Title:
Virtual Reality-Enhanced Configuration Design of Customized Workplaces: a Case Study of Ship Bridge System

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Introduction:

New market paradigms forces companies offering tailored products to meet customers' demands. A way to reduce complexity in the management of different product variants is to use engineering methods which address the configuration of available solutions, without producing deeply and costly design modifications [4]. Configuration design can be defined as a design approach able to develop complex products by using a set of predefined components or components' features [6]. Configuration management allows to create product families and platforms, by assembling modules and components in predefined manners to satisfy a set of requirements and constraints [10].

Several methods for configuration design have been investigated in literature as well as their link with computer-aided design technologies [12] [14]. Configuration tools have been developed and deployed in industrial contexts with the aim to facilitate the management of complex issues (e.g. components' manufacturability, assemblability of product variants) [13] [2]. Currently, these tools are consolidated systems in the development of industrial products (e.g. automotive, appliances) [5]. The link with 3D CAD systems allowed the development of platform-based products which are considered an efficient way to manage product variants and customizations [7].

Shifting the perspective from product design to the development of more complex systems, such as workspaces and workplaces' equipment, the issue of customization becomes even more acute. Configuration design of customized workspaces requires a multi-disciplinary approach which includes mechanical design, materials selection, ergonomics, product architecture, etc. [3]. In the last two decades, virtual reality (VR) tools have appeared in the development process of customized product [1]. In particular, these tools have been adopted to include ergonomics factors in the development of specific products (e.g. passenger's vehicles) [8] or to define assembly tasks in specific environments (e.g. plant's control rooms) [11]. Only few examples are provided in literature for the configuration of customized workplaces in maritime domain where, typically, the bridge control room is set up based on the specific requirements of the ship owner and/or captain [9]. Indeed, it need to be designed considering tailored characteristics of the end-user, general arrangement of navigation equipment, mechanical/safety features, etc.

The present paper proposes a method for the configuration of customized workplaces including anthropological features. The approach allows arranging configurable equipment based on specific needs. By using computer aided design tools, designers are able to combine both workplace configuration and visualization in a 3D environment. The adoption of immersive environments (e.g. virtual reality) allows supporting the configuration process, engaging end-users in the final customization. A software tool for the configuration of yachts' ship bridge console is proposed as a case study. It allows a fast layout definition of monitors and navigation tools including the reliable validation of its usability by ship owner and/or captain.

The final goal of this research activity is to include ergonomics and physical aspects as configuration parameters for the development of customized shipboard workspaces. The main novelty is related to its application in specific fields which require a high degree of personalization, such as assembly workspaces, control rooms, cockpits, etc.

Method:

The proposed methodology is shown in Fig. 1. The approach has a generic validity in the configuration of customized workplaces and it has been deployed for the specific purpose of ship bridge console.

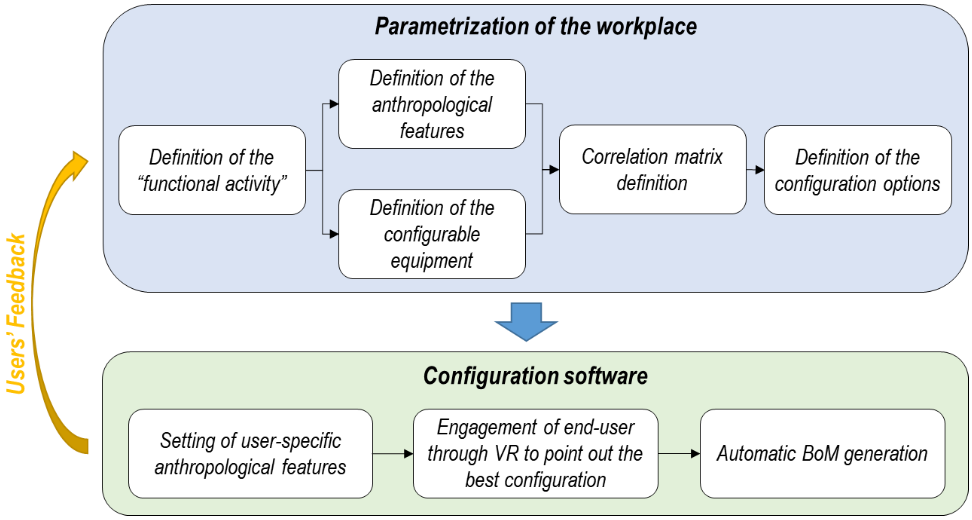

Fig. 1: Proposed methodology for design configuration of customized workplaces

The methodology can be divided into two main phases.

In the first phase the workplace is parametrized, and the configuration options are defined depending on the anthropological characteristics of the generic user. This phase is performed once for each workplace, although the configuration options can be latter modified based on feedbacks coming from the second phase or technological improvements. The first step of the first phase is the "functional activity" definition. The functional activity is the purpose of the product for which is being designed, and thus the activity that the product should enable to do with safety and comfortably. Two main tasks characterize this step: (i) the definition of the configurable equipment and, (ii) the identification of the anthropological characteristics that should be considered during the design process. These activities can be performed independently, and thus there is not any priority constraint between them. The meaning of configurable equipment is defined as: "each item in the workplace that can be modified during the design phase and replaced with functionally equivalent alternatives that can grant the fulfilling of the functional activity". On the other hand, the anthropological characteristics are all the characteristics of the final user that can affect his use experience. Personal taste should be considered as one of these characteristics, since several configurations may depend on aesthetics choices and personal preferences. At the end of these steps, two lists of items will be produced. These two lists are used to create a correlation matrix that enables to identify the anthropological characteristics that affect each configurable equipment. For each relation it is possible to define a finite number of configurations, considering technological and dimensional constraints.

The second phase of the proposed methodology consists in the development of a configuration software tool based on the model previously created. Firstly, it has to ask for the user-specific physical characteristics. At this moment, personal taste preferences are not requested yet. After the information is gathered, the workplace can be pre-configured, and the user can explore it by the use of virtual reality tools, like Cave Automatic Virtual Environments (CAVEs) or headsets. For this purpose, a virtual model of the workplace and its possible configuration has to be created using CAD technologies. By the use of virtual reality instruments, the user can evaluate all the remaining configuration options based on personal taste, and verify if the pre-configuration, based only on physical characteristics represents the best option. If the user is not fully satisfied, his feedbacks and suggestions, together with the feedbacks of other users, can be gathered as design knowledge and reused to modify the configuration rules. Finally, when the configuration is completed, the software tool is able to export the necessary information for the generation of the Bill of Materials (BoM).

Case study:

The methodology described in the previous paragraph has been applied for the configuration of a motor-yacht bridge system by using a VR tool developed for this purpose. A yacht is completely customized for the final user, and thus can be considered a craft product. The bridge is the core of the ship, and thus it must guarantee to user the full control of the yacht functionalities with safety, and providing a comfortable and tailored environment. The "functional activity" has been defined as follows: "the control of a luxury yacht for recreational use". After that, the lists of the configurable equipment and anthropological features have been defined. These lists have been used for the creation of the correlation matrix shown in

Tab. 1. Rows report each configurable equipment and columns the anthropological features.

	Height	*Right/Left-handed*	*Personal taste*
Number and position of the monitors			X
Rake angle of the monitors	X		
Position of the control stick		X	
Colour and material of the bridge			X

Tab. 1: Correlation matrix between configurable equipment and anthropological features.

For each one of the four relations identified through the correlation matrix, the configuration options have been defined considering technical, dimensional and functional constraints. For example, four possible configurations have been defined for the number and the position of the monitors, which are represented in

Fig. 2. Within the four configurations, the upper rows represent the monitors in vertical position, while the lower rows the monitors in horizontal position.

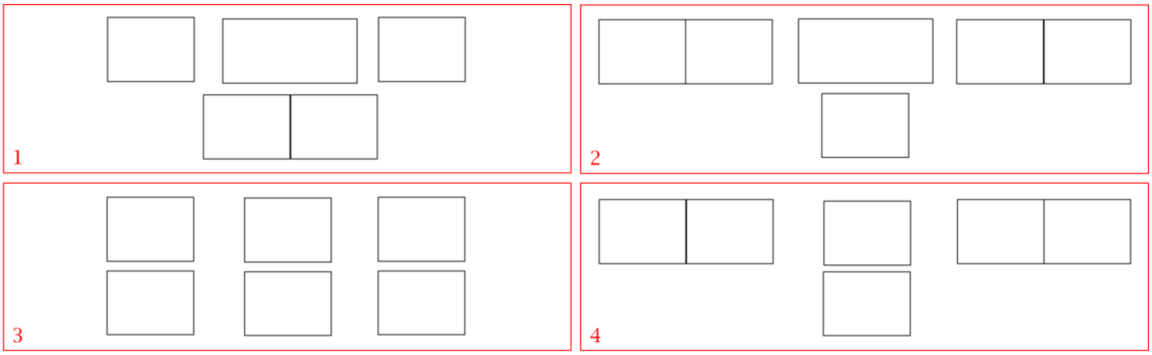

Fig. 2: Number and configuration of the monitors.

For the rake angle of the monitors, two configurations have been defined: vertical position for users under 1.75m, and 15° rake angle for users taller than 1.75m. The control stick can be moved from right to left of the main central monitor, depending on if the captain is right-handed or left handed. Three alternatives for the bridge material have been chosen: blue leather, black leather and carbon look.

The 3D model of the bridge and of the equipment have been realized with *3DS MAX by Autodesk*, while *Unity* has been used as graphic engine. *HTC VIVE* headset has been used for the VR application. The result of this implementation is a software application as presented in

Fig. 3. In particular, the picture highlights a pre-configuration for a left-handed user taller than 1.75m.

Fig. 3: Screenshot of the configuration software.

Once that the configuration is completed, the software allows the user to save a XML file containing a list of all the equipment used in the current configuration. This file can be imported in a product life cycle management tool (PLM) for the automatic handling of orders and the BoM generation. This configuration tool based on VR has been deployed to a design department of an Italian shipyard and it has been tested for six months (14 end-users involved). Feedbacks from end-users have been collected through a survey with the objective to understand the effectiveness of the system in the correct configuration of the ship bridge control and related equipment. Results confirm the effectiveness of the use of VR tool in this field evalueting: (i) end-user elicitation and satisfaction, (ii) easyness in equipment customization entering antropological features (iii) missing functionalities (e.g. not configurable options, etc.).

Conclusions:

This study showed that the configuration of customized workspaces and equipment needs the involvements of representative users. Configuration tools based on VR can be developed to integrate typical aspects in this context such as ergonomics, anthropological features, personal attitude and taste. Advantages of these systems are shown in terms of product configuration efficiency and time saving for the development of different workplaces design alternatives. Another benefit of this approach is the automatic generation of an associated BoM and its management through PLM tools.

Lastly, the application of the proposed approach in a real case study (ship bridge system) indicates that the evaluation methods and representations would be useful to close the gap between design and end-users avoiding continuous design reviews or even worse post-manufacturing adaptations.

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