending on the initial quality and price of the product and its variants.
3. Minimize the negative impact on the environment throughout the PLC.

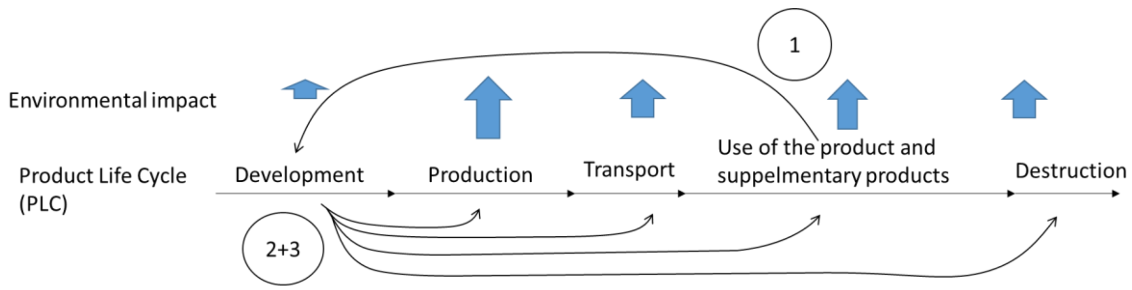

Figure 3 Actions to develop a sustainable product solution (Ottosson et al 2016)

Seen from a user's point of view a product can have at least six important values, which can overlap each other (Ottosson 2015):

- *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. a 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 e.g. when closing our eyes. Brand names, patents, the image given on web pages, stories and the expressed experiences of the product by other users, etc., 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).

The decision-making tasks in the product development process in Figure 3 (e.g., the choice of solution principles or the specification of materials and geometry) are often difficult to determine because the basic objectives (such as cost, function, and quality) are interdependent. This was the reason why the approach/concept of "Design for X – DfX" was proposed in the early 1990's (Hubka 1995). Today we have a large number of DfX to take care of in product development. Some of them are shown in table 1

Table 1: Design methods to use to achieve different product solution values (Ottosson et al 2016)

Product values	DfX etc.	Abbreviations for
Functional values Emotional values	DfU DfEr DfSe	Design for Usability Design for Ergonomics Design for Service
Sensorial values Image values Emotional values	DfAe	Aesthetical design (industrial design)
Sustainability values	DfEn DfMA DfQ DfL LCA FTA DfR	Design for Environment Design for Manufacturing and Assembly Design for Quality Design for Logistics Life Cycle Analyses Failure Tree Analyses Design for Rescycling

To achieve good functional values usability is important. 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, organizational change, etc)?
- *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?

Still another aspect of usability of a product is that it shall contribute to a "barrier free world" for different types of (disabled) users. That is called Universal Design, for which seven principles have been proposed (Equitable Use, Flexibility in use, Simple and Intuitive, Perceptible Information, Tolerance for Error, Low Physical Effort, and Size and Space for Approach and Use) (Story et al 2001).

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 2015). 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 4 explains the abbreviations as well as that the recommendation to start the work at an abstract and wholeness level ending up at a detailed and concrete level. Which order the different activities are done is dependent of what products to be developed, the newness wanted, time limits, etc.

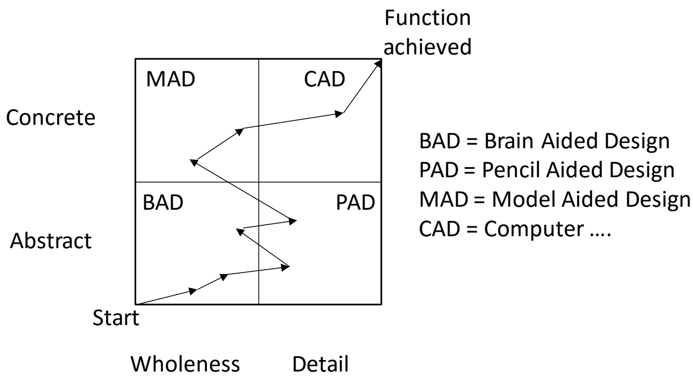

Figure 4: To find a functional solution combination of BAD-PAD-MAD-CAD can be used (Ottosson 2015)

There are many definitions of the terms "models" and "prototypes". In this paper we with a model will mean a formed solid that demonstrates the function and/or the shape of it. The model can be a part of a product concept used in the further development of a new product. From when a model exists, a prototype can be developed, which means to develop a production ready solution. The definition of a prototype can be "An approximation of the product along one or more dimensions of interest. (Ulrich & Eppinger 2016)". The development work to make a model is here 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 further from than if only a picture or digital mock-ups exist. Thus, models help us to get a better understanding of our 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 2015). Simple materials as clay, paper, wood, etc., is quick and easy to change which is why they should be used before using harder materials. Quote: “When a model starts to harden up, so also does the thinking.” (Schrage 2000, p 79). To note is that modelling with “mock-ups”, used in the shaping of new products, in general do not demonstrate the function of the products.

Another effect of modelling - and prototyping - is that as well tacit and explicit knowledge is used both on an individual as 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)

3D-printing is an alternative way of modelling to the traditional modelling. In that case a CAD-model must be done before the MAD can start. Therefore, in that case the sequence in figure 4 must be changed in principle to what is shown in figure 5

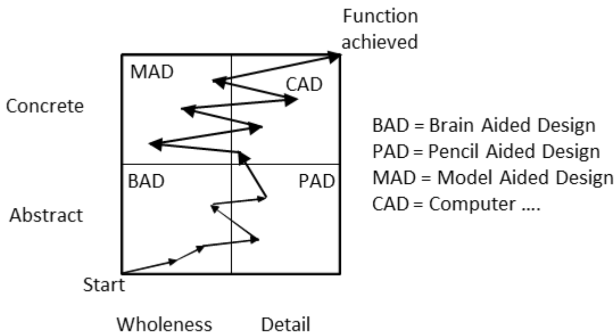

Figure 5: When 3D-printing is used as modelling the sequence can be like this

Contradictory to what is taught in general – that all demands must be set before the creation of a concept starts – it has been found that a faster and less risky way is to start only with one primary and 2-3 secondary demands and then start to create concepts and solutions to satisfy them (Ottosson 2015).

When one or more concepts & solutions have been found based on creative thinking, more demands are added for each of them. These demands can result in that new solutions must be found. If a solution does not hold in the test and evaluation, it is stopped from further development and the findings and experiences are documented. Using this principle, which is shown in figure 6, the work can go ahead at a high speed to end up with a final concept and solution that is well documented.

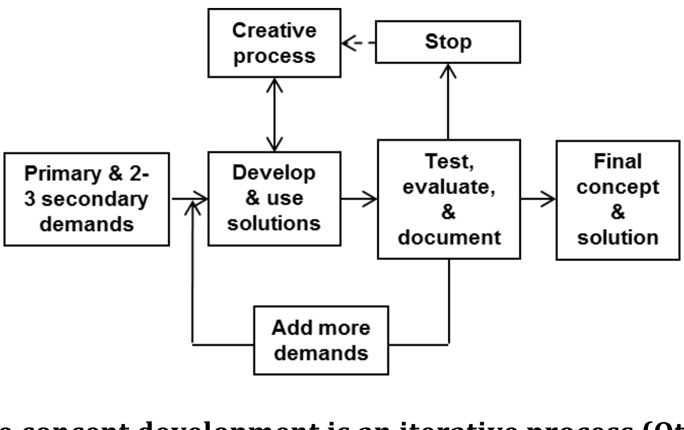

Figure 6: The concept development is an iterative process (Ottosson 2015)

When the functional values have been satisfied the other product values and product demands mentioned above can successively be satisfied in new creative processes. [By creativity here is meant the ability to create meaningful new ideas, forms, methods, interpretations, etc., which is well in accordance with the statement that "creativity involves the production of novel useful products" (Mumford 2003 p 110).]

4 The modelling example

The first 3D printed model was a strict copy of the functional metal cover. However, it was soon realized that the product name sticking up 0,5 mm could be done so that it would add to the image value of the product and company. Also the shape of it could be done to closely resemble the lock itself, which should increase the sensorial and image values. The different models done from August to December 2015 are shown in figure 7.

Figure 7: The development chain from the original metal lock to a functional prototype.

Then it was realized that a thin line sticking up 0,2 mm under the lock could ensure that the cover did not un-intendedly slide off the locking (see figure 8). Possibly that could also give a clicking sound indicating that the cover fitted correctly when pushed over the lock. In product value terms that meant an addition to as well the functional as the sensorial values of the product. Also the heavy pushing of the metal cover over the lock could be taken away as no tight tolerances would be needed any more.

Figure 8: The first idea to add a clicking and holding line under the cover

Our tests showed that the line had to stick out 0,5 mm instead of 0,2 mm to give the desired requirements on clicking sound and ensuring that the cover did not fall off when the lock was shaken.

One negative effect with the cover is that children can feel imprisoned, or claustrophobic, which is problem for the existential design to overcome. We had no satisfactory solution for that as the safety demand was prime for the product. 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 figure 9).

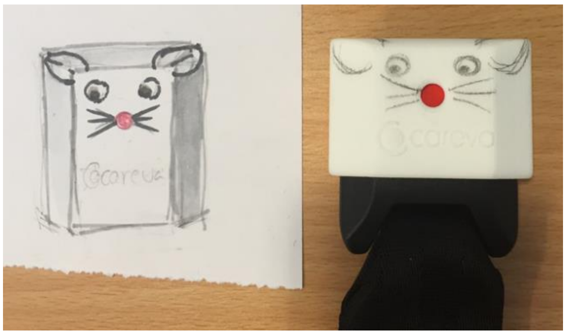

Figure 9: The left sketch by professor Kari Øverseth transformed to instructions how to realize the idea in reality

We then made a prototype with the lines in figure 9 sticking up 0,5 mm. However, as we did not find any good method to paint the lines, we made them going down 0,5 mm from the cover surface instead. With that change, it is possible to use e.g. a 1 mm marker pen for the painting work. This solution can also solve the problem of the paint wearing out. Figure 10 shows the end result reached at the end of January 2016. The “cat cover” has no functional value but can be used in a positive way, e.g. as 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 10 did not give a pleasant feeling although the shorter cover meant a more sustainable solution - 35% less material was used in that case.

Figure 10: The end result of the development experiment showing the PAD-draft, the 3D printing outcome and result after that the marker pen had been used to fill in the “ditches”

5 Some findings

All the product demands in the left column of table 1 were included in the design of this product although not all the methods in the middle column were used.
The development of the new product model, as shortly described here, was based on an existing solution why BAD-PAD was only used in a limited way. Figure 11 shows in principle the sequences used. That a functional solution existed from the start contributed to that the so called anchoring (or focalism) effect appearing, which – looking back on the process - delayed the development in the form of more steps than were needed.

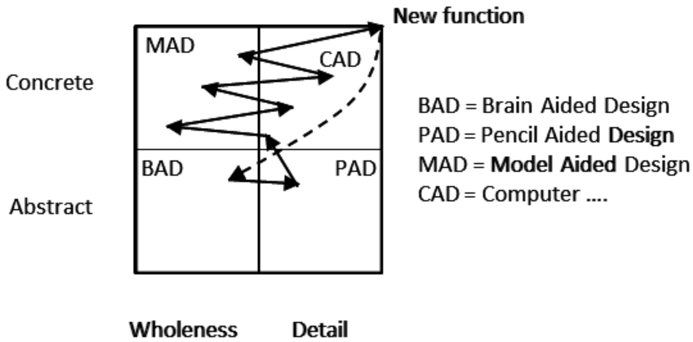

Figure 11: How the design activities were done in the test example

The use of 3D-printing made it possible to satisfy all the product demands mentioned in the theory part of the paper, the usability demands, and the 7 UD-principles. In addition the production price will be lower as well as a more sustainable (green) product can be made.

The 3D-printed covers can be used to get dealer, user and customer feed-back before a final decision of production of the product is made. However, for production the surface roughness is not good enough, which is why other plastic manufacturing methods have to be considered.

5.1 Conclusions based on the research questions

RQ 1: To what degree can creative thinking be boosted using 3D-printing as realization vessel compared to when traditional methods are used?

In this case, the creativity was felt to be higher than what possibly could have been the case if 3D-printing had not been used. The main reason for that conclusion is that there were few – if any - limitations as how the product could be designed when it comes to 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 complicated tools in that case had had to be manufactured and changed before each test iteration.

RQ 2: Can different product values be better taken care of using 3D-printing in the modelling process compared to when traditional methods are used?

As it was easy to make changes new ideas could easily be tested, which in an iteratively way increased not only the functional but also the other product values described ahead.

RQ 3: What kind of limitations can there be to go from a functional 3D-printed model to a sustainable innovation?

The surface roughness is at a level that makes Additive Manufacturing not useful for the production of this product. Going to other production machines will need new tests as 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 acceptable wearing result 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 produced in other ways, which influences the environmental aspect from the cradle to the grave in figure 3.

6 References

Erichsen, J. A. B., Pedersen, A. L.; Steinert, M. & Welo, T. (2016): Using Prototypes to Leverage Knowledge in Product Development: Examples from the Automotive Industry. I: *IEEE International Systems Conference (SysCon 2016) Proceedings, Orlando, Florida: IEEE 2016 ISBN 978-1-4673-9518-2*, 491-496.

ISO 9241-11:1998: *https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-1:v1:en*

Hubka, V. (1995): DESIGN FOR – DF. Fertigungsgerechtes Konstruieren. *Paper presented at the Beiträge zum 6. Symposium, Erlangen Germany,* 1-6.

Mumford, M. P. (2003): Where have we been, where are we going? Taking stake in creative research, *Creative Research Journal*, *Vol 15, Issue 2-3.*

Ottosson, S., Moldavska, A., Ogorodnyk, O., and Skogsrød, T. (2016): What is and how to develop sustainable innovation?, *The International Conference on Leadership, Innovation and Entrepreneurship as driving forces of the Global Economy (ICLIE), April 20th – 22nd, The Palm, Dubai, U.A.E.*

Ottosson, S. (2015) (first edition 2009): Frontline Innovation Management, *Tervix, Göteborg, Sweden, (ISBN 978-91-977947-7-0).*

Ottosson, S. (2003): Participation Action Research – A Key to Improved Knowledge of Management, *Technovation - the International Journal of Technological Innovation and Entrepreneurship, Vol 23,* 87 – 94.

Schrage, M. (2000): Serious Play - How the World's Best Companies Simulate to Innovate, *Harvard Business School Press.*

Story, M.F., Mueller,J.L., Mace.R.L. (2001): The Universal Design File: Designing for People of all Ages and Abilities, *Raleigh, North Carolina: North Carolina State University*.

Torkildsby, A B. (2014): Existential Design – Revisiting the" dark side" of design thinking, *PhD thesis at University of Borås, Sweden*

Ulrich, S.D. & Eppinger, K.T (2016) (6th edition): Product design and development, *McGraw-Hill Education, NY.*