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Involving users in a ship bridge re-design process using scenarios and mock-up models

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Abstract

The context for this study is the maritime domain and the design of shipboard workspaces. Due to the globalized nature of shipping, the traditional approach to a participative ergonomics process can be a logistical challenge since stakeholders like designers, manufacturers and operators are often scattered both geographically and organizationally. The participative design study presented in this paper addresses this challenge by exploring the ability of three types of simple three-dimensional (3D) models to act as mediating objects for representative users in order to elicit design feedback in a use scenario-workshop format. The study found that all three types of 3D models, when coupled with a scenario description, elicited several types of useful design feedback that served not only as direct input to changing proposed design parameters, but also as an unprompted long-term learning opportunity for the design team to gain insight into the lives and challenges of their users, who both work and live on board.

Relevance to industry

The paper presents a procedure for a participatory design process in the maritime domain where the involved stakeholders are geographically and organizationally dispersed. Mock-up models coupled with use scenario descriptions elicited useful design feedback and an unprompted long-term learning opportunity for the design team.

Keywords

Ergonomics, Participative Design, Mediating objects, 3D models, User study, Focus groups.

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1. Introduction

Frequently, ships are built without a designated crew in mind, thus there are no obvious end-users to appoint to a user-centred design process. Consequently, it becomes necessary to engage other *representative users* as domain experts. The benefits of involving operators in the design and development processes of new work systems, workspaces and equipment are well established (e.g. Broberg, 2010; Eklöf, Ingelgård, & Hagberg, 2004; Koningsveld, Dul, Van Rhijn, & Vink, 2005; Launis, 2001; P. Vink, Koningsveld, & Molenbroek, 2006). The operators as end-users bring important knowledge about processes, tasks, equipment and potential risks into the development process; knowledge that contributes to both the quality and acceptance of the design outcome. A participatory approach to ergonomics is believed to create a sense of ownership and commitment to agreed-upon solutions, more rapid implementation of workplace changes, and increased learning within the organization (e.g. Mallam, Lundh, & MacKinnon, 2015; J.R. Wilson & Haines, 2001; P. Vink et al., 2006). The earlier in the development process the intended operators can be involved, the greater the possibility to improve the work environment in a cost-efficient way (Hendrick, 2003). It is always costly and not always possible to make alterations once the actual construction has started.

To this end, the present paper explores the types of feedback that can be elicited using model representations to support operator involvement in ship-bridge design evaluation. Focus is placed on the ability of three types of simple three-dimensional (3D) representations – 1) a 1:1 plywood scale model, 2) a 1:16 foam-board scale model, and 3) a digital CAD-model – to act as *mediating objects* (Broberg, Andersen, & Seim, 2011) for representative users with limited work experi-

ence and engineering skills in order to elicit design feedback in a use scenario-workshop format.

The context for this study is the maritime domain and the planning of new or altered shipboard workspaces, where the traditional approach to a participative ergonomics process can turn into a logistical challenge by assembling a collaborative team of designers, manufacturers and operators. Due to the globalized nature of shipping, these stakeholders are often scattered both geographically and organizationally. Furthermore, to the extent that seafarers as end-users do participate in the planning and designing of workspaces onboard, this is traditionally addressed by an invitation to comment on technical drawings, chiefly in the form of two-dimensional paper drawings. With different educational and professional backgrounds, the seafarers' command of technical drawings and ability to communicate in engineering terms with designers can vary greatly, thus further complicating a collaborative design process. At the same time, the 2D paper representation is familiar and therefore usually taken seriously. It is therefore necessary to explore and develop complementary means to elicit, communicate and utilize the seafarers' knowledge and experiences into the early stages of design and development process of shipboard workspaces.

The range of organizations and decision-making structures involved in the shipping industry can be illustrated by the example of the ill-fated oil tanker *Prestige* (CEDRE, 2014), that broke up and sank off the north coast of Spain in 2002, spilling 64 000 tons of oil. The Bahamas-flagged *Prestige* was built in Japan, owned by a Liberian company, managed by a Greek operator, chartered by a Russian-owned Swiss-based oil trader, classed by American Bureau of Shipping and

insured by the mutual London P&I Club. On her last voyage, *Prestige* was carrying Russian heavy fuel oil bound for Singapore. The multinational crew consisted of 27 seafarers from Greece, Philippines and Romania, using English as the working language on board. With such a multitude of stakeholders of different nationalities, the regulation of the shipping industry is inevitably complex with intra- and inter-organizational relationships within and among various members of the global maritime community.

2. Purpose and aim

The purpose of this study is to investigate the potential of using 3D-representations as enablers for involving seafarers in a participative design process. Based on the established success of using 3D representations in other product design domains, it is believed that also the ship-building domain can benefit from using 3D representations as a feasible, useful, effective and inexpensive way to elicit use-related design feedback. The aim of the paper is to examine whether *representative users* (as opposed to end-users) are able to generate useful feedback on design parameters using simple 3D representations, and what kind of feedback a designer can expect from using a combination of scenarios and 3D models.

3. General framework of participative ergonomics and workspace design

Participative ergonomics and workspace design are disciplines based on the acceptance of the employee's expertise on how and within which context work tasks are performed. The participatory approach establishes design processes that enable employees to influence the design so that it is compatible with their goals and beliefs (Eason, 1995). The overarching aim is to improve working conditions, ergonomic fit and acceptance of the workplaces (J.R.

Wilson & Haines, 2001). Involving those who are affected by the outcome of a design process is a way to exploit user knowledge and experiences of work and to fulfil user requirements and needs. Moreover, a participatory approach generates feelings of ownership and commitment to the solutions among the specific target group of a designed product or system (J. R. Wilson & Haines, 2006), often referred to as the *end-users*.

Thus, 'know thy users' is a popular mantra in ergonomic design research and practice, pointing towards issues of face validity and optimal end-results. Often, this is accomplished through observations or direct involvement of either the end-users or *typical users*. These persons are not necessarily the same persons that eventually will use the finished product or systems, but may share some characteristics and background with the intended end-users, such as age, sex, education or job experience.

A *mediating object* is any material object or immaterial aspect that can be comprehended and interpreted by all participants. Mediating objects serve to enable connections and discussions between different participants and work practices in a collaborative design process, for the purpose of eliciting user needs and requirements (Engelbrektsson, 2002). It may be a representation of the product or workspace, ranging from simple sketches to fully functional prototypes. It can also be mental, a thought or an idea that may support dialogue and the transformation of an object into an outcome (Hiort af Ornäs, 2010). The degree of realism in a mediating object does not necessarily predetermine the detail level of feedback from the user (Söderman, 2002). Rather, the users' previous knowledge and experience of different representations influence their capabilities to

focus their feedback on the actual design proposal, rather than the model itself.

The outcome of a participative design process in terms of user requirements can be more or less accessible. Karlsson (1996) divides user requirements into three categories; captured, elicited, and emergent. *Captured user requirements* are easily accessible; the users are already aware of and have reflected over the problems. If a designer simply asks users for requirements, these are the ones received. By creating systematic breakdowns, e.g., by probing with questions or by using different mediating objects such as mock-ups, prototypes or scenarios, requirements can be *elicited*. *Emergent requirements* are impossible to articulate before a new solution is tried. Conversely, the value of the latter two more elusive types of requirements may require greater skill or better tools on the part of the designer, for it to be possible to access them as design input.

4. Research design

The research methods in this study consist of observations, an on-site questionnaire and focus group interviews. A proposed design of a ship bridge workstation (a limited section of the whole bridge) was evaluated by the participants using four different representations of the bridge; one 2D drawing and three different 3D models. This procedure was used to pre-empt participants' feedback on a familiar basis, since 2D drawings are commonly used as a starting point for evaluation of a ship design (as evidenced by Mallam et al., 2015). Three different use scenarios were presented in writing to trigger each participant to reflect on the proposed design as an enabler for the implied tasks. Each evaluation was first made individually on the questionnaire before being discussed in groups. The participants were given no instructions about what kind of feedback was desired, in order to examine what un-

prompted reactions could be obtained using the models.

All focus group material and discussions were written, presented and held in Swedish. Translations into English for the benefit of this paper were made carefully based on the verbatim transcripts in agreement between the three authors, one of whom is a native speaker of both Swedish and English. The order of shown models was alternated for each group to cover all possible cases. This was to eliminate the effects of bias or preference caused by a) the order that the 3D representations were shown in and b) the effect of fatigue on the participants' motivation to contribute to discussions as the experiment progressed.

4.1. Participants

Six groups of three participants ($n=18$) were recruited among nautical cadets in their third or fourth year at a Swedish merchant marine academy. The participants were assigned into groups of three based on their availability, since they volunteered in their free time. Thus, the distribution of ages and genders in the groups was a consequence of convenience sampling. The participants' seagoing experiences ranged from six months to three years. Two of the cadets had worked as ordinary seafarers (for one and two years respectively) before joining the academy. The other participants' experience was limited to the mandatory on board training integrated in the education (TSFS, 2010:20). Thus, all participants had at least some previous experience from bridge work on various vessels. One participant had worked with CAD software before, seven of the 18 participants had experienced shipyard visits, and one person had participated during a new- or rebuilding of a ship.

4.2. Procedure

As illustrated in Figure 1, each evaluation was made with one group of three participants at a time, each session lasting approximately 1.5 hours. Each group was welcomed by the session moderator (one of the authors) and the procedure was explained as the experiment progressed. During the entire session, a paper booklet was available for each participant, where the fictive ship bridge design proposal was put in the context of an existing ship. The booklet included a 2D general arrangement drawing of the whole bridge and described the particulars of the ship, the ship's exterior and various working operations on board, with texts, photos and illustrations. The aim of the booklet was to provide the participants with a general understanding of the ship's performance as a whole, putting the limited bridge representations in context.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Age:	♂♂♂ 33 21 24	♂♂♂ 24 25 23	♀♂♂ 34 23 21	♂♂♂ 28 24 26	♂♂♂ 30 41 25	♂♂♂ 24 25 23
Step 1	Info booklet & 2D drawing					
Step 2	Individual questionnaire & group discussion					
Step 3	1:16	CAD	1:16	1:1	1:1	CAD
Step 4	Individual questionnaire & group discussion					
Step 5	CAD	1:1	1:1	1:16	CAD	1:16
Step 6	Individual questionnaire & group discussion					
Step 7	1:1	1:16	CAD	CAD	1:16	1:1
Step 8	Individual questionnaire & group discussion					
Step 9	Final Discussion (comparing and ranking models)					

Figure 1. Composition of participants, procedure steps and order in which the participants were introduced to the different representations.

For consistency, each group session was moderated by the same researcher who, following a manuscript to ensure that the same information was given to all groups, explained the plan for the session and the use scenarios. With the participants' consent, the session was partially video and audio recorded to capture the group discussions.

After an introduction using the booklet and 2D drawing (Step 1), the participants, in silence, wrote down comments in an individual questionnaire to collect their independent impressions of the model without affecting each other. Afterwards, the comments and opinions were discussed within the group (Step 2), allowing for the interaction and dynamics in the group to result in one idea furthering another. The group dynamics and interaction occurring during the group discussions are a vital part of the method, using the communication between the participants to generate data. Instead of a researcher asking individuals to respond to a series of questions in turn, the participants are encouraged to, in their own vocabulary, ask each other questions, narrate anecdotes and comment on each other's experiences and points of view (Krueger & Casey, 2009), probing not only what the participants think, but also how and why they think that way.

The ship was then presented in one of the three 3D model forms (Step 3) and the participants were encouraged to interact freely with the model by physically manipulating and testing it, in order to trigger evaluative comments to each use scenario; these in turn were also recorded individually in writing and then discussed in the group (Step 4). This was repeated for the two other 3D models (Steps 5-8) and finally the participants compared and ranked the three models according to preference (Step 9). The differing introduction order of the 3D models for each group was intended to mitigate potential effects of increased design familiarity, cumulative learning or fatigue.

All sessions were videotaped, complemented with observation notes taken by hand by the observing researchers.

4.2.1. Ship bridge representations

The participants were asked to evaluate four different representations of a ship bridge, with respect to work environment and workplace efficiency. First, the ship bridge was presented on the 2D paper drawing that is mandatory in Sweden for every new- or re-building of a ship (TSFS 2009:2). Second, the bridge was presented in the forms of a 3D drawing in a CAD program with a manikin function; a 1:16-scale paperboard model; and as a 1:1-scale plywood mock-up (Fig. 2). Efforts were made to ensure that the three design representations were built to the same level of detail, showing the relative placements of physical objects within a room boundary with no human-machine interfaces, controls, textures or colour schemes. As a result, all models were designed to provide the same information level so that they could be compared, irrespective of the degree of detail design that can be ideally represented by each model. However, all elements were to scale and all three included human representations (in the case of the 1:1 model being the participants themselves).

Figure 2. The bridge workplace represented in 3D CAD, a 1:16 paperboard model and a 1:1 plywood mock-up.

The 3D CAD model took approximately eight hours to prepare for a skilled CAD engineer with access to all relevant measurements. The 1:16 paperboard model took four man-hours to make and approximately 25 USD for material costs. The 1:1 mock-up took 14 man-hours for two untrained carpenters to make and 700 USD in material costs.

4.2.2. Use scenarios

The evaluation sessions featured three different use scenarios for the bridge work. The first scenario described a mooring situation, with two persons on the bridge and two persons on deck. The second scenario featured the ship operating in a busy fairway, with other ships in close proximity. The third scenario described a specific work operation where an officer on the bridge had to manoeuvre and hold the ship in exact position while keeping an eye on the traffic, while two persons were conducting a lifting operation on deck.

4.2.3. Ranking of models

After completion of all four model evaluations, the participants were asked to rank the four model types, from most preferable (1) to least preferable (4), in relation to each other regarding the following model usefulness characteristics:

- Easiest to interact with
- Most convincing (as a representation)
- Easiest to discuss (if the model triggers and maintain discussions on relevant topics)
- Easiest to consider alternative solutions
- Easiest to modify
- Works best 'in practice', considering surrounding pragmatic factors influencing the model use situation; e.g. cost of making the model, accessibility, transportation difficulties etc.

As in the evaluations, the ranking was first done individually on paper and then discussed within the group. The reasons for the ranking were also given and then discussed by the participants.

4.3. Data analysis

The written questionnaire answers were transferred to written digital format in a spreadsheet and the video recordings of the group interviews were viewed several times

and transcribed verbatim. The authors worked in parallel with the web-based application Dedoose to manage, code and analyse the data collected from the six focus groups (Dedoose, 2014). Coding analysis was performed on the transcripts and questionnaire data. This coding process involved several iterative cycles of coding by all three authors, discussions to reach consensus on the choice and consolidation of codes, and note-taking to capture additional insights during the analysis process. This was iterated until distinct categories had emerged (Bryman & Bell, 2007). The video data was also subjected to an observational analysis of how the participants interacted with the models.

5. Results

The individual questionnaires and the six focus groups elicited rich and varied input concerning all four representations. It was also confirmed that the participants were able to relate past seafaring experiences to the suggested design. This was largely manifested as spontaneous storytelling and anecdotes. Below is a distilled version of the findings, where focus is placed on the nature of the different types of design feedback received and model-related considerations. This forms a basis for recommending how workplace designers can extract typical users' expertise for the benefit of better design decision support in both the short and long term.

5.1. Design feedback from the 2D and 3D representations

The following sections report on the main types of design feedback elicited and some relevant aspects of using 2D and 3D models to stimulate user comments. Although some pertinent points can be made about differences between 3D model types and their specific limitations and place in the workplace design process, the authors have cho-

sen to focus this paper on feedback received regardless of 3D model type, only commenting briefly here on model-specific aspects. A separate paper is dedicated to discussing such aspects specifically.

Some distinct types of design feedback that may inform the workplace design process were identified in the qualitative analysis. An overview of these is illustrated in Table 1 and is further elaborated on in the subsequent sections.

While there was some subject overlap between the different feedback types, these have been identified as most readily translatable by designers either into requirement specifications, indications of user acceptance, or directions for detailed design changes. Table 2 provides an overview of the relative frequency of coded statements belonging to each category and 3D model type¹, although the authors would like to strongly caution against over-interpretation of the quantification, since coding of many excerpts may overlap. Also, in spite of all authors reading all the material and the intentional, iterative process of reaching consensus on the meaning of codes, the length of individual excerpts may vary in length and coverage depending on the individual researcher. However, this was mitigated as much as possible by constant dialogue during the coding process.

¹ The 2D drawing was always shown first and therefore consistently predominated the greatest number of coded statements both in written and spoken form; for this reason, the "Predominant model type" concerns which 3D model was the most frequent 'elicitor' of additional feedback statements after the pre-emptive showing of the 2D drawing.

Table 1: Main identified types of design feedback elicited by model representations

Feedback type	Explanation
Detail-specific design feedback	Evaluative comments on measurements and placements of operator seats, windows, table heights, passageway widths etc.
Design change suggestions	Comments suggesting that a design element be added, removed or changed (in size, proportion or function)
Movement and space	Comments related to how space between elements in the design affects movement patterns of on-board personnel, room for activities and where to put objects (such as maps, plates etc.)
Evaluative comments related to body dimensions	Comments evaluating design elements to human dimensions, either represented by the user's own body or by an avatar representation in the model
Evaluative comments based on tasks, experiences and alternative scenarios	The design functionality is evaluated and questioned in relation to operator activities and spontaneous user anecdotes. Users also bring up work conditions not directly suggested by the experiment use scenarios (such as bad weather, strong sunlight, dust, non-work activities such as eating at the desk, etc.).

Table 2. Relative number of statements (from all 18 participants) classified into each feedback type

Feedback type	Individual written questionnaires	Discussion statements
Detail-specific design feedback	357	936
Design change suggestions	75	227
Movement and space	76	294
Evaluative comments related to body dimensions	12	155
Evaluative comments based on tasks, experiences and alternative scenarios	161	861

5.1.1. Detail-specific design feedback

One distinct type of feedback was coupled to the visible elements in the model representations, including the overall layout and spatial arrangements as well as the physical details such as windows, seats, tables, counters and screens. All models prompted both questions and evaluative statements from the participants.

(From individual written comments)
"Station A is too far from the port side station so you can't use their monitors. Would like to be able to walk between the station and the windows. Generally find this layout bad. Prefer the more traditional bridges where the stations for long sea journeys are close together."

Certain aspects were awarded more attention than others – for example, a great proportion of comments concerned line of sight within the ship bridge area. The qualitative analysis showed that this subject overlapped significantly with a multitude of concerns, indicating that line of sight and visibility in a ship bridge has an impact on many activities and design elements concerned with the central task of manoeuvring the ship.

Many design dimensions were commented on in relation to body sizes and movement patterns, and to tasks performed on board. Interestingly, many tasks brought up by participants were not prompted by the presented use scenarios, but rather thought up as alternative scenarios (some of them extreme cases) that could influence the suitability of the design. Also, as illustrated in Table 4, many comments highlighted the participants' focus on how the design dimensions facilitated or hindered teamwork.

(From individual written comments)
"The layout does not support collaboration."

(From individual written comments)
"If you want to be two people co-piloting – there's no room for you in the pilot system (...) If you want to point & show to discuss the ECDIS [Electronic Chart Display and Information System, authors' note] it'll be really cramped."

(From group discussion) *"If you want to be two people working there, two screens would be good. This is actually a team sport, but this station is made for being alone on the bridge. Perhaps that's what they primarily do, but (...) I think that it'll be difficult to collaborate on navigation or work when it looks like that."*

It can be noted that as a rule, the written statements tended to be shorter and less elaborate but more precisely formulated, while spoken statements were sometimes revealing in terms of complex reasoning, but more difficult to comprehend if the participant trailed off or used incorrect terminology (for example referring to either of the models as 'the scale model').

5.1.2. Design change suggestions

Participants often volunteered direct suggestions for changing aspects of the bridge design, proposing to add, remove, re-locate or change the size of design details. Such comments were often accompanied by explanatory reasons and reflections on why this would improve comfort, facilitate function, task performance or teamwork, or simply address personal preferences:

(From individual written comments)
"Would have liked to move the monitors at station B. They block the navigator's view at station A and would have liked to place the control panel where they are standing. It'll be harder to keep the ship in position if you have to turn around all the time."

Some design change suggestions involved increased functionality, such as being able to stow or re-adjust certain types of equipment when not in use, and occasionally revealed awareness among users of alternative technical solutions. In some 3D-mediated discussions, participants also involved other participants to see things from their point of view:

(From 1:1 model group discussion)

Participant 1: *"Just sit down once and take a look."*

Participant 2: [sits down] *"Ok, I'm pretty tall, but this position is probably more like lying down than sitting for most seafarers. They can sink down and then they'll have their feet up on the table. No, well it's difficult."*

(From 1:16 model group discussion)
"Remove that (expletive) and put windows there instead, they'll see much better." [starts moving the human avatars around in the 1:16 model]

5.1.3. Movement and space

One specific area of interest when assessing the ship bridge was devoted to movement and space issues, which frequently overlapped with teamwork aspects.

(From 1:16 model group discussion)
 [points to a table segment] *"Remove this middle part here to leave it open, in between here* [uses fingers to indicate the new layout in the model]. *Because if you need two people to staff the bridge in the night-time, in bad weather, you'll both want to check the instrumentation at the same time. There's only room for one here (...) if you're two here you encroach on each other's space."*

(From 1:16 model group discussion)
"I got to thinking, now that you see them here [indicates the human avatars in the

model] (...) not all seafarers are skinny, you know."

The cadets supplied feedback not only regarding movement patterns of onboard personnel and room for activities, but also to issues of where to put and store objects like papers, equipment, plates, mugs etc. A frequently reported issue was the problems they foresaw with sometimes-used furniture like chairs:

(From individual written comments)
"The size of the chairs, as in that they are too large, can become a cause of irritation. Only being able to adjust forwards/backwards is not enough. More degrees of freedom, and possibility to remove completely maybe"

5.1.4. Evaluative comments related to body dimensions

In certain instances, it was evident that certain users had 'pet peeves' that they devoted special attention to elaborating. This was noticeable among participants above or below average height, who often offered their perspective of problematic situations that could arise when their body size was not considered in the ship bridge design.

(From individual written comments)
"I as a tall person spend a lot of bent-back time on the bridge, when driving, working the ECDIS, RADAR, maps. Would be great with height-adjustable tables and panels"

(From 1:1 model group discussion) *"I still think [90 cm is] too low. I felt now that I was standing up and writing, that you had to, like... [bends back to show]... so for map work and the like... for example at that station [points to the table] it would be heavy for the shoulders."*

5.1.5. Evaluative comments based on tasks, experiences and alternative scenarios

All four representations generated anecdotes and comments originating from the informants' seagoing experiences and contextual knowledge. Some anecdotes were self-experienced while others were second-hand accounts of stories heard from colleagues.

The elicited responses showed that participants were able to come up with work tasks and situations beyond the given use-scenarios, which ranged from safety related issues during adverse weather conditions, at night or in bright sunlight, to more mundane undertakings such as cleaning of the bridge or where to place a checklist or the coffee cup:

(From 1:1 group discussion) *"This sounds like something to joke about, but now that there's two monitors here, where's he going to put his coffee mug? Those are the things people really care about. Say that he didn't have time to go eat, then maybe he wants a plate there to eat his lunch (...) you have to find an ergonomic situation that works for all, and maybe he needs to have his check-list right there to tick off, you can't put it anywhere but there."*

The responses described different task and function related aspects such as workflow priorities and multiple uses of the same workspace in different situations. The comments included movement patterns on the bridge and requirements for space and reach when working alone and in a co-pilot situation.

(From 1:1 group discussion) *"In principle, this is built for one person to run the bridge. But it's not suitable for a lone person in bad weather because it'll be a huge workload if you have to have full focus outward on a task and at the same time maintain sea*

safety. (...) There'll be too many things to focus on, so you might miss motorboats or something."

Other anecdotes recognized the ship as a social environment as well as a working environment, relating to social dimensions and comfort concerns. As a rule, illustrative anecdotes almost never came up in the written feedback, but more in the conversational flow of the discussions:

(From 1:16 model group discussion) *"I'm thinking about [Name of ship...] it was just newly rebuilt when I came on board. And then they had that DP-station at the back of the bridge [points in the model] and there was a chair stuck there that was turnable, nice and ergonomic, but it was just a bother to almost everyone on board."*

(From 1:16 model group discussion) *"Last time I worked on board a ship... (...) or rather on a new build... (...) the first captain had designed the bridge and he was over 2 meters tall, so he could see right out. (...) then he quit and his replacement wasn't as tall, and he had some mates who weren't taller than 1.65 meters, and he could barely see over the monitors either [points in the model]. So he wasn't too happy."*

5.2. Model-related comments and considerations

The study confirmed that based on the provision of scenarios and a visualization, typical users are able to give feedback on both detail- and use-related issues. As shown, already the 2D representation itself elicited many design-related comments from all groups, showing that a drawing is able to function as an initial mediating object for stimulating participative feedback conversations. Participants commented on being familiar with the 2D drawing format, expressing a level of acceptance for its credibility as a representation.

The 3D representations were considered more helpful than 2D for envisioning the workplace design and enabling user participation. Irrespective of the order in which the 3D models were presented, all models elicited additional feedback (on visible design elements, their associated activities and work tasks) that was not given by the 2D representation. Specifically, the participants appreciated the possibility to be able to move and walk around in the 1:1 mock-up, using their own bodies as a size reference when evaluating the ship bridge design. However, it was believed by most participants that this option was less likely to be used in a real ship design project, since they believed high costs were associated with the building of the mock-up, and that logistical challenges could arise in bringing together a number of users that may well live in different parts of the world.

While a rather large proportion of detail design discussions began with straightforward opinions on dimensions (many of them on the continuum too high / too low) it was noted across all experiment sessions that participants sometimes altered their opinion when encountering a new model type. Many expressed surprise at the alteration of their perception of heights and distances, both when switching from 2D to a 3D model and when progressing between 3D models.

(From 1:1 model group discussion) *"I think the other one we saw [1:16] was misleading... (...) it felt messier, more cramped, that's my opinion about all of them (...) There's more space in this one [1:1] because I'm standing in it myself, I can relate to it all on a different level here so this, I feel, gives a better overview. I'm not saying it makes the bridge any better, but the overview is better."*

(From 1:1 model group discussion) *"90 cm seemed much lower [in the previous model]... This height was actually pretty good."*

It was noticed that the instances where participants made design change suggestions coupled to teamwork activities (such as removing a chair to make space for movement) were significantly most frequent for the 1:16 model, followed by the full-scale, 2D and CAD models. This suggests that the 1:16 model triggers a different focus, towards overall movement and teamwork concerns.

One major study design issue deserving attention was that many participants expressed unfamiliarity and exasperation with handling and manipulating the CAD model on the screen. This was in part due to the setup with a specialized 'puck' mouse that was especially designed for professional use in 3D-CAD environments to facilitate the rotation, translation and zooming, but the participants had little or no experience with 3D CAD models and found it discouraging to not be able to rotate, translate and zoom the model predictably. This led to a recurring situation where most groups ended up with one person or the moderator manipulating the CAD model while others hung back and sometimes refrained from engaging with the model. This was observed across all groups, and in each session the moderator gave a proper demonstration of it at the request of the participants, but the degree of interaction with the CAD model was noticeably lower as a result. However, participants were still able to voice feedback based on the model.

5.3. Results of ranking

To gain a sense of the users' perception of each model's usefulness, the participants were asked to rank them from a number of

Table 3. Relative ranking of models in order of preference, where 1= most preferable and 4= least preferable. Each cell shows the mean for all 18 participants)

Model usefulness characteristics	2D	1:16	1:1	CAD
Easiest to interact with	3,06	2,56	1,39	3,00
Most convincing	3,06	2,72	1,28	2,94
Easiest to discuss	3,17	2,39	1,33	3,11
Easiest to consider alternative solutions	2,94	2,44	1,56	3,06
Easiest to modify	2,11	2,44	3,06	2,39
Works best in practice	2,61	2,33	2,17	2,33
Mean order of preference	2,825	2,480	1,798	2,805
Relative order of preference based on all the above criteria	4	2	1	3

Table 4. Main identified types of design feedback and usefulness in: change of an existing design, in the detailed design phase, and learning for future design.

Feedback type	Usefulness in different design situations		
	Change an existing design	In the detailed design phase	In learning for future design
Detail-specific design feedback	X		
Design change suggestions	X		
Movement and space	X	X	X
Evaluative comments related to body dimensions		X	X
Evaluative comments based on tasks, experiences and alternative scenarios		X	X

perspectives. Table 3 shows the overall mean rankings of all 18 participants' preference for the different model representations. The results are based solely on the questionnaire results on an individual level.

The mean of all the ranking criteria show a general appreciation of the 1:1 model; however its use in practice is perceived by participants as less likely than the other variants.

According to the reasoning of the participants, building a 1:1-mock-up must be both difficult and expensive, and the supposed restricted mobility of a full-size workplace model, was perceived as a drawback to what was otherwise a unanimous favorite. It was suggested by several cadets that a combination of a 2D drawing and one of the 3D models as a complement would combine the needed holistic overview with easy assess-

ment of movement space, field of vision, reach and accessibility.

Without being prompted, the participants also considered economic aspects when evaluating the models' usefulness for a real ship design process. Several comments concerned the costs and resources for making and modifying the different models. The order in which the models were presented inevitably affected feedback from participants since they gradually relate models more and more to each other. Fewer and fewer unique comments on the models were made towards the end of the sessions, probably due to fatigue and the possibility to refer back to previous comments.

6. Discussion

This study has sought to examine *what kinds of feedback a designer can expect of representative users if they are presented with model representations of a proposed workplace design*. While the domain for testing this query (the maritime domain) is highly specialized, work-life balance oriented, international in nature and involves an operational vocabulary that demanded some seafaring experience on the part of one of the researchers, this test situation has highlighted many considerations that may prove to be transferable to other work domains that involve workspace-related assessment.

The study confirms that based on task scenarios and model representations, representative users are indeed able to provide not only useful feedback on design parameters, but also experiential reflections on the consequences of the design and alternative use situations (both ordinary and extreme) that may pose other requirements on the design. In the evaluations the participants commented on things that were not visually present in the models, a phenomenon also observed in other studies such as Söderman

(2005). This is a good indicator that the model evaluations could help improve knowledge beyond aspects considered by the designers when planning the tests. However, as mentioned by Söderman (2005), there is always a possibility that the participants will evaluate the quality of the model instead of what the model represents. This phenomenon was not directly detected in this study, probably due to the intentionally low fidelity of the models, which minimized the tendency for participants to notice differences in the models themselves.

The results show that combining task scenario descriptions with 3D models as mediating and discussion-stimulating artefacts is a successful way for designers to make dialogue happen in a group of users. Designers learn about the success of their design when participants apply their experiences and know-how to the design and discuss how well their typical activities are supported. Representative users are demonstrated to be able to give the designers valid reasons why a solution will be appropriate or not, with regard to their body, movement patterns, preferences that lead to atypical use, etc. Typical users are also able to alert designers to suboptimal user behaviors (hazards or misuse) that result from fatigue, laziness, annoyance etc.

In this study, the categories of feedback that were identified as useful by the qualitative analysis fell into all categories of user requirements (captured, elicited, and emergent) described by Karlsson (1996). While there was some subject overlap between the identified feedback types, the five defined categories have been identified as most readily translatable by designers either into requirement specifications, indications of user acceptance, or directions for detailed design changes.

One clear conclusion of the study's outcomes is that the combination of scenarios plus model representation is a good source of all types of user requirements even without specific prompting. But *elicited* and *emergent* requirements, which are more elusive according to Karlsson (1996), are obtained particularly well in the focus group discussions that arise, when participants relate and associate to each other's statements. The individual questionnaire statements tended to be brief and referring back to previous written statements as the study progressed, and often focused quite heavily on *captured* requirements such as suitability of heights and other measurements.

This study was performed in the spirit of participatory ergonomics but focuses on one particular aspect: the representative user as a source of information. When applying a multi-step participatory ergonomics process flow in a project (eg. Tappin, Vitalis, & Bentley, 2016; P Vink, Imada, & Zink, 2008; Yuan, 2015), all stakeholders need to be involved and there also needs to be a transfer of information from the designer and/or ergonomist to the users. To support the participatory process, Table 4 suggests the usefulness of different types of feedback in different design situations. With this in mind, design teams can use model representations to steer focus group discussions toward either long-term learning or short-term design tweaks.

Falck and Rosenqvist (2012) emphasize that ergonomics requirements need to be very clear and distinct to work in a development setting. Nonetheless, the authors of this paper feel that it is valuable to recognize that not-immediately implementable feedback can help the designer to get a deeper understanding of the contexts of use. The not-immediately implementable feedback is also a valuable opportunity for the designer's life-

long learning process about user needs and requirements. Such knowledge cannot be underestimated in the endeavour of designing workplaces in a long-term sustainable manner, where the end-users' tasks are not hindered by the design. Many of the anecdotes and comments generated by the participants covered aspects that a design team most likely would benefit from taking into account, but would be nearly impossible to ascertain without the first-hand user experience that the seafarers bring. However, considerable skill is necessary on the part of the design team to be able to interpret anecdotal stories into actual design parameters. But if wisely used, this deeper learning about users and their day-to-day range of use situations can function as decision support for prioritizing design requirements.

This study used typical future users with basic shipping knowledge for the evaluation. A real design situation would most likely benefit from involving real intended users. If no designated crew exists yet, it is still possible to use other ships' crews, or as in this case, students.

With results of this high detail and richness emerging from representation by naval cadets, the researchers are convinced that an additional level of experiential relevance can be achieved with professional seafarers as evaluators, and will also have the additional benefits of increasing participation, empowerment and design acceptance. However, in a situation where seafaring colleagues are present as evaluators, hierarchical differences (such as rank, age, gender etc.) and (potentially) language differences due to differing nationalities may be a factor that inhibits younger, less verbose / extroverted or lower-ranking individuals from voicing their opinion freely. This is however not confirmed or explored in this study. In such situations, it is hoped by the researchers that

offering both an individual channel for input (the written questionnaire) and the focus group discussion will support the input of all participants regardless of such differences. The advantages of such combined approaches have also been described by Garmer, Ylven, and Karlsson (2004) in a study combining usability testing of medical equipment with a focus group.

One interesting reflection by the researchers regarding the fact that all the models except the 2D drawing were partial models (i.e., they demonstrated only part of the whole ship bridge) was that many function-related comments signalled differing mental models among the participants regarding size and function of the rest of the ship (e.g. the parts visible on the 2D drawing, but delimited from the 3D model representations). Sometimes, participants gave feedback on design details based on experiences of ships they had work experience from, rather than the actual ship that they were set to evaluate and that was represented in the booklet. Whether this is regarded as an advantage or disadvantage to the design team collecting input depends on their goal and the type of learning they are seeking. With deeper knowledge, it is possible to make feasible compromises and prioritizations regarding the general design regarding layout and functional variation across different use situations. User anecdotes may benefit the understanding of the variation in use conditions ranging from regular operation to extreme situations.

The results support the notion that 3D-representations can function as feasible, effective and inexpensive enablers for involving seafarers in a participative design process, based on trials with non-expert representative users.

7. Recommendations for designers

Many of the design feedback comments generated by the participants addressed movement patterns on the bridge, multiple uses of the same workspace or surface in different situations, vision-related requirements, differences between day- and night-time activity, comfort concerns, and behaviours related both to work and leisure. Thereby, the ship is recognized as a social environment as well as a working environment. These are design aspects that a design team would benefit greatly from considering both in the long and short term of the ship's life cycle, but would have great difficulties to cover without first-hand user experience. Also, the elicited responses to different functional aspects suggested the participants' priorities in their workflow.

By way of synthesis, the following recommendations can be given to designers:

- First decide if you want a better holistic user understanding, design parameter inputs or indications for user acceptance and system performance – then select a model, use scenarios and feedback input method to support that goal.
- A 2D representation goes far, but accessibility to the model should be a priority
- Physical interaction with a model representation supports and stimulates team input
- Offer both individual and group input possibilities, since individual preparation of an answer first is a good foundation for discussion
- Discussions can give the designer access and insight into the users' reality, and can be a valuable learning experience about users' long-term concerns
- Bear in mind that certain aspects, particularly space, distances and height, can be

very differently interpreted across 3D models

- Use the relative strengths of model types wisely: overview (1:16) vs. subject immersion (1:1) elicit design feedback with different foci, leading to different design change suggestions
- Some interpretation of the collected feedback is still required, and it is up to the design team to combine Human Factors Engineering competence with the users' rich experiences and perspectives.

To collect model-supported design feedback, designers need:

- A good, knowledgeable moderator who can allow different individuals to participate evenly
- Knowledge of the specific domain terminology – both to help interpret the results and to prompt appropriate further questions
- Knowledge of ergonomics principles
- In the chosen model(s): a clear representation of a human, with size reference that helps users relate to their own body
- Clearly expressed use scenarios

8. Conclusions

This study showed that design feedback can indeed be elicited by involving representative users in a discussion mediated by 2D and 3D representations of a ship bridge, and that it is useful from two perspectives:

- 1) Direct design change suggestions based on the options shown by the model, and
- 2) Eliciting user needs, use context and experiences that increase the designer's understanding of the problem and can stimulate inspiration for future innovative and well-supported design solutions

All representations stimulated discussion and comments from all participants; this was interpreted as an acceptance of the models

as mediating objects. The representations elicited various types of comments: detailed design feedback and tangible suggestions for engineering changes, specific design change suggestions, movement and space, evaluative comments related to body dimensions, and evaluative comments based on tasks, experiences and alternative scenarios.

In conclusion, the results indicate that the evaluation methods and representations used in the study would be useful in a real ship design process and probably even more so with experienced seafarers participating. With relatively small means, the procedure supports the benefits of employee participation, contributing to a safe and efficient ship design and subsequent operation.

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