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Assisting Human-Centred Ship Bridge Design Through Virtual Reality

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ABSTRACT

Blindly introducing technology into social-technical systems does not guarantee improved user experience and enhanced performance, as evidenced by recurrent maritime accidents. Transitioning from Technology-Centred Design (TCD) to Human-Centred Design (HCD) is widely acknowledged. HCD emphasizes participatory and collaborative design activities. Regarding to certain specialized and niche design entities, designers adhering to HCD often face challenges in fully and effectively utilizing data from field research and secondary sources to elicit design reflections and produce solutions. In contexts such as ship bridge design where designers may lack relevant knowledge and experience, insufficient understanding of using context will harm subsequent design production. This paper proposes a novel application of VR technology in ship bridge design, distinct from traditional educational sector and usability testing uses. By digitizing the map based on Lurås's (2016) layered scenario technique, utilizing VR's immersive and interactive capabilities, the proposed approach will aid the ship bridge design team in comprehending the using context, accurately capturing design orientations, stimulating design thinking, and ultimately achieving user-friendly design concepts to enhance performance in ship bridge.

Keywords: Ship bridge design, Human-centred design, HCD, Virtual reality, VR, Scenario, Layered scenario mapping technique, VR-constructed layered scenario mapping

INTRODUCTION

Maritime industry is undergoing rapid evolution fuelled by technological advancements. Despite advancements in navigation equipment and automated aids, human errors remain a significant contributor to maritime accidents (Grech, 2008). The MAIB (2022)'s 2021 annual report identified a connection between safety issues and design deficiencies in some commenced accident investigations. This aligns with Wróbel (2021)'s proposition, emphasizing the importance of addressing latent risks and underlying problems associated with human errors rather than solely attributing them to navigators' "inattention" or "mistake".

Transitioning From TCD to HCD in Ship Bridge Design

The empirical evidence indicate that the mere adoption of updated technology does not suffice the prevention of maritime accidents as anticipated.

While seafarers exhibit adaptability to evolving work environments, combined with various contextual factors, surpass operators' capabilities. This mismatch results in human errors, leading to incidents or accidents (Lützhöft and Dekker, 2002; Nilsen et al., 2016; Puisa et al., 2018). The indiscriminate introduction of new technologies may outpace operators' training and familiarization processes, posing risks of over-reliance on equipment/systems rather than the well-honed navigation skills. Additionally, the absence of consistent interfaces across diverse navigational equipment can elevate cognitive load. As Norman (2019) advocates, a shift from technology-centred design to human-centred design (HCD) is crucial for optimizing the intricate social-technical system, such as the ship bridge, thereby enhancing human-machine interaction and overall performance.

Adopting HCD in Ship Bridge Design

The integration of human factor knowledge into ship bridge design has been consistently advocated by pertinent researchers over several decades (Millar, 1980; Lützhöft, 2004; Costa and Lützhöft, 2014; Mallam et al., 2015; Praetorius et al., 2015; Ahola et al., 2018; Gernez, 2019; Danielsen et al., 2021). The adoption of Human-Centred Design (HCD) in ship bridge design seeks to optimize navigator performance by enhancing user experiences through a design-oriented approach. Human-centred ship bridge design incorporates HCD principles, promoting active user involvement and a comprehensive understanding of their tasks, capabilities, limitations, and working contexts (Marguire, 2001). Given the complexity and multiplicity of stakeholders in ship bridge, primarily involving seafarers, shipowners, and equipment suppliers—a multidisciplinary design team is essential. Successful implementation of HCD in ship bridge design hinges on collaboration among stakeholders and the application of human factor knowledge (Mallam, 2017). Stakeholders are encouraged to participate in the HCD design process, contributing insights from diverse professional perspectives. An integral aspect of HCD is iteration, leveraging end-users' and stakeholders' feedback, along with designers' reflections, in a continuous improvement design cycle. However, challenges may arise in this participatory ergonomic process, such as discrepancies in designers' understanding of users and their work environment, and varying perceptions of the navigator's role in relation to the technical system (Meck et al., 2009). Additionally, the geographical and organizational diversity of stakeholders poses collaborative challenges. To address these issues, digitized prototypes play a valuable role in presenting design concepts for feedback, supplemented by using scenario descriptions to gain insights and inspirations for ongoing design enhancements.

Potentials of VR in Ship Bridge Design

In tandem with the accelerated pace of technology, virtual reality (VR) has emerged as a novel tool of visualization and interaction to facilitate design reviews (Wolfartsberger, 2019). VR offers the capability to construct 3D assets and narrative scenarios within a virtual environment, enabling the integration of prototypes and immersive experiences. Representative prototypes play a pivotal role in usability testing, aiding designers in identifying and rectifying issues throughout the iterative design process. Engaging end-users in usability testing, whether through physical or digital model representations, 2D or 3D presentations, and within or without working context, proves invaluable in eliciting insightful feedback based on users' experiential reflections. This participatory approach enhances designers' understanding of user needs, working contexts, and existing design challenges, inspiring innovative and well-supported design solutions (Osterman et al., 2016). While physical prototypes are often time and cost-consuming to produce and require additional effort for adaptations to design changes. VR serves as a versatile and collaborative alternative. It addresses those limitations by offering adjustability, flexibility, and collaboration. Moreover, VR provides interactive scenarios in a close-to-realistic environment, fostering user immersion, motivation, and emotional engagement. Drawing parallels with industrial practices, VR adoption has gained popularity in the automobile sector for usability testing with virtual prototypes, dynamic simulations, and component aesthetic evaluations (Freitas et al., 2020). The ship bridge domain can similarly benefit from integrating VR technologies. In summary, VR presents a cost-effective and agile solution in design and development processes. Notably, a recent development includes the launch of web-based collaborative platforms for designing, sharing, and reviewing 3D models online (Bezel, 2022), offering potential enhancements in working efficiency for establishing VR environments.

Within the maritime domain, Virtual Reality (VR) technology has garnered recognition for its efficacy in crew training, facilitating experiential learning through meticulously designed simulation tasks (Stevens and Kincaid, 2015). The presence in virtual environments enhances spatial comprehension, delivering navigators with contextual and scenario-based learning experiences (Renganayagalu et al., 2021). Over the past two decades, full-mission bridge has emerged as primary tools for maritime education and training. VR, in conjunction with other immersive technologies such as augmented reality and mixed reality, heralds a new era of effective teaching and learning within the Maritime Education and Training sector. Aylward (2021) and her colleagues employ VR environments to replicate simulation scenarios, training seafarers to adeptly navigate operations in Arctic waters. Renganayagalu et al.'s (2019) research substantiates the efficacy of immersive training simulators involved VR technology in eliciting higher motivation among trainees compared to traditional methods. Some leading companies and organizations, including Kongsberg, Lloyd's Register, and LNG Shipping (UK), have actively embraced VR technology for maritime safety education (Markopoulos et al., 2019). VR's advantages of participatory, collaborative, and adaptive capabilities become particularly evident when integrated with traditional simulators. Beyond the purview of training, practitioners advocate for the utilization of VR in ship bridge design, emphasizing its utility in both iterative design processes and collaborative design evaluations. This strategic incorporation ensures to deliver a user-friendly and intuitive User Experience (UX), enhancing overall performance ultimately.

METHODOLOGY DEVELOPMENT

This study proposes a methodology for integrating VR technology into human-centred ship bridge design, with the objective of creating a user-friendly interface and interaction to enhance maritime navigation. Following ISO: 9241–210 (2019), HCD activities encompass understanding the context of use, specifying user requirements, producing design solutions, and evaluating design solutions. The involvement of VR can be applied to each phase of the iterative design process within HCD, as illustrated in Figure 1. In the development demonstration, emphasis is placed on establishing a VR-constructed layered scenario mapping to facilitate designers' comprehensive understanding of the ship bridge's usage context, employing the layered scenario mapping technique proposed by Lurås (2016).

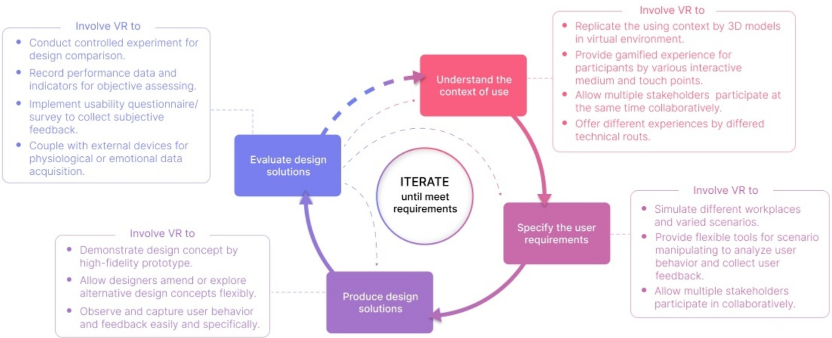

Figure 1: Applying VR's potential involvements to the HCD design activities (2024).

VR's Involvements in the Iterative Design Process of HCD

To understand the context of use, field research assumes a pivotal role in aiding designers to acquire detailed insights into the intended design parameters (Lurås and Nordby, 2015). Crucially, the data collected from field studies necessitates translation into representative outcomes such as user profiles, personas, and "as-is" scenarios, enabling designers to achieve a unified and comprehensive understanding of users, tasks, and work environments. This representation often faces inadequacies, as highlighted by Diggins and Tolmie (2003) in their assertion that it is a "relatively unexplored topic". They advocate for representative insights derived from raw field research data to be economical, presented in an appropriate format, logically organized, and indexical. Aligning the representation with the concept of "boundary objects" as delineated by Star and Griesemer (1989), representative insights should serve as shared knowledge repositories for design team members. VR's incorporation becomes essential in creating a close-to-real and interactive representation of using contexts. Designers take on multiple roles in building this VR representation, acting as collectors and visualizers of primary and secondary research data, developers constructing the virtual environment, and users interacting subjectively with simulated VR scenarios of the workplace replica. Other stakeholders' engagements primarily manifest as pragmatic advice and knowledge input. They serve as instructors guiding designers through the VR representation's development.

They may also immerse themselves in VR scenarios to offer intuitive feedback on similarities and differences compared to actual using contexts. VR's integration establishes a collaborative platform for the entire design team, fostering a consolidated and comprehensive understanding essential for a multi-disciplinary team faced less familiar design entities.

During the user requirement specification, VR proves instrumental in eliciting user needs and requirements through simulated environments and diverse scenarios. VR offers flexible toolkits enabling designers to observe, record, and analyse user challenges within gamified scenarios, thereby elucidating user capabilities and limitations. Designers can immerse themselves in the context experienced by users, facilitating a comprehensive review of requirements. This immersive experience aids in resolving trade-offs by considering professional guidance and adhering to regulatory standards.

In the design production stage, transitioning from "as-is" to "to-be" scenarios is imperative to meet specified user requirements. This involves integrating user tasks, user-system interaction, and interface considerations into the design concept, iterating as needed. Utilizing VR, a high-fidelity prototype of the ship bridge is developed, fearturing 3D models of equipment, workplace layouts, task scenarios, and interactive interfaces, for a comprehensive representation. VR facilitates flexible and collaborative decision-making of design, allowing exploration of alternative concepts. Specific user behaviours and feedback captured during evaluation enhance the refinement of design concepts in terms of quality and completeness.

HCD underscores the iterative design process by prioritizing user-centred evaluation, ideally conducted within a context closely resembling real-life conditions (ISO, 2019). This approach facilitates collecting additional user needs and feedback, aiding continuous improvements. The fulfilment of user requirements serves as a fundamental indicator for examining design solutions, contributing to the establishment of design criteria. VR-involved evaluation bridges the gap between design demonstration and field validation in a virtual way, offering a collaborative and flexible evaluation method in an immersive context. This allows for convenient manipulation of conditions for controlled experiments, facilitating the recording of the evaluation process with time-stamped precision. In addition, VR's interactive interfaces enable the integration of usability questionnaires during without frozen time, and its compatibility opens avenues for acquiring additional physiological and emotional data through external devices.

VR-Constructed Layered Scenario Mapping Technique

In accordance with HCD principles, a foundational aspect for subsequent design production is comprehending the usage context, especially in specialized domains such as ship bridge design where designers often lack prior experience and knowledge. Field studies, as previously mentioned, emerge as an irreplaceable method for obtaining valuable information, stimulating design reflection, and fostering insights within the design team. Lurås (2016) recognizes the challenge of appropriately presenting and transferring fragmented data collected from field research within the design team. In the Ulstein Bridge Concept design, Lurås proposed and employed the layered scenario mapping technique to interpret the "situation to design for" for the entire team. The representative map generated, a 0.9*4.3m poster hanging on the wall, efficiently communicated knowledge of the using context for unfamiliarized designers and served as a well-structured guidance for design inspiration and discussion in future. However, Lurås (2016) suggests exploring the digitization of layered scenario mapping to create a digital knowledge database, offering easy access, revision, editing, and communication without constraints of time and place (Wodehouse and Ion, 2010). Despite the advantages, concerns about the scenario technique focusing on user actions rather than the person (Nielsen, 2002) persist. Lurås and Nordby (2014) highlight "experiencing life at sea" as a crucial element in design-driven field research for ship bridge design, akin to empathetic approaches in emotional design (Norman, 2004). To address these concerns, integrating Virtual Reality (VR) technology becomes a viable solution, potentially compensating for the identified deficiencies.

VR has the capability to convert diverse materials acquired from field studies and secondary resources into visualized 3D assets within an interactive virtual environment. Scenarios in VR are furnished by replicated 3D prototypes of ship bridges and simulated videos/animations. The layered information deconstructed of the selected scenario can be presented in the interactive VR interface, enhancing the design team's understanding, and encouraging iterative design thinking. Technically, VR scenarios can be systematically developed into an integrated application tailored for VR head-mounted devices, facilitating immersive engagement. Simultaneously, a web-based digital twin can be established to enable convenient remote access and foster collaborative interaction.

This study aims to develop a VR-adapted layered scenario map for a 60-minute training scenario. We draw upon methods employed in Lurås's map (2016) and incorporate additional techniques such as Hierarchical Task Analysis (Annett and Stanton, 2000) and Decision Action Diagram (Kirwan and Ainsworth, 1992). The inclusive information "layers" (refer to Figure 2) encompass *scenario description, decision-making, tasks and goals, operations and activities, equipment utilization, involved actors and their positions, required information,* and *VR-provided touchpoints* to enhance designers' understanding of using contexts. The layered scenario information is dynamically constructed in VR scenes, aligning with scenario sequences, utilizing various mediums and touchpoints offered by VR technology. Diverging from the paper-based map, the VR mapping narrates the scenario in a gamified manner, engaging participants through interaction rather than relying solely on textual descriptions, charts, and images in a linear timeline matrix.

This exemplary map delineates layered scenario information through key event sequences on a timeline. Extracted from a 30-minute segment of a training session in an actual ship bridge simulator. The deconstruction serves as a crucial preliminary step subsequent construction in VR environment. Marked sequences encompass ongoing navigation tasks and pre-set emergencies designed to challenge the bridge team's capabilities. Each event in the scenario necessitates corresponding decision-making and a series of operations. The equipment used and required information are pivotal for design orientation, while the involved actors and their positions elucidate the structure and interactions within the bridge team. Noteworthy is the bottom 'layer', VR touchpoints, which suggest potential interactive prompts for use in the VR-constructed layered scenario map. VR technology, equipped with interactive touchpoints, communicates through gamified narratives, actively engaging users' interests. Some touchpoints are adapted from serious games to meet the specific goal of aiding designers in understanding the ship bridge's using context.

The subsequent phase involves creating the VR environment for the chosen scenario within the simulator. The floor plan of the simulator (depicted to the left in Figure 3) was detailed in a previous study (Guo et al., 2022), providing a scaled representation of equipment layout in a top view. The initial step towards constructing layered scenarios in VR is the replication of a digital twin of the simulator, utilizing the floor plan and dimension measurements. Figure 3 (displayed in the middle) showcases the ongoing modelling efforts in Blender 3.1 (Blender, 2024) for the interior and equipment layout of the simulator.

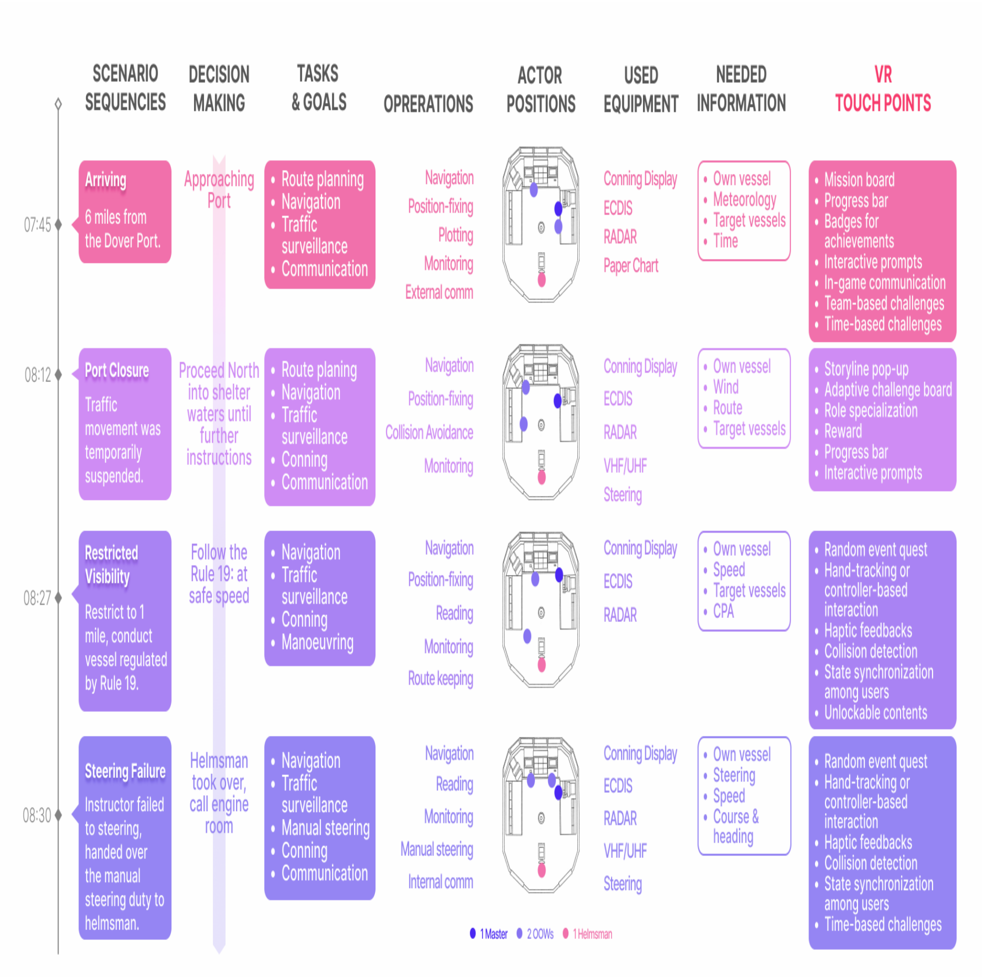

Figure 2: Example of layered information by deconstructing the training scenario (2024).

In the agile development of the VR-constructed layered scenario mapping for the understanding using contexts, the focus lies on replicating spatial perceptions and interactions between users and equipment within the 3D replica. To adhere to time constraints and budget considerations, the intricate tasks of sculpturing, texturing, rendering, and lighting have been streamlined. In this instance (Figure 3, right side), the 3D models are prototyped with precise shapes and dimensions, albeit not fully polished. They are predominantly coated with general, glass, and metal materials to align with the actual textures of the objects in reality. Monochromatic colours are applied to distinguish different equipment, while one point light and an HDRI image of ocean environment are utilized to simulate natural shadows and reflections within the authentic usage context.

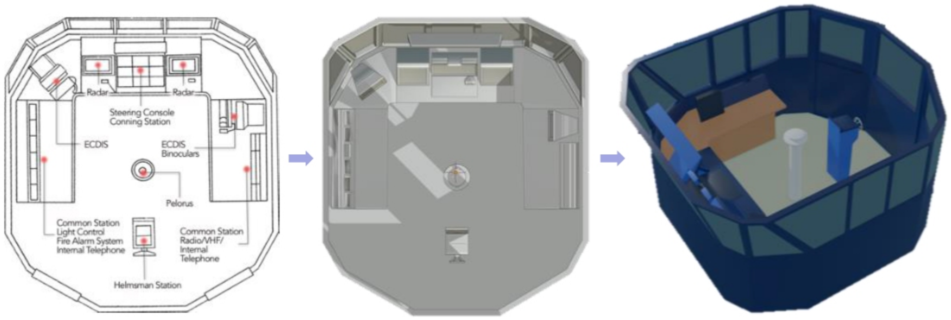

Figure 3: Development progress of 3D prototypes for VR-constructed layered scenario (2024).

Subsequent efforts will focus on the ongoing development of graphic user interfaces within VR to implement the layered information mapped in Figure 2. Leveraging the endowed touchpoints, VR facilitates a rapid understanding of the interface and interactions within the using context for inexperienced users (unfamiliarized design team), when they engage with the virtual scenarios.

CONCLUSION

Integrating VR technology into human-centred ship bridge design expands its application beyond the prevailing focus on maritime education and training. This study, building upon the layered scenario mapping technique (Lurås, 2016), digitizes paper-based maps using VR to enhance effectiveness in design activities. This methodology empowers designers to leverage research data comprehensively, gaining a nuanced understanding of the design situation within a virtual context, thereby supporting subsequent design activities. The proposed approach aligns seamlessly with research objectives on multiple fronts. Firstly, information layers offer requisite details at a necessary granularity for design activities. Secondly, VR's interactive capabilities allow designers to subjectively experience and understand the design situation within the using context, fostering design reflection without excessive time and cost constraints. This achieves the essence of "experiencing life at sea" (Lurås and Nordby, 2015). Thirdly, VR-constructed layered scenarios, as digital content, can be easily stored, modified, and shared, evolving into a continuously refined digital repository to support ongoing design activities. Furthermore, this approach is adaptable to design situations in other domains, particularly those specialized and niche social-technical systems involving both human and technology elements.

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