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Evaluating a digital ship design tool prototype: Designers' perceptions of novel ergonomics software

Steven C. Mallam*, Monica Lundh, Scott N. MacKinnon

Human Factors & Navigation Division, Department of Shipping and Marine Technology, Chalmers University of Technology, SE-412 96, Gothenburg, Sweden

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ABSTRACT

Computer-aided solutions are essential for naval architects to manage and optimize technical complexities when developing a ship's design. Although there are an array of software solutions aimed to optimize the human element in design, practical ergonomics methodologies and technological solutions have struggled to gain widespread application in ship design processes. This paper explores how a new ergonomics technology is perceived by naval architecture students using a mixed-methods framework. Thirteen Naval Architecture and Ocean Engineering Masters students participated in the study. Overall, results found participants perceived the software and its embedded ergonomics tools to benefit their design work, increasing their empathy and ability to understand the work environment and work demands end-users face. However, participant's questioned if ergonomics could be practically and efficiently implemented under real-world project constraints. This revealed underlying social biases and a fundamental lack of understanding in engineering postgraduate students regarding applied ergonomics in naval architecture.

1. Introduction

Ship design and construction is a large-scale, multi-disciplinary project beginning with an initial investment plan which evolves through design concepts into a fully constructed and operable ship (Eyres and Bruce, 2012). Ship design primarily involves technical development, complex calculations and modelling to optimize mission requirements, efficiency (e.g. design, build and operational costs) and overall structural safety. Ship designs are predominately developed through computer-aided design (CAD) tools. Advancements in CAD technology have boosted productivity, reducing product development time (Chryssolouris et al., 2009) and allow for rapid computation and comparison of design parameters (Eyres and Bruce, 2012). Due to increasingly globalized design and manufacturing operations, geographically distributed stakeholders require close collaborations over a project lifecycle. Various computer supported collaborative design tools are utilized to facilitate effective management and knowledge transfer between distributed stakeholders. Examples include digital visualization systems, data exchange and management platforms and social software for mass, Wiki-style collaboration (Shen et al., 2008).

Although specific CAD programs exist which consider ergonomics issues, the integration of the human element through CAD software tools is often difficult and ineffective (Feyen et al., 2000). Designers identify a lack of technical tools, domain knowledge and time as barriers to integration of ergonomic issues (Broberg, 2007). Additionally, the lack of flexibility of these tools can limit its application in early stages of ship design planning (Lundh et al., 2012). The adoption of new technologies is influenced by factors such as perceived usefulness, perceived ease of use, subjective norms, facilitating conditions, self-satisfaction and cost tolerance (Ma et al., 2016; Schepers and Wetzels, 2007). Thus, in order to facilitate the adoption of ergonomics technologies in ship design the methods and tools themselves must be perceived useful, usable, and ultimately add value to the ship design process and final product.

1.1. Facilitating participatory ship design

The shipping industry is an extremely competitive domain, where a fundamental requirement of survival is maximizing the efficiency of operations (Bhattacharya, 2015). Within the shipping industry there is little data on the cost-to-benefit ratio of investing in ergonomics and in general ergonomics is under-researched

* Corresponding author.
E-mail address: steven.mallam@chalmers.se (S.C. Mallam).

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(Österman and Rose, 2015; Österman et al., 2010) and under-applied. This can be attributed to a general lack of knowledge, mandatory regulatory support and practical, value-added methods and tools for naval architects and industry stakeholders (Mallam and Lundh, 2013; Mallam et al., 2015). Ship owners and investors traditionally place higher importance on a ship's cargo carrying capacity, speed and versatility, rather than detailed design factors (Veenstra and Ludema, 2006). However, naval architects are responsible for not only developing a structure optimized from a technical engineering perspective, but also the working and living environment for onboard crew. As ships are large financial investments which stay in operation for several decades after being built (International Maritime Organization, 2010) a well-designed, user-centered onboard working environment can contribute to not only increased safety but also improved productivity and economics (Zare et al., 2015).

End-user considerations are seldom integrated into the planning processes of production projects (Jensen, 2002), and even if included do not guarantee measurable success (Hall-Andersen and Broberg, 2014; Neumann et al., 2009). Designers are not always aware of their influence over the people who will be using their finalized design (Broberg, 1997) and do not have many direct interactions with end-users or a deep understanding of their work demands (Darses and Wolff, 2006). This can lead to designers relying on their own experience to anticipate end-user behaviors (Darses and Wolff, 2006). This is of particular concern for ship design because seafaring is a unique and inherently isolating profession and work environment compared to land-based industries. Naval architects are trained as engineers and may have little understanding of onboard work practices or knowledge of seafaring operations. Gaining access to ships in operation at sea can be difficult for naval architects (both professional and students), as well as for researchers due to the logistics and permissions (e.g. security and safety requirements, granted access from shipping companies, etc.) involved in organizing onboard visits. More common are visits to ships docked in port or being repaired in dry dock, leaving naval architects with little to no exposure to onboard operations, access to seafarers or knowledge of the demands of work and life at sea throughout their education.

Applying participatory design practices to the ship development process is a logical method to fill the knowledge gaps between seafarers, who hold tacit, domain-specific experience of onboard ship operations, and naval architects, who are experts in engineering and design methods, and create the ships and work environments which seafarers work on/in. However, ship design and construction processes are highly interdependent, and involve numerous multi-disciplinary, geographically dispersed stakeholders (Stopford, 2009; Österman et al., 2009). Employee engagement levels within the shipping industry are lower than in shore-based domains (Bhattacharya, 2015). Specifically, in ship development it can be difficult to gather all the required stakeholders together for meetings at the appropriate times throughout the relatively long and variable timelines of ship design and construction (Chauvin et al., 2008). The major challenge for effectively supporting participatory practices in the shipping industry is bridging the geographical, cultural and professional gaps between disciplines involved in ship design and construction. Sanders and Stappers (2008) note this can only be possible if stakeholders have appropriate tools and techniques to facilitate effective knowledge transfer.

1.2. Developing E-SET

The objective of the software prototype, *E-SET* (Ergonomic Ship Evaluation Tool) was to create a digital visualization tool aimed to promote and facilitate the integration of the human element early and continuously throughout conceptual ship design and construction. *E-SET* was designed to facilitate participatory design processes and knowledge transfer particularly between stakeholders involved in the development of ship specifications and general arrangement drawings. As investing in maritime shipping requires significant capital, ship investments are closely tied to financial strategies and economic forecasting. A ship is not only a structure for transportation, but a speculation on future markets (Stopford, 2009). A customer interested in procuring a new ship will define its general purpose and scope based on investment strategies and market predictions. However, after the initial mission requirements and ship purpose are defined, the stakeholders who should be involved during the idea generation phase of design are the employees (onboard crew), ergonomists and designers (naval architects) (Vink et al., 2008).

E-SET was developed to open communication channels between these key stakeholders from differing professional backgrounds in order to facilitate the optimization of crew movement and physical ergonomics issues in ship design. Previous work has followed an iterative human-centered framework, developing from identification of user and context goals and needs to low-fidelity pen-and-paper prototyping to its current state as a first generation digital prototype (see Fig. 1).

Shared “in-the-making” objects such as drafting general arrangement drawings create a common language and understanding between multi-disciplinary stakeholders (Broberg et al., 2011). Tangible mapping of end-user movements and tasks visualized through objects such as physical mock-ups and models (e.g. full-scale 1:1 or scaled 1:8, 1:16, etc.), 2D and 3D CAD drawings and 2D paper drawings and sketching can enhance ergonomics evaluations throughout the design process (Anderson and Broberg, 2015; Aromaa and Väänänen, 2016; Mallam et al., 2015; Österman et al., 2016). This is particularly advantageous during early general arrangement design drafts where basic physical dimensions and areas are developed and crew logistics and space requirements can be optimized early and cheaply in the overall process.

E-SET uses task and link analyses methods to evaluate crew work tasks within ships' work environments as its foundation for facilitating human-centered design in naval architecture design practices (Mallam et al., 2015). Work environment information is important for engineering (Broberg, 2007) and virtual reality can help designers identify flaws in prototype designs before they are implemented in real life (Perez and Neumann, 2015). An online database was developed for *E-SET* which captures and organizes crew work tasks. These tasks are then imported into the 2D and 3D ship models of *E-SET* which visually maps crew movements required for task execution on the general arrangement drawings. The task database was populated from data collected through onboard ship visits, interviewing subject-matter experts and reviewing operational literature and manuals. Initial crew tasks were then prioritized based on duration, intensity and frequency of execution. Fig. 2 displays the graphical user interface (GUI) for *E-SET*, presenting a partial ship model in 3D mode. The left-hand side scrollbar displays the database of crew tasks uploaded which are visualized and analyzed within the ship's 2D and 3D models.

Similar to web mapping services, data are visually mapped in *E-SET* where output metrics including frequency of movement, duration and obstacles encountered are calculated and presented. Combining multiple crew tasks and mapping them together within a single ship model exposes high-traffic areas throughout a structure. The visualization of high traffic areas and logistical bottlenecks reveal critical areas to naval architects where obstructions (e.g. auxiliary equipment, electrics, piping, etc.) should be minimized in order to facilitate safe and efficient crew movement (see