Using 2D and 3D models as tools during a workplace design process - a question of how and when

Lars-Ola BLIGÅRD[1], Cecilia ÖSTERMAN[2] and Cecilia BERLIN[1]

[1]*Product and Production Development, Chalmers University of Technology*
[2]*Kalmar Maritime Academy, Linnaeus University*
Sweden

Abstract. The benefits of involving users in a development process are well described. This paper describes a procedure for using 2D and 3D models in a workplace design process, which is based on three rounds of user studies within the maritime domain. The process includes various kinds of models that can be used in order to elicit design feedback in a cost-effective manner. Design teams can greatly benefit from using such mediating objects to draw out the users' previous experiences. It was found that different model types allow different levels of reflection and questioning of the design from the prospective users.

Keywords. Participative ergonomics, 3D models, User input, Design evaluation

1. Introduction

The contemporary shipping industry still suffers from high levels of occupational accidents, despite significant changes in working conditions and as work tasks on board evolve towards more monitoring and administrative work (Ellis, Sampson, & Wadsworth, 2011; Hansen, Tüchsen, & Hannerz, 2005). Occupational mortality and morbidity rates for seafarers remain among the highest for all occupations (Roberts & Marlow, 2005). A continuously moving work area and whole-body vibrations prompted by ship machinery and sea motions cause slips, trips and falls, musculoskeletal disorders and fatigue (Lützhöft, Dahlgren, Kircher, Thorslund, & Gillberg, 2010; Oldenburg, Baur, & Schlaich, 2010; Törner, Almström, Karlsson, & Kadefors, 1994). In addition, a merchant ship is not only a working environment, but also a social environment where seafarers representing a multitude of cultures and backgrounds work, eat and socialize together, often for many months on end.

The approach of participatory ergonomics involves end-users in the design and development processes of workplaces, for the purpose of resulting in an adaptation of the environment to the human (Vink, Nichols, & Davies, 2005). End-users contribute important situational knowledge to designers on processes, tasks, equipment, and potential risks. A participatory approach to design and development processes further creates a sense of ownership and acceptance of solutions, more rapid implementation of workplace changes, and increased learning within the organization (e.g. Wilson & Haines, 2001; Vink, Koningsveld, & Molenbroek, 2006).

Figure 1 illustrates a typical ship building process and the design related activities in this process (Veenstra & Ludema, 2006). Ergonomic ideas on elements of the ship's design can enter the process either in the phase of the shipowners' tender, or at the stage of the basic design by the yard. At this latter phase, however, some of the main contours for the ship have already been set and changes may therefore be discouraged, limited or cut short. When the design is already finalized, human adaptation to the circumstances is the only avenue left to achieve a safe and effective operation.

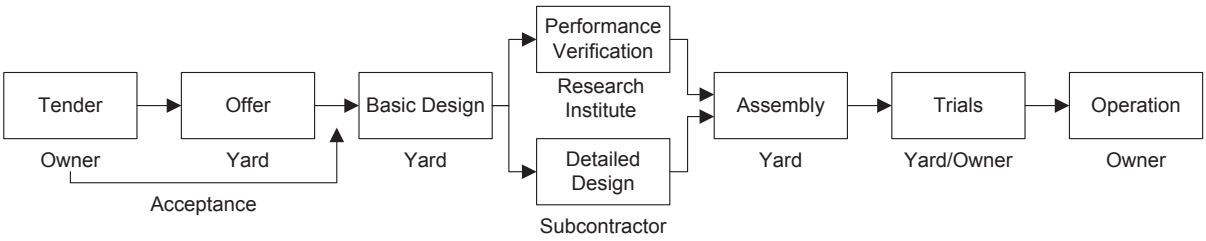

Figure 1. Example of the ship building process. Adapted from (Veenstra & Ludema, 2006)

To achieve good ergonomic design, human factors must be addressed already during the requirement analysis, expanding the framework of 'design for service', operationalized for the shipping industry by Veenstra and Ludema (2006).

The paper will first present research based evaluation of different workplace models as representations of future ship workplace designs and then present a procedure for using 2D and 3D models as a representation form in a workplace design process for ships. The procedure describes when to involve users (seafarers) to evaluate design proposals, and which form of representation to use, in order to efficiently elicit user feedback.

2. Model comparison

The suggested procedure draws on insights from three different empirical studies where 2D and 3D models played a central part: (1) the redesign of a ship bridge in a real company case, (2) experimental comparisons of different 3D representations, and (3) a drawing review with seafarer safety representatives. In all of these studies, model representations were used as mediating objects to stimulate group discussions meant to serve as user feedback to designers, but the explicit comparison was made only in study 2.

2.1 The *four representation forms*

This paper focuses on four representation forms: (1) paper 2D- drawing, (2) 1:1-model, (3) scale model and (4) CAD-model. The paper 2D-drawing (Figure 2) is the classic blueprint, visualizing the proposed workplace from above. The 1:1-model (Figure 3) is a physical 3D mock-up of the workplace in full scale, where it is possible for a user to move around the design elements.

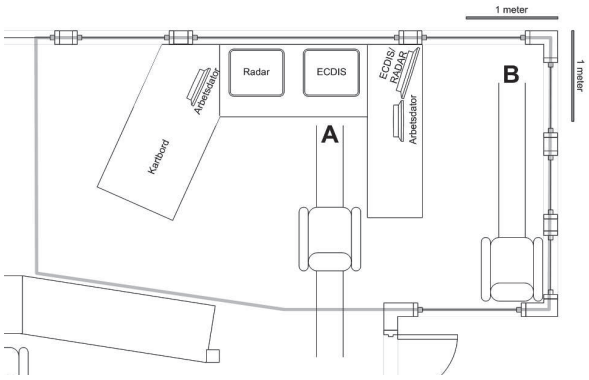

Figure 2. Example of a 2D- drawing

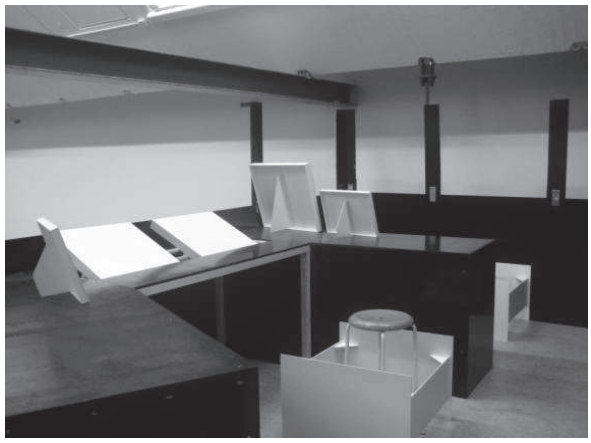

Figure 3. Example of a 1:1 model

The scale model (Figure 4) is a physical 3D representation in a smaller scale. The human can be represented in the model by a scale manikin. The CAD-model (Figure 5) is a

virtual 3D computer model of the workplace viewed on a display. The model can be rotated so it is possible to see the view from different directions. The human can be represented as a computer manikin in the model.

Figure 4. Example of a scale model (1:16) made of foam-core board

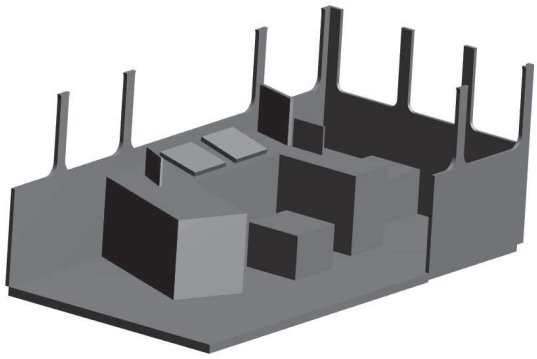

Figure 5. Example of a CAD-model (Computer Aided Design)

2.2 *Redesign of a ship bridge in a real company case*

The setting for this case study (Study 1) was a major re-design of a ship bridge on a Swedish work and supply vessel. The bridge was totally rebuilt and new automation, navigation and communication equipment was installed in new pulpits. The re-design process started with an analysis of the tasks and functions performed by the crew onboard. In the design the project started out using simple 2D drawings. In order to enhance communication and support mutual understanding among and between the researchers and all crew members, 3D models were built and introduced: first a 1:16 scale and later a 1:1 model. The main contribution of the case study to this paper was the practical experiences from using the representations at different stages in a real design process, and the comments and feedback from the users that the different representations elicited.

2.3 Comparisons of 3D representations using nautical cadets as typical users

This user study (Study 2) was a spin-off from the case study above, where four different representations (2D-drawing, 1:1-model, scale model and CAD-model) were used to experimentally evaluate the same ship bridge design. 18 participating nautical cadets in groups of three discussed and commented on the design representations, based on three given use scenarios. The comments from the evaluation were then studied to compare the effectiveness of the four representations in eliciting useful user feedback. The study is described more in detail in (Österman, Berlin, & Bligård, 2011). The main contribution of the comparison study was highlighting the differences between the representations and the different types of feedback that were acquired.

2.4. Review of technical drawings with seafarer safety representatives

Study 3 was a project aimed at guiding seafarer safety representatives towards reviewing drawings and building simple mock-ups themselves to review design proposals from a work environment perspective (Österman & Osvalder, 2011). In all, observations were made during three separate training sessions utilising input and collected experiences from a total of 70 participating seafarers. The main contribution of this study was exploring the possibility to involve seafarer safety delegates in a ship design process regardless of their command and experience of technical drawings.

3. Model findings

The studies described above allowed the researchers to draw some general conclusions regarding the four different model representations as mediating objects. These are illustrated in Table 1. The comparison in Table 1 draws from the researchers' experiences from the three different model use studies, and preliminary coding results from group interview transcripts from Study 2. The comparison was qualitative and no predefined criteria were used.

Table 1: Comparison of advantages and disadvantages for different model representations

	2D drawing	***1:16 scale model (3D)***
Advantages	Easy to read and interpret Easy to change Easy to distribute and multiply Provides good overview of whole design area	Gives 3D-representation with depths and relative heights Provides an overview Easy to make Easier to move and multiply than 1:1 model
Disadvantages	The height dimension cannot be evaluated The flat representation can distort perception of space	Slightly harder to move and multiply than 2D and CAD Modifications require access to materials and model-building competence
Particular considerations	When each participant has their own drawing, interaction is limited A legend should be at hand for any abbreviations, symbols etc.	One shared model can elicit group discussion with users pointing, moving things etc. Possible to rearrange equipment "hands on" to get a better discussion
	:1 model (3D)	***CAD model (3D)***
Advantages	Gives 3D-representation of depths and heights in full scale Possible for the users to be inside the model and relate measurements to their own body	Easier to model bigger part of work space Can provide both a "zoomed out" overview and close-up visualizations Possible to "look through" the eyes of the virtual user to assess heights Easy to distribute, modify and multiply
Disadvantages	Provides no "zoomed out" overview Requires competence and resources to build and store model Modifications require access to materials and model-building competence Difficult to move and multiply, users must be brought to the model	Less intuitive to understand heights and depths since it is a 3D visualization on a 2D surface Harder to navigate and view without experience of manipulating a 3D CAD system
Particular considerations	• Users may want to test the strength of objects, such as sitting on chairs, leaning on surfaces etc. • A too-finished or detailed model may make users afraid to move around and make changes in the model	• It is important that the model is easy to navigate in, especially for users that are not accustomed to CAD environments

4. Generic model use in ship design processes

Drawing on the process of ship design described by Veenstra and Ludema (2006, as illustrated in Figure 1) and the previous results, comparisons and experiences of the authors, here follows a suggestion of how the models can be utilized to elicit design feedback.

In the *Basic Design* phase, a 2D drawing is sufficient to confirm rudimentarily that the design proposal fulfils necessary requirements and needs. If in doubt, a simple 3-dimensional 1:16 model can be built to discuss and confirm space, height and physical ergonomics requirements. If a 3D CAD model is available in the project, it can also be used but the users need to feel able to navigate it. The benefit is that it can be sent to multiple users in other parts of the world and no travel expenses are needed to get their evaluation.

At the stages of *Basic* and *Detailed Design*, suggested design proposals should be evaluated with the end-users and approved using more or less advanced model representations, mock-ups or simulations. This will allow designers to elicit valuable feedback on the design at a stage where it is still feasible to make changes, as well as create a sense of user ownership and acceptance of the design. The designers can either be present at the evaluation or view video recordings afterwards.

In the *Detailed Design* phase, the small-scale model is an appropriate representation to use for initial feedback on the physical environment, layout and furnishings. This stage also offers an opportunity to use 3D CAD if it is available.

In the *Assembly* phase the 1:1 full-scale model can be utilized to confirm the overall layout with users and to move on towards cognitive interface design with appropriate placing of controls, displays and instruments.

During the *Trials* and *Operation* phases the final evaluation is performed. It is often difficult to make changes at this stage, but still imperative to offer the users confirmation of the design, and also to support development and transfer of knowledge from the design process to future projects. No specific models are needed here, since the evaluation is made with the real ship.

The model evaluations can all be performed with a similar procedure. The authors recommend that evaluations be performed as a focus group discussion using the model as a mediating object. First, the model is shown to the participants and they can freely ask questions and explore the model on their own. After that follows a specification of a few user scenarios or work tasks that the user should think of when giving comments – this has been found to draw out the users' previous experiences of performing such tasks, and allows them to voice concerns and alert the designers to common problems or "workarounds". The next step is a moderated group discussion where relevant aspects are walked through. The authors found that the best design-related feedback (related to design parameters, suitability of dimensions and measures and common annoyances in typical use situations) arises when the model (the mediating object) stimulates discussions among the users, where they react to each other's opinions and discuss preferences, work behaviours and use issues.

5. Discussion and concluding remarks

This paper focuses on what type of model is suitable for gaining feedback from the users - no consideration was given to determining an appropriate order to show several models in, to support the technical development of the workplace.

In this paper, only four forms of representations were presented, selected for their

relative ease of manufacture and display to users; the authors concede that there may be additional types or variants that are relevant for workplace evaluation.

This paper explores only one form of user participation. Another useful manner to include users in the design process is to make them part of the idea creation and the design work - for that, an altered use of the models, and indeed a deliberate process for ensuring that users are mentally prepared for handling the model representations, may be needed.

Most importantly, it is important for designers to recognize the value of making discussions between users happen, and to 'fill in the gaps' that are pointed out as design input – it is important to recognize that although users may sometimes not have all the answers, or may not speak directly to the designer's need to tweak placements, dimensions and measurements, there is much to be learned from hearing the users voice experiences, concerns and anecdotes, which can all serve the designers as valuable lessons to make more user-centered workplace designs.

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