How tangible mock-ups support design collaboration

This paper is a contribution to a more conscious use of tangible mock-ups in collaborative design processes. It describes a design team's use of mock-ups in a series of workshops involving potential customers and users. Focus is primarily on the use of three-dimensional design mock-ups and how differences in these affected the dialogue. Reflective conversations were established by using tangible mock-ups as "things-to-think with". They served as boundary objects that spanned the gap between the different competencies and interests of participants in design. The design mock-ups evoked different things from different participants whereas the challenge for the design team was to find boundaries upon which everybody could agree. The level of details represented in a mock-up affected the communication so that a mock-up with few details evoked different issues whereas a very detailed mock-up evoked a smaller variation of issues resulting in a more focused communication.

Eva Brandt
Center for Design Research
Danmarks Designskole
Strandboulevarden 47
DK-2100 Copenhagen Ø
Denmark
eva.brandt@dkds.dk

INTRODUCTION

This paper addresses problems related to using tangible mock-ups and the level of detail and finish in these prototypes in collaborative design processes. Within product development and system design producing and using various design models has for long been viewed as a central part of the design process. For instance Buur and Andreasen describe product development as a modelling activity where the designer's work is a progression between models with different purposes throughout the development process. They describe modelling as an important tool for the designer to describe, visualize and sculpture her thoughts when designing by herself or when designing or communicating with others [10].

Among others Preece [20, 21] and Beyer and Holtzblat [3] stress the importance of using various prototyping techniques in user-centred system design. According to Preece et al. [21] "a prototype is a limited representation of a design that allows users to interact with it and to explore its suitability [21, p. 241]. They continue to write that prototypes can take many different forms. A prototype can for instance be a scale model of a house or product, a piece of software, a paper-based outline of one or more screens, a video-simulation of a work task or a three-dimensional mock-up of a workstation.

Preece et al. divide prototypes into two categories: low-fidelity prototypes, and high-fidelity prototypes. Low-fidelity prototypes should not be kept and integrated into the final product. They are often made of simple and cheap materials like paper and cardboard which results in prototypes that are very different from the final design. Low-fidelity prototypes are often cheap, fast to produce and modify. Examples are storyboards and mock-ups. According to the Concise Oxford Dictionary a mock-up is an "experimental model showing appearance (part of) proposed book, ship, etc." [25, p. 650]. The other prototype category is high-fidelity prototypes that look more like the final design and which are made of the same materials as the final design. High-fidelity prototyping is more time-consuming and hereby more expensive than producing low-fidelity prototypes. An example is a software system developed in Visual Basic.

Prototypes can be used in a variety of ways. For instance they can support designers and stakeholders to choose between different design alternatives, to test technical aspects of an idea or concept, to clarify requirements, test usability, or check if a certain design direction is in line with other parts of the design [21]. This paper focuses on the use of three-dimensional mock-ups in collaborative design sessions. The mock-ups belong in the low-fidelity category.

When the purpose is to try out future use situations in collaborative design among others Bødker and Buur stress the importance of using tangible prototypes as one can interact with them, get hands-on experiences, the prototypes can be held, placed, pointed at etc. [11]. Carroll describes the use of mock-ups in general in scenario-based design [12], Binder [5] has focused on how users with simple cardboard mock-ups as props can create improvised scenarios in their own environment, and Brandt and Grunnet [8] have described how drama and mock-ups can help evoking possible futures.

Even though that several authors in general terms argue for producing and using mock-ups, their role in collaborative design and how they influence the communication between different stakeholders are poorly investigated. This paper include: What to discuss and the level of details in collaborative design with customers and users, how tangible mock-ups act as boundary objects between participants having various competencies and interests, and how the level of details and the finish of the mock-ups affect the communication and hereby the outcome of the collaboration.

THE WORM PROJECT

In a large company in Denmark a design team was to develop a product program for machine manufacturers in the food industry. The machine manufactures develop special purpose machines and transportation equipment for dairies, slaughter-houses and cheese factories, for example. The product program was to be a complete "building kit" consisting of components like motors, valves and cylinders. To assure anonymity the project described will be called the WORM project. WORM is just a name. It is not an acronym of any kind.

The WORM project succeeds a first generation of products, which were developed under a rather high degree of secrecy. This pre-existing product program was developed behind closed doors, which secured advantages in terms of novelty on the market, but also many believe it did not attend to the detailed requirements of customers in the design of individual components. With this in mind, leaders of the WORM project decided to involve core customers and users in the design of the new product line. The customers were machine manufactures and the "users" were technicians from different companies in the food industry in Denmark.

Figure 1. At the WORM project 10 - 15 people participated in each workshop. The customers and users were invited in pairs, so that both customers (machine builders) and end users (technicians) from the same industry were present.

For one and a half years I have been involved in action research [6] arranging, holding and evaluating workshops with customers and users in collaboration with the design team (for a more elaborated description of the WORM project see [7]). Four workshops were held at intervals of 3-4 months. Each workshop lasted one-day (figure 1). Customers and users were invited in pairs to the workshops to assure that both customer and end-user from the same line of business were present. For instance participated a customer that designed and manufactured the applications in slaughterhouses and a user that took care of the daily maintenance in a specific slaughterhouse.

A colleague and I were invited as facilitators because the WORM team wanted to have ongoing evaluation and critique of this new type of collaboration by some external participants, and because we had experience with user involvement from other projects. All the workshops have been video-recorded and in the following examples of transcripts from these are discussed.

PROTOTYPES; 'THINGS-TO-THINK WITH'

Buur and Andreasen [10] give examples of models in mechanic, electronic, and software design and present a model morphology as a convenient system for categorizing important aspects of all these. Their design model morphology is divided in two parts; the modelling activity and the design model itself as illustrated in figure 2. According to Buur and Andreasen, the design morphology is an attempt to describe important aspects the designer must consider before building a model. These aspects are: The object (the product to be designed and sometimes also its surroundings), the properties to be modelled, the purpose of modelling, the user of the model, the code (or 'modelling language'), and the medium. Buur and Andreasen claim "when using this (morphology), it is possible to describe precisely the purpose of the intended modelling and the characteristics of a suitable design model type" [10, p. 157].

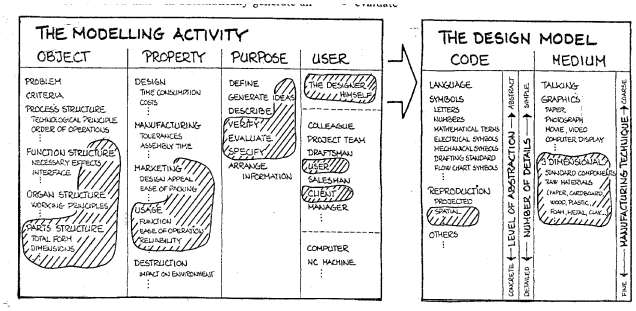

Figure 2. 'Morphology of design modelling characteristics' [10]. The hatched area illustrate that for instance more than one characteristics of the object were addressed using the same mock-up during a workshop in the WORM project, e.g. to verify, evaluate, specify, and generate ideas from.

While the major categories in this design morphology are useful as an overview of important aspects to consider before building a model and these considerations can help the designer choose, build, and use appropriate models for different purposes my findings show that when models are used in a collaborative design setting it is important not to be too focused on one particular purpose of the model as it can unnecessarily limit the designer and users in their search for better solutions. In my attempts to use this morphology as a starting point for analysis of what went on in several workshops I drew the hatched areas in figure 2. The areas show how more than one characteristic from each class were addressed using the same mock-up during a workshop. If the purpose of the scheme is to make clear and set apart different phases and steps in designing it seems not to describe designing in the WORM project very well.

Buur and Andreasen stress that when mechatronic products are developed at least three different engineering fields are involved; mechanics, electronics and software, and that the difference in engineering fields complicates the collaboration because the specialized education makes it difficult to understand each others problems. This is a very important point; the problems participants experience in understanding each other do not only derive from their specialized education's but also their ways of working and thinking after

their education; ways which are strongly influenced by often further specialized tasks as employees. A central question in my research is how to surmount the problems of collaborating across different competencies. The potential for improving collaboration between different competencies with benefits for both the participants and the product depend upon answering the questions of how to communicate across different professional languages, how to be aware of differences in interests and agree on the design task - in short how to design the process of designing.

Buur and Andreasen maintain that there is a need for a more abstract meta-language. ('a model language or model type that can improve communication both between mechanical, electrical and software engineers, and between the project team and, for example managers and users' [10, p. 162].) They base their understanding of modelling on the general problem solving model [1] and the general communication process illustrated in figure 3. These models suppose the problem to be well defined, that the designer is certain about what is needed in order to solve the problem, and that this basically is about having the "right" information accessible which can be found by asking the right questions which is questionable and ought not to be assumed.

In contrast I will argue in line with Schön that the designer doesn't know how to solve the problem beforehand and indeed what information is needed [22]. In order to design the designer therefore has to engage in a reflective conversation with the problem; one can't solve problems by asking questions alone but constantly choose and work with a possible solution and let it "talk back" to you. Recognition of this problem comes from working through different possibilities.

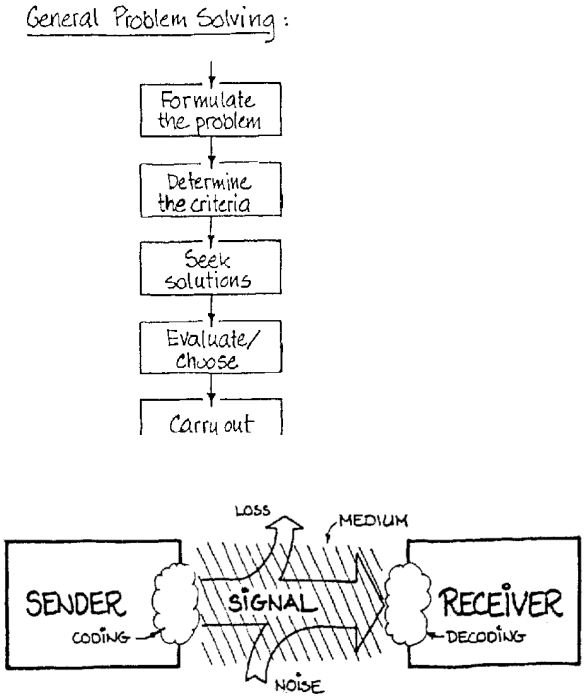

Figure 3. 'Model for general problem solving [1], taken from Jones [17] and the general communication process' [10]. These models do not describe how to solve problems in practice as when one have to solve problems one have to engage in a reflective conversation with the problem as suggested by Schön [22].

Later in this paper I will show how the participants in the WORM workshops engaged in reflective conversations of the type described by Schön. The design models were not just used to present what the designers had in mind, but they were used primarily as 'things-to-think with' where reflections from different participants resulted in re-seeing the design which gave new meanings [2, 19].

WHAT TO DISCUSS WITH THE USERS?

A question we confronted as facilitators was what could be of interest to customers and users? What would they find fruitful to discuss? At the first workshop the participants included customers, users, managers of engineering and marketing departments from the design team, my colleague and myself. Most of the day was used to explain the aim of the project. The customers/users filled out a questionnaire on requirements for a particular class of components, and they were all given time to explain to the other participants their interests in the new product program. Most of them had rather elaborate suggestions for potential applications that made use of the new components. When evaluating the first workshop the managers found that the dialogue became increasingly fruitful as the customers/users got involved with questions about how to use the new components. On the basis of this observation it was decided that all the designers in the team had to be directly involved in the workshops in order to explore these questions themselves together with the customers and users.

From then the full design team was present and focused on design issues and the progress of the project. The customers and users were requested to comment on the design teams' suggestions either orally or by writing 'yellow stickers' and placing them on posters, products from competitors, and mock-ups.

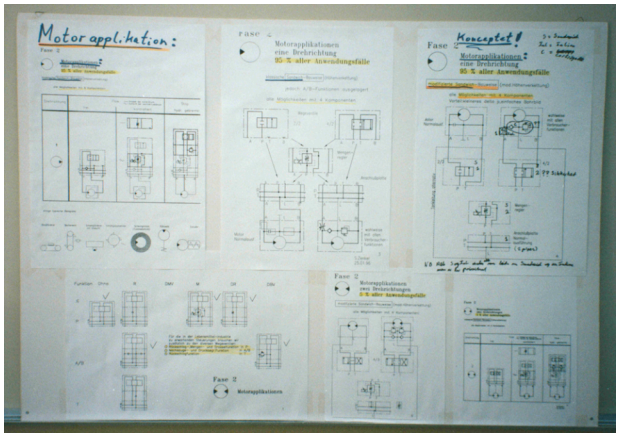

Figure 4. In the second WORM workshop the designer who presented status of the motor design used these posters in his presentation.

The following section discusses an example of the level of details the designers discussed with the customers and users. At the second workshop a designer introduced the status of, and problems in the design of the motor using posters with detailed technical drawings (see figure 4). He talked for five minutes in great detail about their work and considerations about two different motor principles and the reason for their choice. For instance he talked about

- how the two different motors worked,
- how the wings in the wing motor are pressed out as to make them move,
- how many pistons are meshed at one time,
- how friction in the bearings limited the minimum revolutions per minute in the other type of motor to be 50,
- how they have to take into their considerations that the wing wear influencing motor and that this consequently limits its lifetime to about 10,000 hours,
- that the wing motor can bear a big radial weight because of the double chamber in the motor,

- that the wing motor's advantage is the little variation in momentum,
- etc.

As time passed, what the designer talked about changed from very technical aspects of the 'very inside' - 'the heart' of the two different motor principles - to the chosen wing motor and its advantages and disadvantages. At one point the designer said:

Designer: *...The drawback with this concept is leakage. This means that if you start and have a load of, for example, 10 bar and the motor has 50 revolutions and you have a load on the shaft, then the motor will lose its revolutions because of leakage inside the motor. At present the loss is about 10 - 15 revolutions when you have a change of load of 40 bar.*

This prompts a customer's reaction:

Customer: *How much power does 40 bar correspond to?*

This question surprised the designer very much. He did not have an answer ready at hand so a marketing employee tried to help the designer by explaining what type of motor the new motor could replace. After that the designer explained that power is equal to momentum multiplied with revolutions and that 10 revolutions is hardly any power. To this the customer said:

Customer: *The danger I see in this is, for example, if you have conveyers one after the other, then time can pass and then they are not synchronized anymore. The conveyers are usually synchronized because we have as many pieces on them as possible. This seems to be a problem!*

The example illustrates that the designer seemed to have misjudged the interest that the customers and users had in the motor when he talked very technically and specifically about "the heart of the motor". Suddenly one of the customers wants to know how much difference does the loss in rotational speed make. The customer realizes a possible problem in synchronizing conveyer belt applications which neither the designer nor the marketing employee was aware of. The customers and users were also interested in whether the motor should be "short and thick" rather than "long and thin," if it could reverse, if the product programme could resist tough cleaning materials, if the various components were easy to clean, and if it was easy to connect the motor to other components and the like.

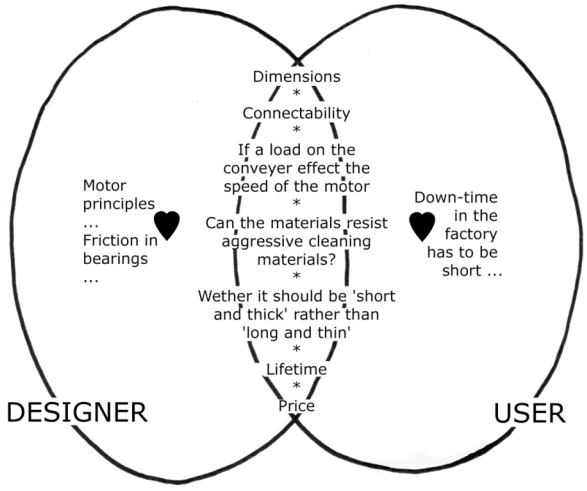

Figure 5. What seemed fruitful to explore and discuss in the WORM project was in the periphery of both the designers' and users' attention and interests during their daily professional work.

What the designer talked about is important in relation to the design, but the prototype he used and the level of details seemed not suitable for discussing with the customers and users. Issues and questions that made more sense to inquire into seem to be in the periphery of professional attention of the designers, the customers and the users. The interesting issues seem to be in the periphery of everybody's daily work, as illustrated in figure 5.

TO DESIGN PRODUCTS FOR OTHER PROFESSIONS

Bucciarelli describes designing in a design team as "a process of achieving consensus among participants with different 'interests'" and says that it "necessarily is social and requires the participants to negotiate their differences and construct meaning through direct, and preferably face-to-face, exchange." [9, p. 159]. Bucciarelli emphasizes that the participants do not have the same interests in the design, and that they have their own ways of looking at it, which derive from their different technical expertise, experiences, and responsibilities in the project. Bucciarelli describes the conditions inside a design team but I will argue that the description is also valid when customers and users take part in design projects.

In his work on the relation between the design object and the conditions in which it has to be used, Wenger emphasizes that the design object has to fit into the professional work the object is a part of, and it has to fit into the surroundings where the work is done [24]. In other words, it has to fit the practice it is supposed to serve.

One of Wenger's main points is that if we are to design an object for a professional practice that we don't belong to and therefore don't understand, the object's fit within the practice is very difficult for the designer to make. To overcome this barrier Wenger suggest that designers and users of the object should collaborate and explore possible futures together.

In the WORM project the workshop series was an attempt to organize and create a forum where a design team, potential customers and user meet face to face and where they explore possible futures as Wenger suggests. As shown with the first example, it was difficult for participants to understand each other and to find out what to discuss, but as the example also shows, they actually succeeded in the end to find and discuss valuable things.

MOCK-UPS EVOKE DIFFERENT ASPECTS

Gradually the WORM design team became more aware of the importance of learning about the potential users' practices and their professional languages. As consultants we understood this as an emerging awareness in the group that users/customers and designers cannot simply exchange information. All are firmly rooted in their worlds of competence, and when this is acknowledged, it is possible to develop a dialogue that can span the gap between these worlds.

Ehn uses Wittgenstein's term "meeting of language games" to describe the framework for participatory design involving users. His point is first of all to go beyond the idea of users as a source of information that can later be turned into requirements. For Ehn both users and designers are able to engage only with topics that fall within the horizon of their professional domains. This means that both users and designers must involve themselves in translating back and forth between their respective worlds in order to come to grips with how, for example, particular design moves will look in the application environment [14].

In this perspective the idea with the WORM workshops was to establish a common ground, a marketplace for the participants in which to create a new language-game that made sense to

everybody. The new language-game was gradually created as the participants began to e.g. understand parts of other participants' professional language and interests. When the customer in the example above, for instance, asks what power 40 bar corresponds to, the new language-game is about to be created. In the WORM project the design team produced posters with statements, questions, drawings, photo-scenarios, and diagrams. They made mock-ups and demonstrations of prototypes to support this evolving language-game. Posters, mock-ups, and demos became 'things-to-think with' that evoked new design considerations just as much as they mediated already finished design work.

Figure 6: In the WORM project the set-up of the workshops was very informal with an emphasis on letting the customers and users be as active in the communication as possible.

Corbett, Rasmussen and Rauner [13] elaborate on Ehn's point. Due to their experiences with user involvement in computer-integrated manufacturing, they emphasize that new insight is not only gained through creating new language-games. The participants learn and gain more when they actively challenge each others' views, needs and constraints on the design time and again. In other words, the aim is not only to make the participants present aspects that are familiar to them so that it makes sense to the others. Designing takes place if the participants are challenged so that they reflect upon their own ways of working which open up new ways of seeing them [13]. At the second workshop a customer explains what he experienced during the workshop this way:

"Usually when I work and have to design a new machine I look in catalogues of components to see what I can get. In the session today you have to specify exactly what you want. I think this is useful also outside this session - we get an experience of what kind of features we want and what to look for in the future."

Binder claims that creating new meaning by challenging one's way of working, etc. is not just a special case for the designer/user situation. When Corbett et al. see conceptualizing as monopolized by certain groups in conventional design, Binder stress that this is the case for work in general and that this "opens up for a more dynamic understanding of competencies and communities as social entities that, in principle, undergo never ending transformations" [4, p. 242].

At the second WORM workshop, the valve designers had supplemented their posters with simple mock-ups of a valve and two manifolds. One of the manifolds was for only one valve while the other was intended for three valves. The mock-ups had few details. They were all quadrangular blocks with smooth edges made of nylon and painted. At the valve, two fittings were placed at the top and in the fittings two short plastic tubes were fastened. The mock-ups were manufactured so the valve could be fitted on either manifold. It was not firmly fixed to the manifold but was fitted in a little elevation.

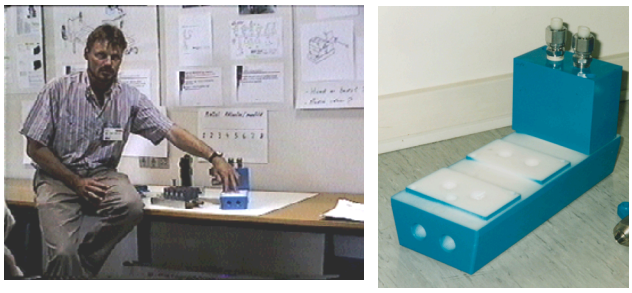

Figure 7: The designer uses a tangible mock-up to explain about the design.

The following exchange took place when a designer asked whether the customers and users preferred the valves assembled in a manifold close to the source, or if the valves should be located close to the application it supplied. While talking, he pointed to the design mock-up several times (Figure 7). Suddenly a customer interrupted and asked if the mock-up showed the final design. The designer began to apologize for the crudeness of the mock-up with its very edgy look, but was prompted to explain why the mock-up looked the way it did. The designer's explanation elicited several reactions from the customers:

Designer: *....at the manifold the dimensions of the fittings are a half inch and it cannot be less because of the loss in pressure. In the design team we have talked about that when P and T goes out in the top of the valve you need a certain minimum distance....*

Customer 1: *What's the reason why you have the tubes coming out of the top of the valve? Is it due to practical considerations?*

Designer*: .....we choose to do it this way because it is too expensive to direct it back inside the valve and we lose too much pressure. When you have 300 bar it does not matter that much but when you have only 50 bar we don't believe it will be a good solution. So we will still suggest that the tubes come out in the top.*

Customer 1: *The reason why I thought of this is that at hydraulic valves you can very quickly change a valve if there is something wrong. You just unscrew four screws and can change it fast. You have no problems with the tubes because they are assembled in advance. This will be a problem here!*

Customer 2: (interrupting): *In pneumatics it is often a choice you have. You almost always have three choices with air. You can decide yourself where you want them to go out; in the top, side, or on the back of the manifold, and then you can plug the ones you don't use. This is very important also if you have to put them in cabinets. It is not very desirable that the tubes come out in the top especially not in relation to maintenance.*

Customer 3: *You have used plastic tubes here. Do we have to understand this literally? Because it says a lot about the whole concept whether it is tubes or pipes. Because if it is flexible tubes then it also opens some possibilities.*

The customers' reflections evoked by the mock-ups varied and each of them seemed to have their own perspective. The two first customers presented various problems with the design of the valve. The third customer had a very different view when saying, that if the tubes are flexible like the ones at the mock-up, then it opens new possibilities.

A lot of the issues about the design of the mock-ups were not a part of the prepared agenda for the workshop. Still the design team concluded that all the aspects were very important for the design. For example the comments above led into a discussion where both customers and users stressed the importance of being able to fast change a valve if it was malfunctioning. One of the customers suggested a kind of "cap" at the top of the valve in which the fittings sat. The idea was that the "cap" could be separated from the rest of the valve if the valve had to be changed. The suggestion let to an important design change meaning that at the following workshop all valves had this "cap", a solution that the customers and users later approved.

In the example the topic of the communication changed after the customer interrupted the designer and asked whether the mock-ups showed the final design. It happened when the mock-up caught the attention of the customer. When the designer used the mock-up in the presentation he had simultaneously committed himself to its design and decided how it looked and how it was produced. If the valve designers had not produced and used the mock-ups it is hard to say if the design change prompted by the discussion would have happened. If the WORM team had omitted design models which illustrated the design the participants would not have had anything physical to anchor their reflections on the discussion would have been, no doubt, more abstract, less worthwhile.

A point is that the relatively simple mock-up seemed to evoke many things about the design and potentials and drawbacks in the use of the product. The customers seemed to take other possessions of the mock-up than the designer. The aspects evoked seemed to be different to different participants as if the mock-up 'talk's back' to each of them individually.

MOCK-UPS ARE USEFUL TO INTERACT WITH

The driving idea behind the WORM workshops was that the designers had the possibility to bring up and discuss questions present in their work. They could, for instance, bring up issues from an earlier workshop they were unsure about. The customers and users on their part could also bring up issues from previous workshops if they wanted. In other words you can say that the designers had more opportunities to learn from the customers and users and vice versa, and thereby design a more satisfactory product programme.

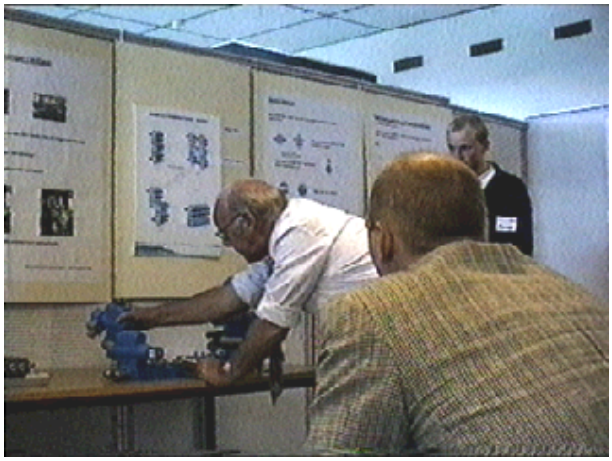

Figure 8. A user interacts with the mock-ups, assembling them to explain his point.

Designers very often brought up issues from earlier discussions, but also the customers seemed committed by to the outcome of the workshops. For instance, a customer returned and said that he was wrong at the first workshop when he said that there was no frost on the shrimp trawlers; he then explained how they had dealt deal with that problem.

At the third workshop the mock-ups were more detailed as more features were built into them than earlier. The amount of mock-ups of valves and manifolds were doubled and made so they were easy to assemble. Issues from the second workshop were brought up again. For instance the design team wanted to discuss valves in connection with cabinets once more. A user (figure 8) explained by using the new mock-ups:

User: *If you are standing out there as a machine fitter or as repairer - if I had to stand there I would very much like it to point this way* (assembling the mock-up to illustrate*)*.

Designer: *Along the wall like that?*

User: *Yes, you can't access the ends of the valves, if you install it in a cabinet like that* (turns the mock ups 90 degrees to illustrate). *But if they are installed this way next to each other then they are both easy to install and repair. I know it becomes a little long, but.*

Designer: *So you have the power supply pointing in this direction and the valves up this way* (illustrates with the mock-ups that the customer had assembled)

User: *Yes, then you need what we call a bottom plate, a big bottom plate in the cabinet because it gets very long.*

This example shows that the mock-ups were very useful both for the user and the designer because it allowed direct interaction and exchange of view. They both engaged in a conversation about how to install the valves in a cabinet as well as problems with maintenance when they are installed.

While interacting with the tangible mock-ups and discussing the participants used their visual, auditory, and tactile senses which I believe evoke more reflections and comments than when limited by a design rendered on paper or in computers. The possibility to physically interact with the mock-ups seems therefore to be one of their major advantages. For other purposes models on paper or in computers might be preferred.

MOCK-UPS AS BOUNDARY OBJECTS

Following the dialogue other customers, users and designers joined in the conversation. The design team sought to identify issues the customers and users could agree upon while the designers took their comments and ideas into account.

The workshops between different stakeholders is about creating a design agreeable to everybody - not in the respect that they understand and 'see' the same but from each perspective the design makes sense. The importance is that the design makes sense from different participants' view according to their interest in the product [9].

Star [23] and Henderson [16] make a notion of objects from which it is possible for different groups to see and understand different meanings as 'boundary objects'. They shall be understood as objects that can give meaning to different participants even though that they have different professional practices and professional languages - different competencies.

The mock-ups at the WORM project can be seen as boundary objects where customers, users and designers can interpret them in different ways according to their interests and yet there is only one design, as illustrated in figure 9. In Star' words boundary objects are 'objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites' [23].

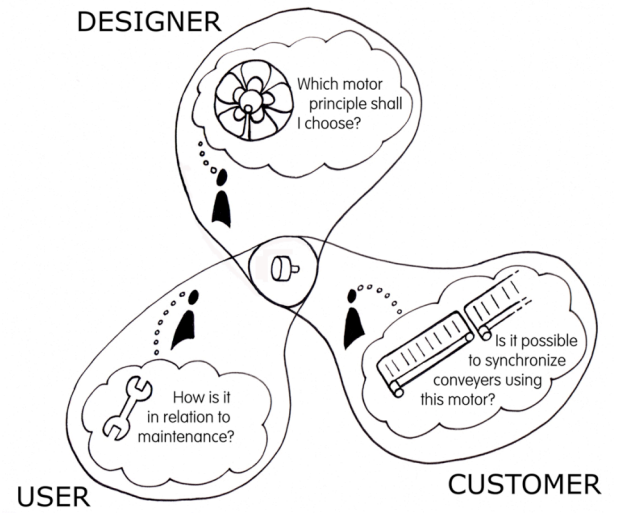

Figure 9. The mock-ups act as boundary objects where different people can understand different meanings from the same model.

Mock-ups as inscription devices

Latour [18] introduces the term inscriptions to describe how 'images from a laboratory setting show up later in another setting where they are cleaned and redrawn for instance as figures in a text'. According to Latour the images are changed but there is still a consistency with the images original source so the internal properties of the subject are not modified.

In the WORM project new mock-ups were produced between workshops. It was clear to see that they had been adjusted in relation to the comments and decisions on the previous workshops. It appears that the customers and users have made their marks on the mock-ups, like if they have scratched in them by their comments and that these were carried to the engineering laboratory from where they effect the design and the new mock-ups. In this respect the mock-ups can be seen as inscription devices through which the design evolves. Mock-ups can act as both boundary objects and inscription devises. This quality though not reserved mock-ups only seems very powerful in collaborative settings where different stakeholders are gathered in design projects.

IMPORTANCE OF DETAILS

Mock-ups are not just mock-ups. Mock-ups can, for example, be made with many or few details. Mock-ups can be manufactured fast and cheap in paper or foam, or they can be made more expensive and time consuming in other materials. Mock-ups can be two dimensional on paper, three dimensional in a computer or three dimensional and spatial.

At the fourth WORM workshop the new mock-ups dealt with more details and a higher degree of finishing than the earlier ones. They looked as if they could almost work. The amount of details and finishing seemed to affect the communication by making it more focused and detailed. This is illustrated in the following discussion where participants discuss different kinds of valves and their needs in relation to each of them.

Customer 1: *It must be possible to adjust the valve without using any tools, and when you have done that it must be possible to lock it by removing a lid, a cap or something. There also has to be something either on the valve or on the cylinder, which tells you its position - something that gives a signal to something else.*

Customer 2*: Isn't it what you use read-switches for today?*

Customer 1: *Yes in air-cylinders that are the way we usually do it.*

Designer: *It is at the cylinder that you want to know whether it has got the message or not?*

Customer 1: *Yes.*

Designer: *The valve does not tell anything about that.*

Customer 1: *It could be that there has to be something that tells that the sleeve valve has changed.*

Designer: *There are some valves with light-emitting diodes, which tell where they are.*

Customer 1: *Yes, they are also very practical when you have to search for defects.*

Customer 3: *We always have light-emitting diodes on all our valves so we can see whether they are activated or not. It also has to do with searching for defects and maintenance. It takes less time to find defects because you can see it physically at once.*

One minute later:

Customer 3: *You need to have light-emitting diodes on the valves that at least tell you if the voltage is on. We always use them - sometimes it is a demand from our customers.*

The customers explain about different kind of light-emitting diodes that exist on the market. Four minutes later:

Designer: *You are demanding that we go to another division in our company and tell them that we want light-emitting diodes on the valves. I don't understand why they* [the electrical division] *haven't said that - they should have them available for sale, but I have never seen them in their product list.*

This example shows how it suddenly becomes clear to the design team that all the customers used valves with light-emitting diodes. Even though it was a designer who said that there exist valves with light-emitting diodes on the market the design team had never discussed this as a prospect for the valves they were designing. During and after the workshop it was clear that the design team was very surprised about this unexpected demand.

The reason why the question about light-emitting diodes appeared seems to be he many details and high degree of finish of the mock-ups. If the mock-ups only had few details and if the finish were very low the customers would probably not have thought of e.g. light-emitting diodes, as they did not look at the mock-up to examine if anything were missing because it was obvious that a lot was missing in the design.

Ehn and Kyng [15] describe experiences with mock-ups made of simple material like paper and cardboard for designing a future computer-software to support newspaper production. They used the mock-ups in collaborative sessions with users to interact with so that designers and users could "play" different use situations in what they call "design-by-doing". Ehn and Kyng claim that the advantages of their paper and cardboard mock-ups were that they gave hands-on-experience, that they were cheap and fast to make, and that it was very easy for everybody to make changes with scissors and pens, and that these changes were visible at once [15]. This is with Beyer and Holtzblatts description of paper prototypes [3].

The time required for model manufacturing can be critical when choosing which model type to use. Simple mock-ups in paper are fast to make and to change which give them the advantage that many different design ideas can be made and evaluated and that no specific skill is needed to make changes. One should not forget, however, that changes in a mock-up

could be very time consuming depending on the design of the object. Ehn and Kyng mention for instance that changes in menus in computer programs can be very time-consuming [15].

Compared with Ehn and Kyng's flexible paper mock-ups the WORM mock-ups were inflexible in the sense that they were impossible to change during workshops. Instead the mock-ups had to be adjusted afterwards in response to discussions. In addition it was quite time-consuming to manufacture the WORM mock-ups, which sometimes meant that the design had developed further between the mock-ups were made and the workshop was held which naturally is a drawback of using this kind of mock-ups. When for instance different use situations were examined we facilitators would have preferred it,, if the mock-ups could have been changed during the workshops and not only in between them.

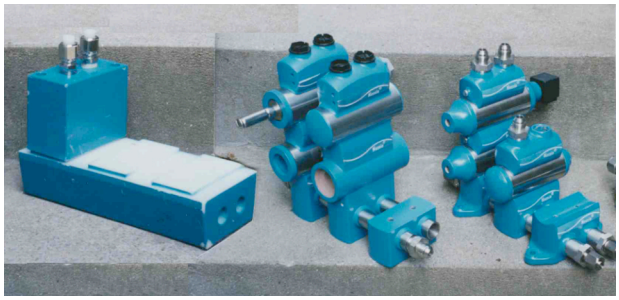

Figure 10. Mock-ups of valves and manifolds from the WORM project. The mock-up to the left was from the second workshop, middle third workshop and the mock-up with most details to the right is from the fourth workshop.

There seemed to be a relation between how detailed the mock-up was and the conversation that develops around it. When the mock-ups are relatively simply without a lot of details the communication around the mock-ups was dominated by associations in many different directions (meaning that there are many comments and the content varies a lot) whereas a very detailed mock-up seemed to give fewer comments and a more focused communication.

This is nether to illustrate that one kind of mock-ups are preferable to others regardless of where one is in the design process, nor that tangible mock-ups are always better to use than other design models e.g. drawings. My point is however that different kinds of mock-ups affect the communication between the participants in different ways and thus influence the design process itself. A question that I find important to explore further is what impact the use of different artefacts has on the collaboration between different groups and if this has an impact on the product to be designed. This is important because findings in this area might give hints to a strategy for improving collaboration and/or the product.

Having workshops with different stakeholders are often a challenge for a design team because different interests and therefore aspects of the design are brought up. Especially in the beginning of the project the design team was concerned about how to define the direction of the design when the customers and users revealed different needs and preferences. It surely is an important questions how to build consensus among participants or how the design team decide which way to go with the design. In this process the use of more and more detailed mock-ups seemed to converge to the final design as the conversation around them became more and more focused. To make models more and more detailed as the design proceeds is part of the nature of designing. My findings show that communication is affected by the degree of details present in the model or mock-up.

As Buur and Andreasen [10] I too stress the importance of intention in choosing the most appropriate design model. But I note that mock-ups can evoke different lines of inquiry other than those intended by the designers of the mock-ups and that these conversations can be essential to the design. The communication about the light-emitting diodes above is an example of this. Therefore I believe it is important in a collaborative design setting not to be too focused on one particular purpose of the model but instead leave room for the participants to bring up whatever the model evokes in them as individuals. The WORM mock-ups were used as "things-to-think with" that evoke different things to the different participants in an open design setting which sometimes results in aspects discussed other than those intended by the design team. These moments often reveal issues that were overlooked in the design. Meeting face to face with customers and users with the aim to share views, interests, and to gain new insight is very fruitful to both the designers and the design of the product. And the customers and users learn new things about their way of working and design possibilities. At least that was what they concluded at the WORM workshops.

CONCLUSIONS

Based on the empirical work, I will argue that the design process is not only about collecting information by asking "the right" questions as design problems seldom are well defined and the designers rarely know all what is needed in order to solve the problems. Design problems are usually framed and re-framed through out the design process as one learn new things and by that get further with the design. The design process in the WORM project is best described as reflective conversations with problems and generation of possible solutions through collaboration between users, customers and designers. The reflective conversations were centred around different design models used as "thing-to-think with"

It seems that collaboration between designers, customers and users can be very valuable during the design process, but still it is not commonplace to know what to discuss and the level of details that are suitable in the meetings between different competencies and interests in the design. What seem interesting and fruitful to explore for all parties is not the most technical issues in the heart of the object, for instance. The overlap of interests between the different participants seems to be in the periphery of each participant's interests and concerns during their daily professional work.

It is important to be aware of the intention with the design model as to choose, build, and use appropriate models for different purposes. Still in collaborative design settings it is important not to be too focused on one particular purpose of the model as e.g. mock-ups can evoke other issues than intended by the designers. Therefore it seems important to give room for the participants to bring up whatever the model evokes in them, as this can be very valuable for the success of the design.

When designers develop products to be used in other professional practices it is very hard for them to design products, which fit within the users practice. This barrier can be surmounted by arranging workshops where representatives from different user types collaborate about the design, if they succeed in creating a new language-game where a mutual understanding of the involved language-games are possible.

Mock-ups appears to be very good in supporting the evolving language-game - the communication between designer, customers, and users as they are very useful in establishing a common ground around which the communication can take place. Tangible mock-ups are perceptible by more senses than

models on paper and in computers and because of this they seems to evoke more reflections from each individual participant. Mock-ups are suitable when explaining aspects of a product, to evaluate or get ideas from, and to interact with and for instance examine a use situation.

The amount of details and the manufacturing technique of the mock-up seem important as the communication is affected by different kinds of mock-ups. Simple mock-ups without many details seem to evoke a very varied span of comments with different content while mock-ups with more details and a higher degree of finishing focus the communication to a 'smaller span' around the model. By building more and more details into the design of both the object and the mock-up the design process seems to converge to the final design as the conversation becomes more and more focused during the workshops.

The participant's reflections evoked by a mock-up varies and each person or group seems to have his or her own perspective. Due to this the collaboration between designers and other stakeholders is about finding out within which limits they can agree on a design. Not in the sense that they understand and see the same things with the product but that it makes sense according to their needs, constraints, and their interests in the future product. In this perspective mock-ups act as boundary objects between different groups and situations.

During the workshops the different participants do not come to see the design task in the same way. They still have different interests in the product to be designed but they increasingly come to learn about their own "design problem" by interacting with each other's problems. This learning process is by no means straight forward but it is dramatically intensified to the extend by which the participants are willing to challenge each others views and temporarily adopt to "foreign" perspectives.

ACKNOWLEDGMENTS

I would like to thank all the people who participated in the WORM project. Thank you to the User Centred Design Group at Danfoss A/S for support and encouragement. A special thank you to Larry Bucciarelli, Jacob Buur and Thomas Binder for feedback on earlier drafts of this paper.

REFERENCES

1. Andreasen M M and Hein L, c1987; Integrated Product Development, IFS (publications) Ltd., UK/Springer-Verlag.
2. Bamberger J, 1991; The Laboratory for Making Things: Developing Multiple Representations of Knowledge, In The Reflective Turn edited by Schön D.A., Teachers College Press, (p. 37 - 61).
3. Beyer H and Holtzblatt K, 1998; Contextual Design – Defining Customer-Centred Systems. Morgan Kaufmann Publishers.
4. Binder Thomas, 1995; Designing for Workplace learning, AI & Society, Vol. 7, 1995, (p. 218-243).
5. Binder T, 1999. Setting the stage for improvised video scenarios. In CHI'99 Extended abstracts (Pittsburgh, PA, May). ACM Press, New York, NY.
6. Brandt Eva, 2004: Action research in user-centred product development. AI & Society (2004) 18: 113-133.
7. Brandt Eva, 2001: Event-Driven Product Development: Collaboration and Learning. Ph.D. dissertation. Department of Manufacturing Engineering and Management, Technical University of Denmark.
8. Brandt E and Grunnet C, 2000: Evoking the Future: Drama and Props in User Centered Design. Participatory Design Conference (PDC'00), New York (p. 11 - 20).
9. Bucciarelli Louis L., c1994; Designing engineers, Cambridge, Mass.: MIT Press.
10. Buur J. and Andreasen M.M., c 1989; Design models in mechatronic product development, Design Studies, Vol. 10 No. 3 July 1989, p. 155 - 162, Butterworth & Co. (publishers) Ltd.
11. Bødker S and Buur J, 2002; The Design Collaboratorium – a Place for Usability Design. ACM Transactions on Computer-Human Interaction, Vol. 9, No. 2, June 2002, Pages 152-169.
12. Carroll J M, 2000; Making Use – scenario-based design of human-computer interactions. The MIT press.
13. Corbett M., Rasmussen L. B. and Rauner F, 1991; Crossing the Border: The Social and Engineering Design of Computer Integrated Manufacturing Systems, Springer-Verlag London Limited.
14. Ehn Pelle, 1988, Work-Oriented Design of Computer Artifacts, Arbejdslivscentrum.
15. Ehn P. and Kyng M., c 1991: Cardboard Computers: Mocking-it-up or Hands-on the Future, In the Design at Work, p. 169 - 195, edited by Joan Greenbaum and Morten Kyng, Lawrence Erlbaum Associates Inc. Publishers.
16. Henderson Kathryn, c 1991, Flexible Sketches and Inflexible Data Bases: Visual Communication, Conscription Devices, and Boundary Objects in Design Engineering, Science Technology, & Human Values, Vol. 16 No. 4, Autumn 1991 (p. 448 - 473).
17. Jones J C, 1970: Design Methods. Wiley-Interscience, London.
18. Latour B., 1990, Drawing things together, Representation in Scientific Practice, Edited by Michael Lynch & Steve Woolgar, The MIT Press.
19. Papert Sivmore, 1980, Mindstorms - Children, computers and Powerful ideas, Basic Books, inc., Publishers, New York.
20. Preece J, 1994: Human-Computer Interaction. Addison-Wesley.
21. Preece J, Rogers Y and Sharp H, 2002. Interaction Design – beyond human-computer interaction. John Wiley & Sons, Inc.
22. Schön Donald A., 1983; The reflective practitioner: How Professionals Think in Action. Basic Books.
23. Star S. L., 1989; The structure of ill-structured solutions: Heterogeneous problem-solving, boundary objects and distributed artificial intelligence. In the Distributed artificial intelligence, Vol. 2, edited by M. Kuhns and L. Gasser, (p. 37-54), San Mateo, CA, Morgan Kaufman.
24. Wenger Etienne, 1990; Towards a theory of cultural transparency: Elements of a social discourse of the visible and the invisible. Ph. D. thesis, University of California, Irvine.
25. The Concise Oxford Dictionary. Oxford Press, 1987.