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REVISITING PROTOTYPING – LEARNING IN EARLY DESIGN

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1. Introduction

Product development, in particular the early stages of design, could be described as a learning process where knowledge is created, reflected upon and modified in inductive/deductive and diverging/converging practices [Gerber and Carroll 2012]. Handling sparse information and wicked design problems are inherent in such a learning process. The capability to mange ambiguity in the fuzzy front-end activities has become more important for design engineers. The trend in manufacturing industry to move towards a higher degree of service contents in the developed and sold goods is one recent trigger. Soft products, total offers or similar concepts are evidences of this change in perspective and indicate a challenge for design engineers. One implication for manufacturing companies when providing these service offers is that the core idea of what constitutes a product changes.

The term product is, in manufacturing industry, established as physical goods, something that is engineered and tangible. Services in this context are typically such activities that keep the goods operational, e.g., maintenance and repair, and are sold as add-ons to the standalone goods. The involvement of users is generally done in later stages where a late prototype of an intended product exists, e.g., field tests. The new paradigm based on a service perspective changes the interpretation of the term product from a physical goods inclusive add-on services into *a solution that enables the users to fulfil their goals*, i.e., a more holistic and systemic product-service solution. This integration is adding parameters of less physical substance into early design, for example managing unexpressed user needs in relation to potential innovation opportunities and the existing product portfolio. Further, close collaboration and knowledge sharing in the early scoping, planning and concept generation stages have to be done by a heterogeneous team. One condition for integrating different expertise domains is to implement approaches that empower people, e.g., mechanical engineers, designers, marketing, users and customers, to work together. A traditional product development paradigm is delimited in respect of such explorative activities [Jacoby and Rodriquez 2007], hence the new type of products cannot be designed and developed based on established practices.

Generally, conducting traditional product development is seen as possessing the core capabilities to start from an existing commodity and from that plan and scope the development task. Thus, this makes it possible to compare such product development activities with incremental innovation, i.e., exploiting existing solutions. This is opposed to developing service offers where the choice of the feasible technical solution is not that evident in early stages since the user goals could be solved by distinct technical solutions, for example, the simple goal 'text on a sheet of paper' could be solved by a pen or a printer. Hence, service offers from manufacturing firms include a choice between varieties of solutions. Besides still being capable to offer product-oriented solutions (e.g., a printer), the firm have to decide if they should design the goods for a use-oriented (e.g., a leasing agreement and a printer) or a result-oriented usage (e.g., text on a sheet of paper) [Tukker et al. 2006].

Framed by this changed business scenario for manufacturing firms, a modern design engineer has to possess, not only technical skills, but also a capability to identify, capture and communicate tacit user statements to make them more visual for the design team. In order to contribute to modern product development practice and education, such as for example PSS, the purpose of the paper is to discuss how designers' learning in practice could be supported by applying rough prototyping methods. Thereby, emphasizing the process and activities when doing prototyping. This is done in order to contribute to a more user-oriented approach in early development stages; accordingly the paper provides delimited interest of PSS specifically. In particular, design thinking which is an approach that emphasise user involvement and the use of different means for exploring more open-ended design assignments [Kelley 2001], [Brown 2008] sets the frame for the paper.

In the following, the methodology is briefly outlined. After this, the concepts of artefacts, instruments and design thinking are presented to provide an additional background to a technical development process. The difference between a prototype and prototyping is a vital section that is intended to provide a new perspective and direct focus on activity rather than on object. The paper ends with a discussion on sketches and examples of how prototyping has been applied in some practical and applied cases.

2. Methodology

The changed business scenario where manufacturing firms provide product-service solutions serves as a framework for this paper. Background for the conceptual view on prototyping presented in this paper comes from daily work in design engineer education, and from several years of research into the engineering design area. The choice of perspective has evolved from those activities.

The choice of relevant literature for this study emerged from previous studies emphasising prototyping as a vital element in early design activities. The theoretical view provides a basis for the proposed prototyping perspective.

3. Artefacts and instruments

Bégun [Bégun 2003] argue that the design of an instrument should not be confused with the design of an artefact:

> It is up to the user, in and through its use, to turn the artifact into an instrument. […] an instrument is seen as a composite entity made up of 'the artifact', in its structural and formal aspects, and the subject's social and private schemes. [Bégun 2003, p. 710]

Bégun [Bégun 2003] explains that the design process continues when artefacts are used in real user situations, i.e., where artefacts are further developed by the users into instruments in order to act as resources of their productive activity. Failures or difficulties for the users to fulfil their objective will lead the users to reconstruct or improve the artefact and/or instrument. A situation where the artefact is unsuited to users' needs could depend on the firm's insufficient design process, which provides products that results in many gaps. For example, there can be problem formulation gaps, a discrepancy between the design team's and the users' perception of whether or not the artefact is appropriate for the intended task, and, there can be work context gaps, which concerns differences in culture and social settings. The design process continues in usage due to not adequately consider the users' needs or practices [Bégun 2003]. The recommendation is to devise and conduct design as a mutual learning process between users and designers [Bégun 2003].

From the service offer point of view, a comparison with developing standalone goods and developing product-service solutions, and the artefact/instrument view can be done. At the heart of a service offer is the intention for the manufacturing firm to take full responsibility for the artefact in its use and make sure that it fulfil users' needs, i.e., to manage the transition process into an instrument. In order to achieve this, it seems like the product development activities have to incorporate a design thinking methodology.

4. Design thinking

Traditional product development could simplified be described as going from specification to launched standalone goods, via design and production. Compared to that view design thinking has a broader scope that support and transform the ways products, services, processes and strategy come about [Brown 2008]. And, seemingly, such a mind-set might fit product-service development better due to a focus on users.

Compared to traditional product development, which is commonly visualised in structured process models, approaches within design thinking could seem "totally chaotic" [Kelley 2001, p.6]. As the term indicates, design thinking is based on capabilities to manage reasoning about the design and the process. The benefit of the approach is that design teams can preserve ambiguity, which is important for innovation, and still perceive that they have a well-developed methodology for the work. Further, the concurrent practice of design and process progress makes the methodology continuously refined to suit different use of it according to the nature of the task at hand [Kelley 2001]. By this integration both routine design practice and explorations into new ones are supported.

Design thinking is usually described in few and general steps. Kelley [Kelley 2001] presents the IDEO approach as "a method to our madness" and outlines the steps [Kelley 2001, pp.6-7]:

- Understand the user and the constraints the user perceives
- Use a variety of techniques to observe real people in real-life situations
- Visualize concepts and those who will use them
- Evaluate and refine prototypes in a series of quick iterations
- Implement

The use of quick iterations is vital to build the design on user needs. As the work unfolds during these iterations the view of users, their behaviour and their goals get clearer, in parallel, a candidate design vision arises. A recommendation for user involvement is to avoid conformity as for example in focus groups. Instead crazy users and rule breakers could provide valuable understanding that "people are human" and a source for creativity [Kelley 2001].

Traditionally, the engineers' technical skills are trained in education and practice. Coherent reasoning as a design thinker gains less attention in technical projects, even though the fact that design decisions are made upon experience; gut-feelings and hunches are well known. Brown [Brown 2008] suggests that some people have a natural aptitude for design thinking, but all could with the right practice prosper to benefit design situations. He explains that some characteristics for a design thinker are [Brown 2008, p. 87]:

- *Empathy* – the capability to imagine the world from multiple perspectives, e.g., users, customers and colleagues. Expressed in a people first approach.
- *Integrative thinking* – the skill to, not only relying on analytical processes of either/or choices, but also to see all of the relevant aspects of a problematic situation. Expressed as confidence in managing contradictions to create novel solutions.
- *Optimism* – has to do with the core of design practice, at least one potential solution is better than the existing alternatives.
- *Experimentalism* – an interest in searching for the unexpected, innovations do not come from incremental tweaks. Expressed in ingenuity, creativity and exploration of entirely new directions.
- *Collaboration* – increased complexity in products and services needs enthusiastic interdisciplinary collaboration. Great design thinkers have usually experiences in more than one discipline.

The potential to focus user needs, goals and context when applying design thinking seem to fit the development of product-service solutions. Also, the insights that user needs can be differently approached are vital, e.g., to drive novel solutions (left in Figure 1) and to drive product improvement (right in Figure 1).

Four recommendations to make design thinking a learning process as a key of innovation routines are [Brown 2008, p. 90]:

- Begin at the beginning – important to involve a diverse team before any direction has been set.

- Take a human-centred approach – learn from people and their behaviour.
- Try early and often- encourage rapid experimentation and prototyping in the first week of a project. Measure, for example average time to first prototype or number of users exposed to prototypes during the project time.
- Seek outside help – look for opportunities to co-create with users.

If the intentions from manufacturing industry are to incorporate products *and* services into one development process, design thinking provides an opportunity to take a first step. Design thinking advocates a broader definition of products – it does not manage commodities and services as distinct entities, and it concurrently develops processes and business strategy. Though, for this kind of modern product development practice to evolve, the use of rough prototypes and prototyping seems like a key.

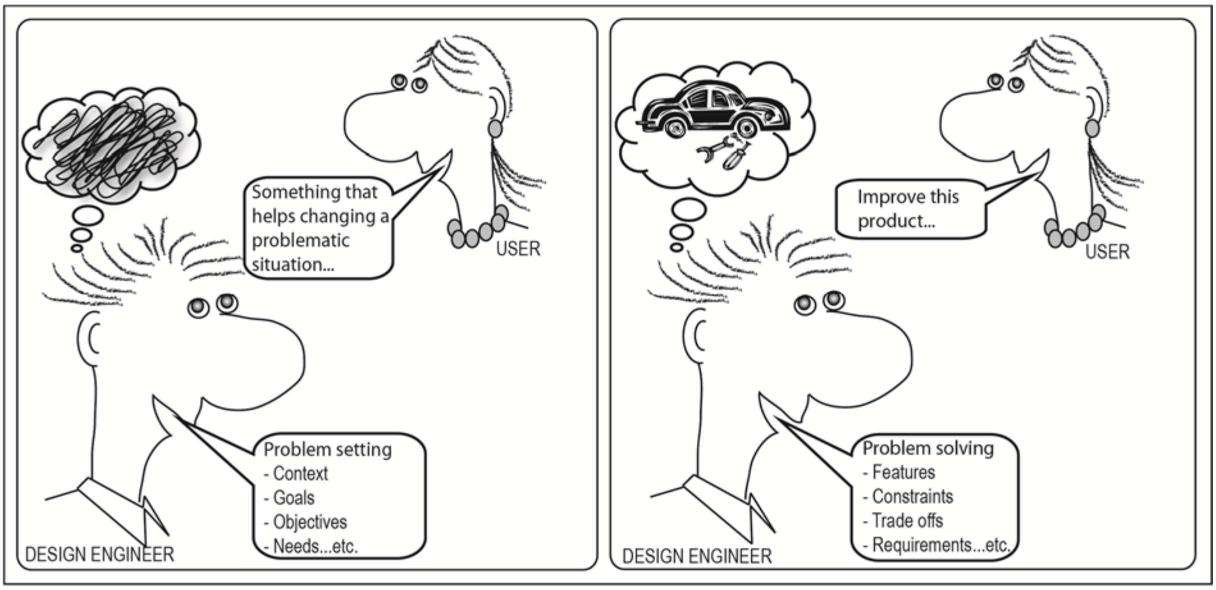

Figure 1. A difference between need-based and product-based early design

5. Prototypes and prototyping

There is a difference between the noun *prototype* and the verb *prototyping* that are of interest for supporting design as a learning process.

The word prototype has a meaning of something that has a primitive form, thus indicating that it is not an artefact or a product yet [Buchenau and Fulton Suri 2000]. Typically, a prototype can be interpreted as a representation of a final product, just lacking some minor features or designs. In such a case the intended use of prototypes is to communicate and verify the final design. Commonly, in manufacturing industry, two or three product concepts are represented by prototypes. These are often alpha, beta or pre-production prototypes, that is, they looks like and works like products ready to launch. The goal for such prototypes is to capture the functions and appearance of the forthcoming product, and is used in field test. These prototypes provide a valuable platform for the users to test, evaluate and rank existing features, as well as suggesting additional ones. Though, only applying prototypes of this kind constraints the communication in the team, since prototypes that appears to be finished decrease the dialogue and feedback in the team [Brown 2008], On the contrary, conducting prototyping activities for the sake of learning about users increase the design thinking, i.e., the dialogue and feedback on ideas within the team. Hence, a wide range of representations ranging from sketches, drawings to different kind of models are suggested to be used as prototypes to mediate user needs and support communication in the team [Buchenau and Fulton Suri 2000].

Prototyping is all activities a design team conducts when working with different kinds of representations of a design, i.e., a wide range of prototypes. From the prototyping perspective, prototypes are used to explore and communicate ideas about the design and its context. This is in

opposite to – or rather what precedes – a traditional use of prototypes, where learning about the product is in focus.
The concept of Experience Prototyping [Buchenau and Fulton Suri 2000] supports the learning process in design by promoting the design team to gain first hand knowledge at various levels, e.g., "looks like", "behaves like" and "works like" [Buchenau and Fulton Suri 2000]. Traditionally, prototypes are tangible and a remaining result of prototyping. But, when applying Experience Prototyping, for example bodystorming is suggested. Simplified, bodystorming is a skit showing a sequence of a situation and its context. Readily available and every-day objects are used in bodystorming, for example, to simulate the inside of an airplane chairs were used to enact different social situations and activities. The design team experienced sitting and reading, sleeping, talking to a travel companion, receiving and eating meals for the purpose to evaluate ergonomic and psychological comfort in distinct arrangements [Buchenau and Fulton Suri 2000]. The prototyping activities enabled the embodiment of ideas and created a shared experience for the design team. The chairs were merely chairs after the prototyping session, thus cannot as such be perceived as prototypes and, concequently cannot transfer any lessons learned about the design situation.
Another concept that emphasise the learning process when using physical or virtual representations of early ideas and concepts is low-fidelity prototyping [Kelley 2001]. Here, simple and rough prototypes are used to capture an idea that spurs out of a moment of thinking toghether, the goal is to promote exploration into the core idea, rather than to jump into problem-solving. For example, in the development of a new device for surgery, a designer took a whiteboard marker, a film canister and a clothespin and taped them togheter to support asking the user; do you mean like this? [Brown 2008]. Such props can be used to enable dialogue about complex or abstract ideas, and the key effort of prototyping *"…isn't to finish. It is to learn about the strengths and weakness of the idea and to identify new directions that further prototypes might take."* [Brown 2008, p. 87]. Low-fidelity prototyping allows the design team to rapidly visualize several ideas, also it has been identified that such protoyping allows reframing of failures into opportunies for learning, support the perception of a forward progess and encourages the team's creative capabilities [Gerber and Carroll 2012]. Thus, prototyping is critical to construct knowledge about the design and the design process, as well as making decisions [Kelley 2001].
McGee, Pavel and Cohen [McGee et al. 2001] argue that physical objects, e.g., prototypes, are given a context by using language. And, they continue, context is not a set of static properties, rather a set of relationships between the people and the world in which they interact. The context evolves, changes or become a new one, due to how people create meaning when using physical objects, e.g., naming and referring. McGee, Pavel and Cohen [McGee et al. 2001] provide an example where officers are using Post-it notes to represent unit positions on a map. The different sizes of the units' evolved and new meaning were associated with the objects, i.e., the Post-it notes, during the task. In the same way that chairs are just chairs after a bodystorming session, these Post-it notes did probably not make sense to an external person coming into the group. By this, it might be doable to argue that low-fidelity prototyping are critical for the design team and for the setting of their task, but the prototypes that are created convey little information as detached objects.

6. Sketching and prototyping

The importance of sketching are confirmed since it is an activity that take place throughout the engineering design process [Cham and Yang 2005]. A sketch could be described as a visual representation of design ideas that lack details, but that is merely one type of sketch. Cham and Yang [Cham and Yang 2005] shows three different levels of sketching, namely:

- mechanical recall – e.g., sketch a bike from memory,
- drawing facility – e.g., sketch an object incl. the human hand holding it,
- novel visualization – e.g., sketch a three-dimensional object from a verbal description.

The mechanical recall relates to a person's ability to understand and visualise spatial constructions, for example how the bike's frame looks like and how the handlebar is located in relation to the frame. Drawing facility is related to the person's hand-eye coordination, sense of visual balance and the quality depends on the person's practice in sketching [Cham and Yang 2005]. The novel visualization

might then relate to a person's creative capabilities to 'translate words into a 3D picture', e.g., relates to both the imaginary ability and the sketching skills.
The ability to "think visually" is necessary to design radical innovations [Kelley 2001], and can prove to be vital in translating tacit user statements into design information. There is a relation between doing sketches and design thinking. Sketching enables the tacit, cognitive and internal processes to become external and observable hence provides possibilities to communicate design ideas.
Nevertheless, sketches are not simply illustrations of design cognition, but important carriers for ideas and knowledge sharing throughout the design process. Generally, in product development, teaching of sketching skills aims to improve the quality in the sketch as such, but design thinking seems to encourage quantity to support thinking visually together in the team. Thus, can be described as the difference in traning mechanicall recall and novel visualization. Such skills can prove fundamental for product-service solutions, especially it seems vital to start define and settle the vague design task when aiming for result-oriented usage. Here, developing simple sketches, e.g., stick figures doing certain activities in a specific context, could provide being a useful prototyping session when interacting with users. Methods and appropriate tools need to be applied to even out differences, people that are not trained in sketching has a high threshold to start sketching.

7. Prototyping and problem exploration

Rapid prototyping is another approach to interact with users and represent a variety of technologies that can fabricate 3-dimensional objects in a single stage directly from CAD descriptions [Gibson 2005]. For the early stages of development, rapid prototyping can assist consolidating the conceptual design, and be used to assist analysis by providing test models [Gibson 2005]. Moreover, the technology can be used for different applications in both manufacturing and non-manufacturing situations. One example is the development of a practice environment for surgeons. The design of the practice environment has been led by one co-author of this paper, and the objective for the task was to achieve a physical representation of the human aorta. Included in the task was to provide as natural feeling as possible and the best setting for the practicing surgeons to become more experienced, i.e., a realistic representation of human vessel defects for the surgeon to be prepared for complex operations. The project team consisted of industrial designers, engineers and medical surgeons all located at different geographical places. A first step was to create a CAD representation of the whole aorta. For this, the team used computed tomography (CT) data from a real person. After this, sketches and fast, simple digital images were used to find methods for extracting the relevant information from the CT data. To ensure correct representation, a digital prototype of the aorta was created and the deviation between the two was measured at multiple locations. The CAD model was created from the digital prototype; hence a rapid prototyping model in silicone could be produced.
During the project, a large number of prototypes were created, and extensive prototyping was conducted, i.e., concurrent discussions and changes in the design which developed knowledge about the use, the user's objectives and the context. In this distributed setting, the extensive use of both rapid prototyping models and prototyping sessions were found invaluable for the communication of ideas and concepts. Further, the use of physical representations enabled the team, not only to share ideas and learn from each other, but did also enable the industrial designers and engineers to combine methods to solve the manufacturing of a final silicone prototype. The prototyping sessions were found as utterly important due to the dispersed expertise in the team. The designers are not surgeons and vice versa, though the physical representations supported mutual learning.
Currently, the final prototype are tested and evaluated of experts to assess the resemblance with a human aorta. If approved, the late prototype will be the base for a commercial product for the practice environment.
Student projects in product development provide another example that highlights how prototyping by using personas can support not only communication, but also problem definition. In a course, given by the co-authors of this paper, the students are assigned a wicked and open design problem. Typically, the close collaboration with industry in student projects provide relatively well defined assignments, more or less like consultant tasks. However, to provide training in more realistic industrial and innovative settings, the lecturers introduce assignments where both the question and the answer are

open and not concise, i.e., the students get a theme, a scenario or an area in which they should identify not only the problematic situation but also the users and their needs, and from that base design a candidate solution. By this approach, the target is to, not only increase uncertainty and realistic conditions, but also to inspire the students to develop innovation and entrepreneurship capabilities. In the end, the intention is to stimulate an ambition in the students so that they start their own company.

One student team chose to work with corporate gifts and started to visualise potential users, i.e., personas. Three different personas were created and refined in collaboration with the affiliated company. Background information from interviews, observations and surveys provided input for the fictions characters of the personas. Also, personal attributes as for example, age, gender, marital status and special interests are given to the personas. The visual representations of personas provide a sense of designing for real people and the efforts are more directed towards people different needs. This makes designers more engaged in user needs and prevent them to design products based mainly on their own preferences. The team analysed the personas and from that aggregated a list of needs and demands. From this, they could conduct benchmarking activities, followed by a comparison and a first idea generation session to develop product concepts. The concepts were compared and weighted against the identified needs resulting in one concept to be further developed. In order to refine the concept, for instance, sketches and digital images were used. A functional prototype, a model that captures key functions and the underlying operating principles, was created after the concept had been explored in relation to the list of needs. Rapid prototyping was used to produce several prototypes, which were used to refine the design.

There was a company that had committed themselves to buy the idea and produce the winning solution from this course. In all, the student projects ended up in a great number of unique and innovative solutions directed towards different target groups. The company decided to go for more than one solution to produce, but also, the affiliation and commitment of the company encouraged the students to put an effort to visualise, communicate and sell their solutions.

8. Concluding remarks

The manufacturing firms' intention to provide product-service solutions is a trigger for this paper. In particular, the variants of such development - product-oriented, use-oriented and result-oriented - increase the intangible service aspects in different degrees. Our starting position was in the new service paradigm and the changed interpretation of what constitutes a product. From this base, the purpose has been to discuss how designers' learning in practice could be supported by applying rough prototyping methods. This was done in order to contribute to a more user-oriented approach in early development stages, consequently PSS provided a trigger describing a future and modern product development practice and not the focus. All in all, the discussion aimed to contribute to modern product development practice and education.

Instead of goods, commodities and things, manufacturing firms now talk about delivering value in terms of solutions that enable, or instrument, the users to fulfil their goals. We have found that an extension of product development knowledge in early stages towards user-orientation seems necessary. Product development activities for design engineers should incorporate approaches to find out how the product is used and adapted to create value and benefit the users' productivity. Yet, it could be assumed that the changed business scenarios with its strong user orientation should challenge the design engineers' social skills. The capability to identify, capture and communicate tacit user statements are likely to become a key expertise area for engineers when aiming towards a more service based market. In this setting, the use visual representations are a key to build shared design visions in the multidisciplinary team.

Manufacturing firms generally develop late prototypes of their physical products, based on such practice, the perception that a prototype is tangible and represents the final solution becomes the norm. However, this also directs focus from the importance of prototyping activities, e.g., those efforts that have provided progress both in terms of process and the learning in the team, and also constitutes a base for the appearance of the late prototype. In line with McGee, Pavel and Cohen [McGee et al. 2001], we have by describing the rapid prototyping case provided an example, that physical objects provide the team to develop an understanding of the relationships between people/users and their context. Moreover, we have discussed that low-fidelity prototyping, e.g., sketches and images, are critical for problem-setting when the design task is unclear, as for example in result-oriented product-service solutions. In this stage, the focus should not be on the prototypes as such since they could not convey the lessons learned after the finishing the prototyping session. Consequently, a modern product development practice and education puts a higher effort in encouraging designers' to apply different sorts of prototyping, e.g., role-plays, personas, rough and simple representations, and to conduct prototyping with potential users.

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