The Implementation of Virtual Reality Software for Multidisciplinary Ship Design Revision

Christopher-John Cassar, UCL, London/UK, christopher-john.cassar.16@ucl.ac.uk
Nick Bradbeer, UCL, London/UK, n.bradbeer@ucl.ac.uk
Giles Thomas, UCL, London/UK, giles.thomas@ucl.ac.uk

Abstract

This paper proposes integrating Virtual Reality (VR) into the ship design process to support Human Factors Engineering (HFE). Virtual reality tools have been proposed for various areas of application in ship design, but the literature includes few detailed investigations that provide evidence of efficient implementation. The first version of a VR-HFE design process and revision tool, based on Unity and C# scripting, is presented. The current functionality includes the ability to import design files into the VR environment at full scale in a straightforward and fast way. The tool allows rapid transition from the model space to VR visualisations with minimal additional workload. The applicability of the tool is demonstrated for a ship design revision application of HFE focused compartments.

1. Introduction

Virtual Reality (VR) for ship design has garnered interest due to benefits such as increased immersion and spatial awareness for graphics visualisation. The development of VR is proposed as the next step in advanced visualisation methods allowing the design engineer to focus on a greater amount of detail within the design *(Šikić and Bistričić, 2015*).

The use of VR within the ship design process is suggested to have benefits that can increase error mitigation for design models from both a naval perspective and commercial one *(Lukas, 2010; Rosenblum, L. et al.; 1996*). It may also lower the dependence of physical models for detailed aspects of the design due to the designer obtaining access to a full-scale version of the design within the virtual environment. As a result the designer is able to look at an up-to-date concept version of the model rather than wait periodically for physical models for further design analysis. These virtual models may be more cost effective due to avoiding the validation of concept design physical model stages and other associated model costs *(Torruella, 2014*).

This paper presents a VR design revision tool for multi-disciplinary design collaboration. The tool was developed using the Unity game engine with C# scripting. Series ship design process models, developed to find areas of implementation, are also demonstrated in this paper. These design process models were based on the Design Research Methodology (DRM) used for engineering design research.

2. Maritime Design Applications

Direct applications of VR to ship design opens some opportunity for further concept exploration. Qualities such as access to multi-user based environments and first person perspective design revision offer the engineers a greater amount of communication opportunities and user-focused design elements to improve the design.

2.1. Off-shore Structure Design

Offshore structural design often requires knowledge in structural arrangement and technical analysis. The increased level of focus and spatial awareness that is offered by VR design based tools can help less experienced designers understand the concept and requirements. Due to the first person environment of VR and the ability to create multi-user based environments this makes it especially useful for design revision and contract design stages *(Kaye et al.; 2017; Streuber and Chatziastros, 2007*). A past major issue for utilising VR tools was the difficulty of interfacing VR with CAD, but recent developments in CAD have allowed for file formats and application plugins to be employed. (*Larkins et al.; 2013*). Developments within the software building environments have made avenues for developers to create user-friendly applications for offshore structural design (*Cook et al.; 1998*).

Design review and visualisation within VR makes it possible for effective management planning through scenario simulations. These applications can be designed to simulate a design of interest during a specific event (*Chapman et al.; 2001*). The information obtained from this event can later be used for lifecycle management and also design refinement if done at an early stage.

2.2. Vessel Design

The use of VR within the ship design process is suggested to have benefits that can mitigate errors from both a naval and commercial perspective *(Lukas, 2010; Rosenblum et al.; 1996).* During the beginning stages of design, rendering into VR environments has had noted issues, such as lack of design clarity and detail, but as the technology has improved the benefits have begun to out-weigh the drawbacks *(Morais et al.; 2017).* This has seen the U.S. Navy implement advanced visualisation systems within their facilities *(Koolonavich, 2018; ProQuest, 2004)*, and also the development of new tools for existing CAD software *(Šikić, 2017)*. Using these virtual environments lowers the dependence of physical models for detailed aspects of the design, because the designer will have access to the full scale version of the design within the virtual environment. The designer is able to look at an up-to-date concept version of the model without waiting for a physical mockup to be constructed. These virtual models are cost effective because they reduce the expense of producing physical models and remove the space required to store such models *(Torruella, 2014)*.

VR within the design process offers a new avenue for design editing and innovation. Understanding the design from a full scale and immersive perspective gives the design team involved a more accurate depiction of the model dimensions and ergonomics of the arrangement *(Alonso et al.; 2012)*. VR allows the designer to find faults in the design in a much easier fashion than traditional CAD *(Jamei et al.; 2017).* Virtual team environments are an important benefit of VR as this gives the designers involved a greater amount of shared visual information to use for illustrative purposes during design revision. This can also make it simple to illustrate design alternatives through annotations as it is important to review information consistently *(Cebollero and Sánchez, 2017).*

Added functionalities within the VR environment, such as first person environment object manipulation or design modification is proposed to make the design revision communication easier to implement between design departments *(Martin and Connell, 2015)*; this allows the design modelling aspect of VR to become a less cumbersome process. VR application of general arrangement designs was proposed *(Ahola et al.; 2014; Reina Magica, 2014)* which uses VR for deck plan modification and other levels of annotation. The stated benefits of this are that it helps with the early stages of vessel general arrangement as this stage relies on the development and analysis of new concept ideas. Using VR and applying it within ship design can allow for thorough navigation of design concepts, which aids in design error mitigation by increasing focus of the designer within the vessel *(Perez et al.; 2015)*.

There have been proposals to use VR technology within 3D model testing for design revision. *Soares (2011)* suggests that the use of virtual environments for presenting model simulations helps to increase the realism and the clarity of the results. VR technology within ship design revision is suggested by *(Fernández and Alonso, 2014)* to allow for more comprehensive ship predictions about the characteristics of a vessel design. This is due to the increased amount of detail that is shown in the visualizer. Giving the design team more visual information to work with will enhance the accuracy of predictions of the impact that design changes can have on the vessel's lifecycle performance.

VR in ship design revision and collaboration is an important addition to the overall ship design process. By creating a VR environment that encourages technical communication this creates a shared representation of the design *(Menck et al.; 2012)*, which can be supplemented by the implementation of work scenarios. This can be used to take into account the needs of the crew members involved in the vessel design *(Nordby et al.; 2016; Thérisien and Maïs, 2008).* The end user is also able to learn from this collaborative environment, which can increase the transfer of relevant knowledge amongst both parties *(Pynn, 2017).*

3. Ship Design Process Applications

There have been logical areas of application for VR within the maritime industry. Placing the technology into an array of sub-fields demonstrates the possibilities of implementation and leads to the work proposed in this paper.

3.1. Design Research Methodology Application

Design Research Methodology (DRM) is a research framework that is used for engineering based design projects. The reason behind using the DRM as a basis for this project is its clear method of application for design research projects, and its implementation of design research guidelines. The details in the stage deliverables, as presented by the DRM, offer more applicable information for this research. This is presented in the breakdown involved in the different stages of the DRM framework as shown in Fig.1.

The aim of DRM is to support the design process of the engineering research industry by creating an avenue for better understanding of the process and product. This aim leads to a series of questions that are the foundation of this research, which is presented (*Blessing and Chakrabarti, 2003*) as the following:

- When is a product considered successful?
- What is the process for the creation of a successful product?
- What can be improved to increase the probability of success?

These questions open up the opportunity to look at the factors involved in an engineering design. Considering the measures of success, an efficient process for this success, and the elements involved in the design process, makes it easier for the design engineer to categorize the requirements of the product to increase its chances of solving its derived issue. This analysis is then expanded upon to develop the basis of the direction for design research.

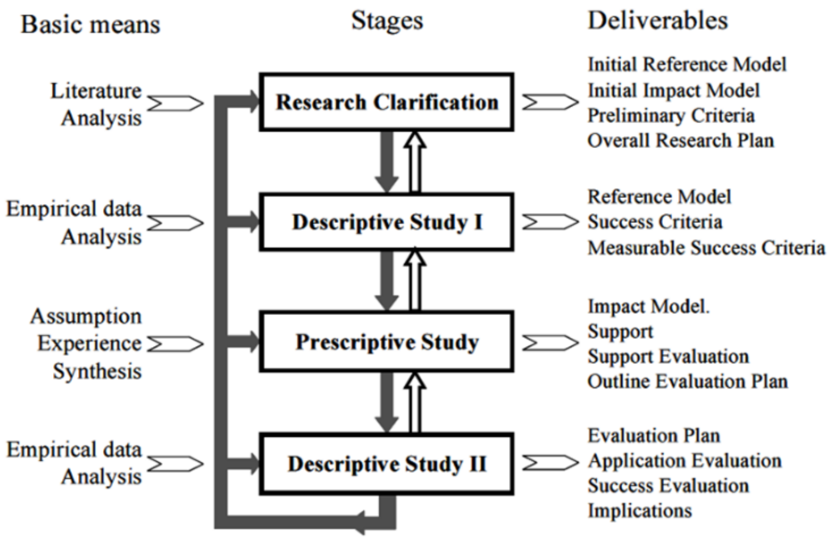

Fig.1: DRM framework process model *(Blessing and Chakrabarti, 2009)*

This guides the project to analyzing the process involved in ship design. The position at this stage is to understand the stages involved in the ship design process and find out where VR could be applied.

These factors would depend on breaking down the benefits of VR and finding out the criteria for the different stages in the ship design process.

3.2. VR-HFE Concept / Preliminary Design Process

In a recent study conducted by the author, a series of ship design processes were developed, which were compiled from literature and information gathered through interviews with Naval Architects and Human Factor Engineers. The first task was to develop a generic ship design process. After the interviews the design process was discussed with external Human Factors Engineers; this led to a first version of the Human Factors Engineering (HFE) ship design process. From this point, specific tasks in the design process were recommended based on their ergonomic requirements for VR-HFE implementation. This led to the first iteration of the VR-HFE ship design process being drafted.

There are HFE considerations that are taken into account during a design review. Some of these conditions rely on observational analysis using specialist knowledge and regulated criteria. Considerations for internal design must look at the following conditions in order to better benefit the crew members *(UK MoD, 2006*):

- Human factors considerations:
    - The motion of the vessel with regards to the placement of the design spaces.
    - Rate of traffic flow within passageways and other busy work spaces.
    - Requirements for hazard mitigation, firefighting, and other damage control aspects.
    - Escape routes and causality routing methods.
    - Recreational criteria for social activities within the vessel.
    - Environmental issues such as vibrations, noise and working temperature.
- Access and egress arrangements:
    - Focus on areas of work traffic flow including areas for embarkations and disembarkation.
    - The requirements necessary for storage and removal of goods and other equipment.
    - Acknowledgement of essential escape routes.
- Requirements for common equipment:
    - Emergency breaker positioning.
    - Location of alarms and other warning systems.
    - Placement of light switches and their operation requirements with vessel spaces.
    - Internal communication equipment location and complexity.
    - Inventory style and location for compartments, including the legend-design and placement.
    - Location of emergency escape equipment.
- System routing:
    - Location of intake and uptakes.
    - Design of pipe joints with respect to end-user requirements.

In these considerations there are some that VR can offer benefits. Areas such as the traffic flow design, escape route design, causality routing methods, and hazard mitigation design specifications can see an increase in design observation resulting from VR first-person design revision. There are also aspects such as the positioning of emergency equipment, alarms, communication equipment, and general inventory that would benefit from the increase design focus offered by VR environments. VR can offer the ability for the design engineer to re-enact the process of using such equipment, which will aid in their design decisions.

The routing of systems with regards to end-user requirements is also an important criteria the design engineer must recognize.

In order to develop a ship design process that was applicable to industry standards it was important to obtain information both from literature research and interviews. The interviews focused on the order of the ship design process tasks and HFE practices, which was used to add information towards the ship design processes developed. This gave the ship design process designed an opportunity for feedback on areas that literature did not cover. The process models were designed in the Cambridge Advanced Modeller tool, which was made for engineering design process model research.

Defining the stages of VR implementation was necessary for the scope of this project as shown in Fig.2. The concept design stage was chosen as the initial area of investigation. This was done based upon the level of flexibility involved and public information available. Also, the information gathered at the concept design stage can often have the impact that can be carried on through the entire design cycle. By implementing a tool that can increase the ability to make accurate decision early in the design process, this can make the later stage design decisions less meticulous.

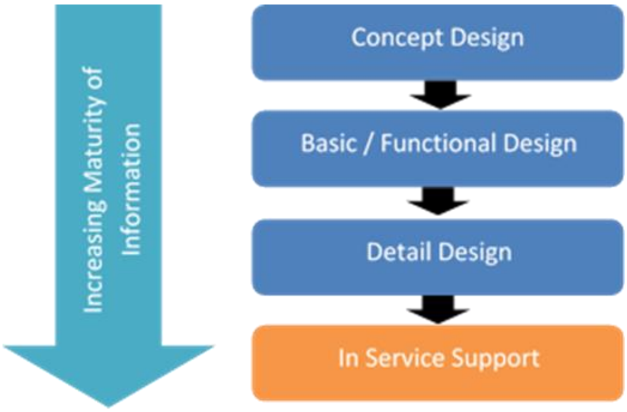

Fig.2: Ship Design Process

Through information gathered in the interviews, general arrangement, machinery arrangement, and payload definitions were recognised as areas that benefit from ergonomic human factors analysis. The design of these areas directly impacts the crew. These areas have a degree of dependence on visualization to make certain HFE design choices. The naval architects involved in this stage will have the opportunity to take into account work conditions from the perspective of the end-user. This means that VR can offer a level of immersion that can impact design decisions.

Fig.3 shows a machinery arrangement sketch during the concept stage. During this stage only the spatial requirements and basic layout design for primary components are known. There is also an HFE analysis which will focus on combining the HFE components into the machinery space design. This will take into account information such as tasks performed in the space (frequency and detailed nature of the task), numbers of people required, space required (i.e. removal routes, lay down areas), taking account of range of target audience body size that is adjusted for Personal Protectives Equipment (PPE), tools and other equipment required, and the different needs for PPE (*UK MoD, 2006)*. All of this data will assist in designing a desired machinery arrangement that acknowledges the end user, which will then be validated utilizing VR within the machinery arrangement design. This will allow for detailed design revision while taking into account HFE criteria.

In these considerations there are some that VR can offer benefits. Areas such as the traffic flow design, escape route design, causality routing methods, and hazard mitigation design specifications can see an increase in design observation resulting from VR first-person design revision. There are also aspects such as the positioning of emergency equipment, alarms, communication equipment, and general inventory that would benefit from the increase design focus offered by VR environments. VR can offer the ability for the design engineer to re-enact the process of using such equipment, which will aid in their design decisions.

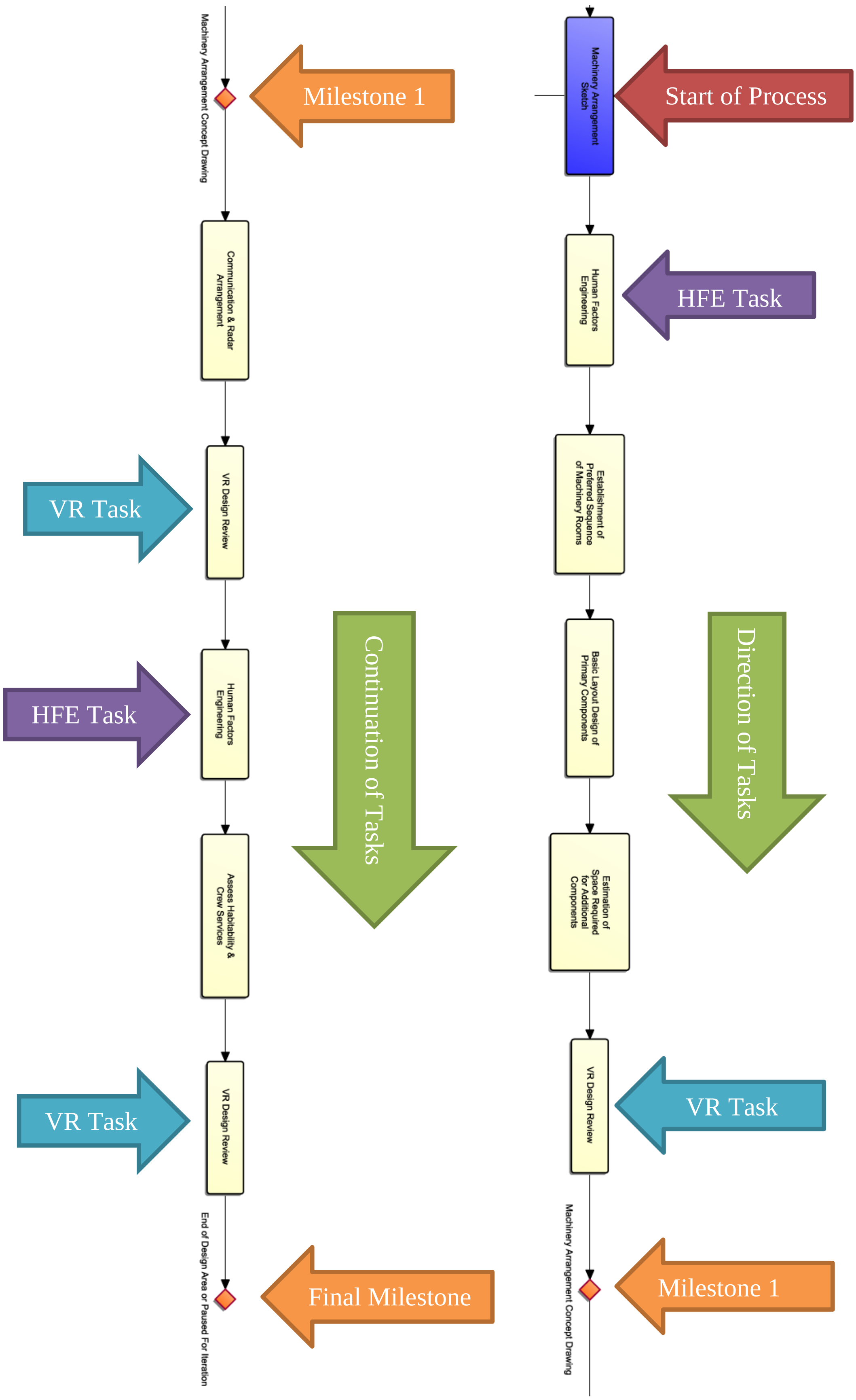

Fig.3: Concept stage – VR machinery arrangement tasks with relation to proposed HFE tasks

The routing of systems with regards to end-user requirements is also an important criterion the design engineer must recognize.

The preliminary design stage is a prerequisite to the basic stage. This stage focuses on the preparation of the basic stage. In this part of the design process there is a substantial amount of information available about the final vessel but there is still a level of flexibility for necessary amendments without excessively prolonging the design process. The Human Systems Activities Analysis which focuses on aspects of HFE orientated tasks *(Lamb, 2003; NSWC, 2012)*. Fig.4 shows a representation of tasks involved at this stage. *UK MoD, (2006*) recommends that the following should be taken into account during human factors' based tasks:

- Skills & knowledge of the desired crew members.
- Physical characteristics of the members, if available, to ensure users can move and work safely within the vessel without having to adopt unsafe body and limb positions.
- Personnel factors, which covers a range of issues such as satisfaction of the job, acceptable work conditions, and rotation of service to mitigate repetitive tasks.

Areas such as initial general arrangements, concept general arrangement, machinery arrangement sketch, payload definition, habitability and crew service diagrams, and the basic design stage all rely on a degree of visualization for HFE design revision. The connection proposed between HFE and VR applications within ship design is based upon the visual benefits that VR offers and the ergonomic considerations that HFE design revision must fulfill. This includes aspect such as areas of work traffic flow including areas for embarkations and dis-embarkation, requirements necessary for storage and removal of goods and other equipment, acknowledgement of essential escape routes, and required space for maintenance. Based on interviews and design process analysis this led to a suggestion of implementing VR-HFE tasks in areas within the ship design process that have a higher degree of HFE design ergonomic criteria. The result of this was the development of process models such as Fig.3, which is the design of the machinery space curing the concept stage, and Fig.4, which is the human systems activities in the basic design stage.

Although there is less maturity of data during the concept stage there is still HFE criteria that can be investigated using a VR design tool. The data at this stage would help guide the allocation of tasks later on during the ship design process. During the preliminary design stage there is more visual design information to work with so the VR-HFE design revision tasks would assist in making more permanent design changes. This correlation has shown itself to be an opportunity for VR implementation. Due to the level of immersion involved in VR the naval architect is able to make design decisions that are in line with HFE conditions.

4. Proposed VR-HFE Software Application

This section will focus on explaining the process of developing the VR design software. The building environment for this program was a combination of Unity and Microsoft Visual Studio. Out of these options C# was chosen due to the availability of Software Development Kits (SDKs) written in this language.

4.1. Unity Development Process

Creating the frame for the Graphical User Interface (GUI) was the first step in this aspect of the project. This involved designing the fundamental input and output parameters that presented the information performed by the background functions. This was done in Unity as it offers a variety of available assets that are customizable. Also, developing VR applications in Unity is simplified due to 'OpenVR' SDK (built by Steam) making it easier to focus on the functionality of the software rather than the difficulty of integrating VR into the Unity game engine. This section describes the development of the event system, GUI, camera system, and briefly the start menu.

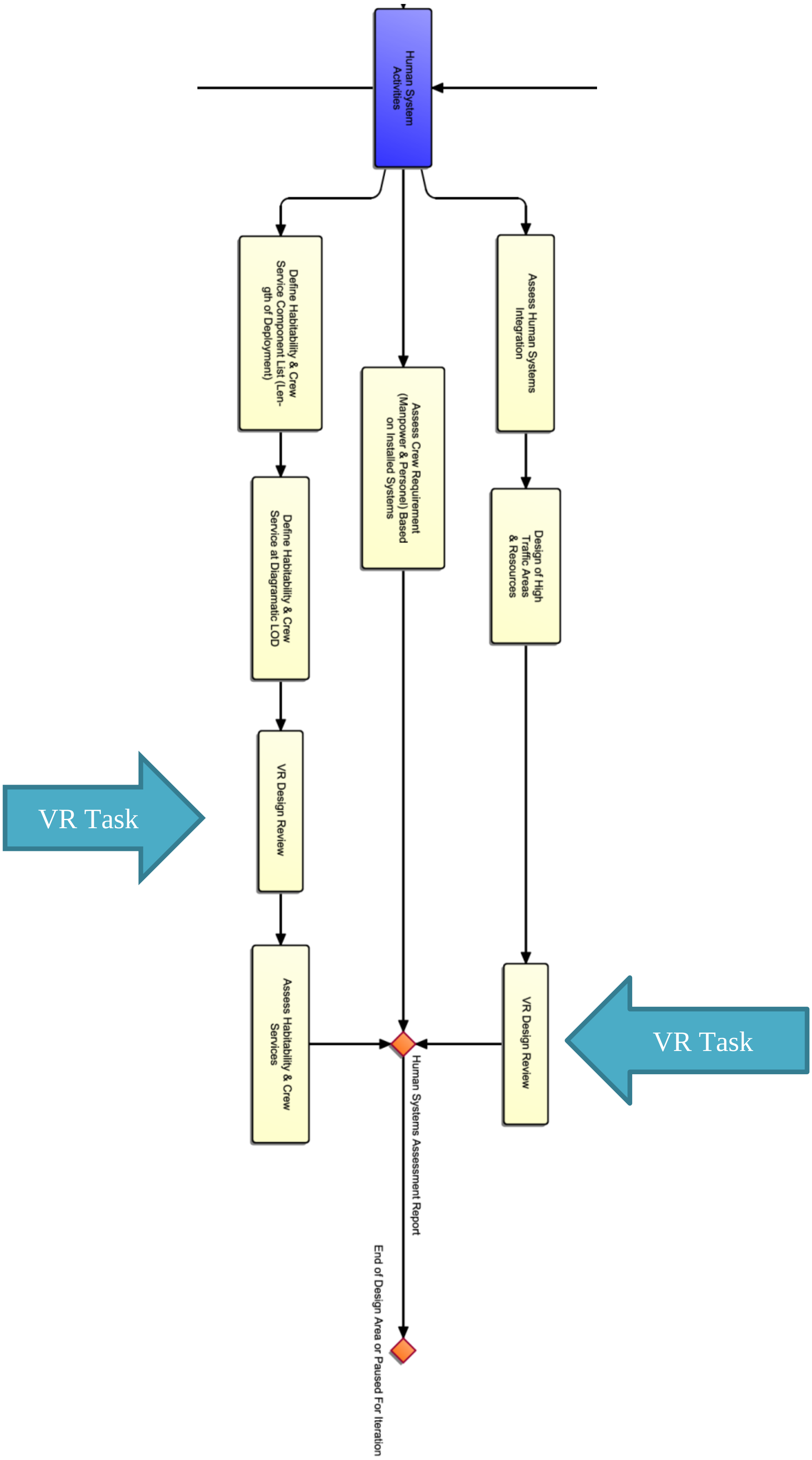

Fig.4: Preliminary (Late Concept) Design Stage - VR HFE Human System Tasks

Before setting up the GUI it was important to make sure that interaction between the inputs from hardware and the software are enabled. This was done by utilizing Unity’s Event System component. The event system allows for the program to organize the inputs to the corresponding function in an orderly fashion. Fig.5 illustrates a simple example of the Yourdon and Coad data flow chart for an application of the event system *(Cooling, 2003*).

Fig.5: Simple data flow chart for Event System application

Once the GUI framework was completed the next stage was implementing the backend functions. The first step at this stage was first breaking down the desired function of the software. This can be summarized as the following for the first stages of this research:

- Uploads design using a file browser.
- Tool’s upload functionality is independent of the Unity driver system.
- Allows for real time design viewing and movement.
- Closes design without restarting the tool.

These functions were deemed as a basic start in order to create the fundamental functionality of the tool. The first task was to create a live file browser which would respond to ‘Upload Obj’ button.

Using an open source SDK package, a movement function was added to the camera to allow the user to move around the design.

Closing the design allows the designer to introduce another design for validation. It is a necessary function when wanting to swap designs instantly. This was implemented using the ‘LoadScene’ function.

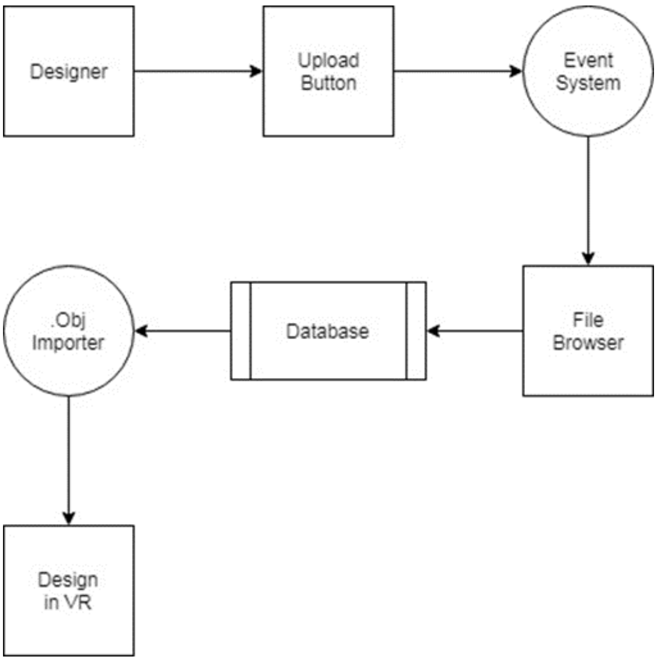

Fig**.**6**:** VR design tool data flowchart

4.2. Basic Software Demonstration

The development of a basic VR design tool has been presented. This tool, at the current stage, allows for CAD files to be viewed and examined in VR. This allows for the implementation of VR as an interdisciplinary design revision tool to be tested in a case study scenario. The functionality of the software, as it currently is, allows for visualization of the 3D model n VR. With the simple models tested within the program there has not been any data loss or corruption; this may change upon the implementation of more complex designs. Fig.7 shows a simple off-shore patrol vessel design being viewed in the VR environment.

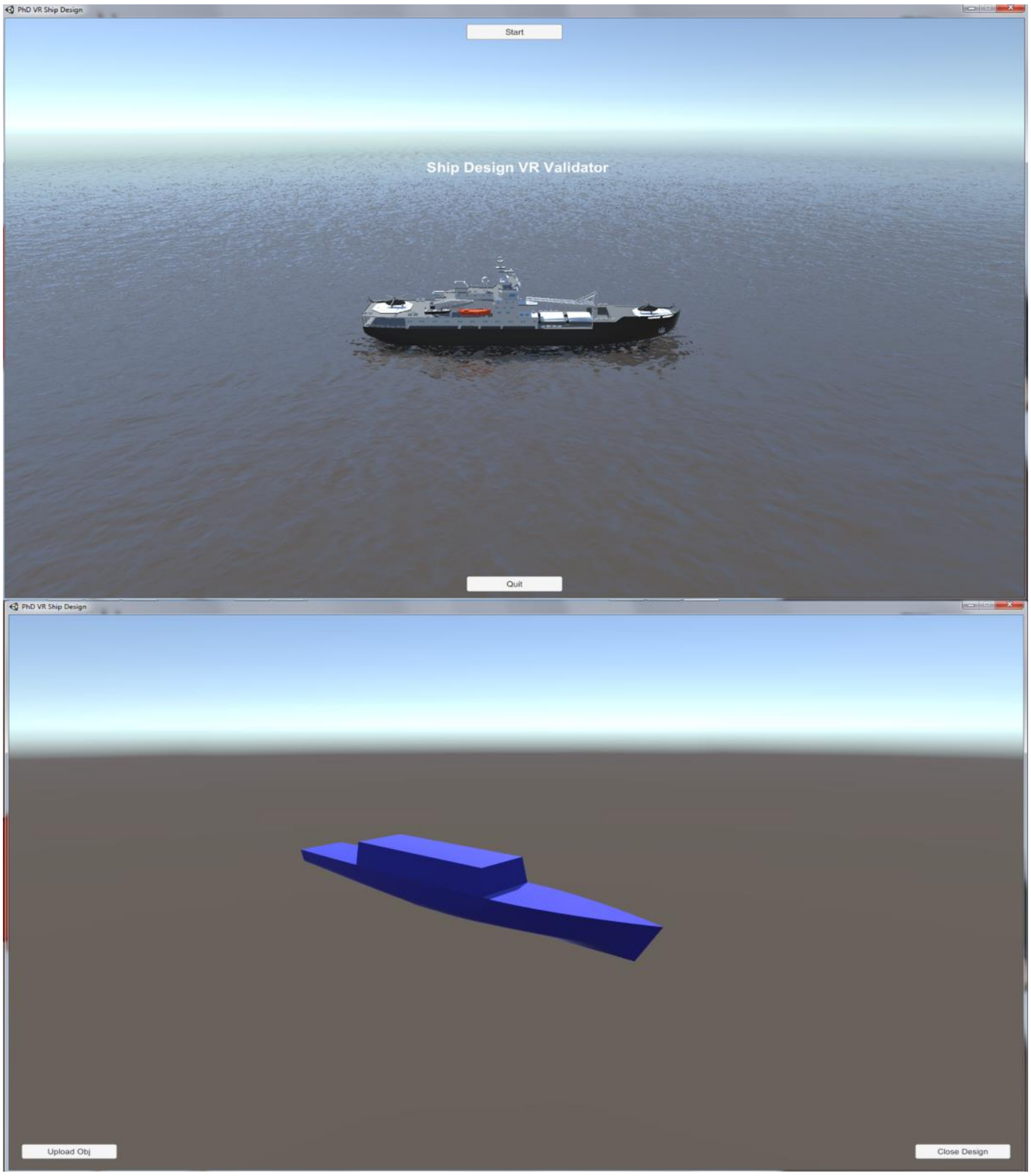

Fig.7: GUI and simple hull form shown in VR environment

5. Future Investigation Method

The next steps in this project will include further functionality development of the tool, and developing test-case scenarios. This will take the project closer to understanding the positives and negatives of using VR-HFE within the ship design process.

A series of design process models, for the concept and preliminary stage, were developed. Each design process model used data collected from literature and interviews from Naval Architects and Human

Factors Engineers to build towards the first iteration of examples shown in this paper. The process models were used to search for areas of application for VR-HFE design revision. A combination of MOD HFE considerations and interviews with industry will be used to further expand on key areas of VR-HFE application. This will be done using a scoring mechanism that highlights activities with ergonomic implication. Interviews from industry will further add towards this part of finalization.

Once further necessary functionalities are added to the tool there will be a VR-HFE case study investigation into the improvement of ergonomics of ship design. This will focus on comparing a standard HFE analysis method to the VR-HFE case study.

The VR-HFE case study will also investigate the impact that this will have on multi-disciplinary communication. This will compare the traditional approach to of project communication to the VR-HFE method.

6. Summary

This paper presented an introduction into the approach being taken for this work. A brief demonstration of the software has also been presented in this paper. Insight into the design process analysis has been explained with results presented based on interviews with industry. The results have shown possible areas of implementation for VR-HFE tasks within the concept and preliminary design stage. There will be further investigation into specific tasks involved in ship design such as machinery space and mission area arrangement design scenarios.

The approach explained in this paper will allow for possible areas of application for VR-HFE within the ship design process to be identified with qualitative data. By using this approach to analyse tasks within the ship design process this will highlight tasks that VR-HFE will impact the most.

References

AHOLA, M.; MAGICA, R.; REUNANEN, M.; KAUPPI, A. (2014), *Gameplay Approach to Virtual Design of General Arrangement and User Testing*, RINA

ALONSO, V.; PEREZ, R.; SANCHEZ, L.; TRONSTAD, R. (2012), *Advantages of using a virtual reality tool in shipbuilding*, SENER, Madrid

BLESSING, L.; CHAKRABARTI, A. (2003), *DRM: A Design Research Methodology*, Berlin, pp.1-15

BLESSING, L.T.M.; CHAKRABARTI, A. (2009), *DRM, a Design Research Methodology*, Springer

BOULOS, S. (2003), *B1. Object Files (.obj) (Technical description)*, Wavefront

CEBOLLERO, A.; SÁNCHEZ, L. (2017), *Virtual Reality Empowered Design*, Int. Conf. Computer Applications in Shipbuilding, Singapore

CHAPMAN, P.; STEVENS; WILLS, D.; BROOKES, G. (2001), *Real-time visualization in the offshore industry*, IEEE Computer Graphics and Applications 21, pp.6–10

COOK, J.; HUBBOLD, R.; KEATES, M. (1998), *Virtual reality for large-scale industrial applications*, Future Generation Computer Systems 14, pp.157–166

COOLING, J.E. (2003), *Software engineering for real-time systems*, Addison-Wesley

FERNÁNDEZ, R.; ALONSO, V. (2014), *Virtual Reality in a shipbuilding environment*, Advances in Engineering Software, pp.30–40

JAMEI, E.; MORTIMER, M.; SEYEDMAHMOUDIAN, M.; HORAN, B.; STOJCEVSKI, A. (2017), *Investigating the Role of Virtual Reality in Planning for Sustainable Smart Cities*, Sustainability 9

KAYE, T.; WAGSTAFF, S.; BLACK, F. (2017), *Multi-User VR Solutions for Enterprise Deployment*

KOOLONAVICH, N. (2018), *US Navy eyes virtual reality application with Moback CRADA*, VR Focus

LAMB, T. (2003), Ship design and construction, SNAME

LARKINS, D.; MORAIS, D.; WALDIE, M. (2013), *Democratization of Virtual Reality in Shipbuilding*, COMPIT, Cortona, pp.316–326

LUKAS, U.F. von (2010), *Virtual and augmented reality for the maritime sector*, 8th IFAC Conf. Control Applications in Marine Systems, Rostock-Warnemünde, pp.196–200

MARTIN, J.; CONNELL, A. (2015), *Accessible Immersive Visualisation for Shipbuilding*, Int. Conf. Computer Applications in Shipbuilding, Bremen

MENCK, N.; YANG, X.; WEIDIG, C.; WINKES, P.; LAUER, C.; HAGEN, H.; HAMANN, B.; AURICH, J.C. (2012), *Collaborative Factory Planning in Virtual Reality*, Procedia CIRP 3, pp.317–322

MORAIS, D.; WALDIE, M.; LARKINS, D. (2017), *The Evolution of Virtual Reality in Shipbuilding*, COMPIT, Cardiff, pp.128–138

NSWC (2012), *The Navy Ship Design Process*, Naval Surface Warfare Center

NORDBY, K.; BØRRESEN, S.; GERNEZ, E. (2016), *Efficient Use of Virtual and Mixed Reality in Conceptual Design of Maritime Work Places*, COMPIT, Lecce, pp.392–400

PEREZ, R.; TOMAN, M.; SANCHEZ, L.; KERAUSCH, M. (2015), *The latest development in CAD/CAM/CIM. The Virtual Reality in Shipbuilding*, 29th Asian-Pacific Technical Exchange and Advisory Meeting on Marine Structures, Vladivostok pp.105–112

POIŠS, S. (2015), *Unity3DFileBrowser*

PROQUEST (2004), *U.S. Navy Opens Center for Concept Visualization for New Ship Design Using SGI Onyx Advanced.pdf*, PR Newswire Association LLC 1

PYNN, W. (2017), *Minimising the Designer / End User Knowledge Gap using Virtual Reality*, Int. Conf. Computer Applications in Shipbuilding, Singapore

REINA MAGICA (2014), P*roteus: A Cruise Design Tool for the Future*, MA thesis, Aalto Univ.

ROSENBLUM, L.; DURBIN, J.; OBEYSEKARE, U.; SIBERT, L.; TATE, D.; TEMPLEMAN, J.; AGRAWAL, J.; FASULO, D.; MEYER, T.; NEWTON, G.; SHALEV, A.; KING, T. (1996), *Shipboard VR: from damage control to design*, IEEE Computer Graphics and Applications 16, pp.10-13

ŠIKIĆ, G. (2017), *Using Virtual Reality Paradigm to Present Ship Structures in CAD Environment*, Int. Conf. Computer Applications in Shipbuilding, Singapore

ŠIKIĆ, G.; BISTRIČIĆ, M. (2015), *Stereo 3D Presentation of Ship Structures Using Low Cost Hardware*, Int. Conf. Computer Applications in Shipbuilding, Bremen

SOARES, C.G. (2011), *Marine technology and engineering*, CRC Press

STREUBER, S.; CHATZIASTROS, A. (2007), *Human Interaction in Multi-User Virtual Reality*, Int. Conf. Humans and Computers, pp. 1–7.

THERISIEN, Y.L.; MAÏS, C. (2008), *Virtual Reality – Tool of Assistance to the Design of the Warship's Complex Systems*, COMPIT, Liege, pp.460–466

TORRUELLA, A. (2014), *Augmented reality labs: Seeing the future of design*, Jane's Int. Defence Review 47, pp.32–33.

UK MoD (2006), MAP-01-011 HFI Technical Guide (formerly STGP 11) (Maritime Acquisition Publication No. 4), MAP-01-011, Defence Procurement Agency, MoD