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TOOLBOX

# Human-machine system design: the integrated use of human factors, virtual environments and product lifecycle management

Virtual environments open new possibilities for taking account of the human early in the product design. This paper provides a brief insight into the research in this area conducted by the Human–Machine Interaction and Virtual Engineering team at VTT Technical Research Centre of Finland. The paper describes the methods and approaches that are applied in case examples, leading to a number of benefits for the industry, such as faster time-to-market, better usability, and improved information sharing and knowledge creation. The vision is to design for humans in the context of human–system interaction. This vision both develops and applies the multidiscipline distributed framework and platform for the integrated use of virtual environments, human factors, and product lifecycle management.

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### The Human-Machine Interaction and Virtual Engineering team – background and framework

The Human-Machine Interaction and Virtual Engineering team (HMI-VE) at VTT Technical Research Centre of Finland investigates the problem of how to design for humans in the context of the human-machine system. The team has been working in the HMI field and has used VEs techniques since the 1990s. The team has been involved in a number of national and EU projects, together with companies in multiple domains: working machines, assembly lines, metal production, industrial robots, cranes, aerospace, shipbuilding, service providers for maintenance of trains and power plants, various software and hardware producers and developers for design, simulation and VE platforms. The HMI-VE team's core competence is based on the system approach and on the engineering framework that combines Human Factors (HF), Virtual Environments (VEs), and Product Lifecycle Management (PLM) (figure 1).

A PLM is a process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal. It enables taking stakeholder involvements into account in the design process, but it also

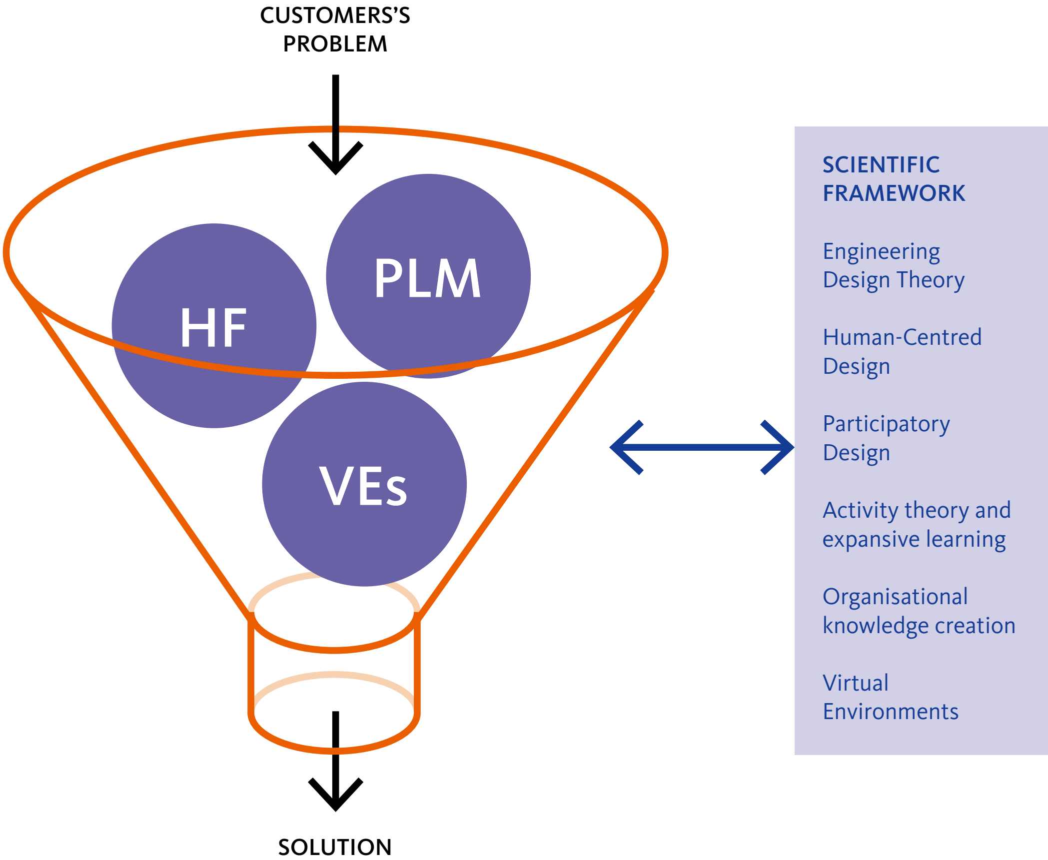



**Figure 1. The Human-Machine Interaction and Virtual Engineering team applies a combination of Human Factors (HF), Virtual Environments (VEs), and Product Lifecycle Management (PLM), and theoretical framework for solving customers' problems**

provides capabilities for efficient sharing and management of product knowledge, information, and data, as well as support for system engineering processes. HF (ergonomics) is a scientific discipline concerned with the understanding of the interactions among humans and system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance (IEA, 2003). Kalawsky (1993) defines VEs as synthetic sensory experiences of humans. VEs provide to the stakeholders the visual, auditory, haptic and kinaesthetic stimuli of the physical events and phenomena of the given system.

The engineering framework with PLM, HF and VEs, is used for solving customer's problems when designing human-machine interaction. During the problem solving, also the scientific methodologies and approaches are used and continuously developed further. The methodologies and approaches are the following: (1) engineering design theory; (2) participatory design; (3) human-centred design (HCD); (4) activity theory and expansive learning; (5) organisational knowledge creation; and (6) virtual environments (VEs).

In the (1) engineering design theory (Hubka & Eder, 1988) the design demands must include the wishes of the customers and requirements of the lifecycle to make sustainable design and development. Participatory design (2) (Muller & Kuhn, 1993) and Human-Centred Design (3) (ISO 9241-210, 2010) approaches focus on the users, their needs and their requirements to solve problems. The activity theory and expansive learning (5) (Engeström, 1987) are used to identify the contradictions to be resolved. Organizational knowledge creation (6) (Nonaka & Krogh, 2009) is the process of making available and amplifying knowledge created by individuals as well as crystallizing and connecting it to an organization's knowledge system. The premises for the efficient use of (7) VEs within human–machine system design and PLM at HMI-VE are introduced by Leino and Pulkkinen (2012). The following section introduces case examples of these theories and framework used in practice.

## Case examples

### Design review in virtual environments

Design reviews ensure that the design is evaluated against various sets of criteria, such as requirements, consistency, and usability during several stages of the design process. Additionally, the design reviews are efficient tools for sharing information about the product and for managing knowledge exchange. VEs have been widely used in the review meetings and VEs are particularly useful in the assessment of interaction systems used by users.

This case example describes a design review meeting which purpose was to evaluate the assembly, maintenance, safety, and structural problems, and also to discuss possible solu-

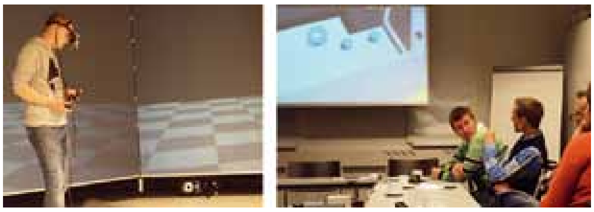


**Figure 2. Engine module review meeting: user and review board (Aromaa e.a., 2012a)**

tions of a forthcoming engine module. The review board consisted of an assembly worker, design engineers, a manufacturing manager, assembly foremen, product development engineers, a VE expert, HF experts, and a review meeting chairman. The VE system was used as a communication channel in which the review board was provided with an overview of the system on a power wall, to understand the design context (figure 2). Additionally, a worker was provided with a head-mounted display view to be immersed within the VEs. Each actor, the worker, and the review board had a customized view of the system that was the most natural for their purposes. The worker's point of view was also projected on the side projection screen so that the review board could perceive the situation from the worker's perspective. The meeting was recorded by taking pictures and notes during the discussions (Aromaa e.a., 2012a).

Several findings for product development were identified. Due to the findings, by changing the assembly order and adding a simple supportive structure, it was possible to give the assembly worker more working space (Aromaa e.a., 2012a).

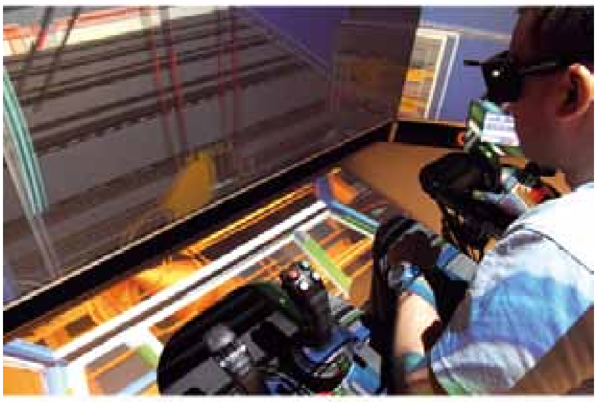
## Human factor evaluation development within virtual environments

For a machine operator the visibility from the cabin is important and it needs to be evaluated thorough during the design. The current operator's field of view (FOV) analysis methods in vehicle design are based on the use of the standard light-shadow bulb tests (ISO-5006, 2006) within real machines or the digital human models (DHM) in the VEs. However, the real operators are not widely employed for analysing the FOV in VEs and therefore the full potential of the visualization that VEs enables is not used (Aromaa e.a., 2012b). By involving real operators in the VEs, new ways are established to analyse the FOV that consider the task and the operator's performance. Moreover, involving operators supports the participative approach and can aid VE design reviews (Viitaniemi e.a., 2010).
There has been a test experiment (Aromaa e.a., 2012b) to evaluate and further develop the task-related dynamic FOV analysis method. The method supports the designers' need for an objective, evaluation and the numeric information from the operator's FOV for evaluating different design alternatives. Additionally it supports the decision making in VE design reviews, where the operator uses a virtual machine and the review board members discuss the design alternatives. In this experiment, the participants executed the same task with the two different cabin alternatives in the VEs. The first cabin structure was ordinary, while the second cabin structure was strengthened resulting in a stronger masking of the operator's view (figure 3).

Two values were calculated using the FOV analysis method: (1) visibility is calculated as the target object's visible pixels as a percentage of all the pixels in the operator's FOV; and (2) occlusion is calculated as the occluded (here by the cabin structure) pixels as a percentage of the visible target object's pixels in the operator's FOV. The percentage values are for a comparison of the visibility of alternative design solutions, not for an absolute value of visibility. Based on this test experiment, it wasn't yet possible to define which cabin solution had a better visibility because the results were not coherent enough between the participants. Still based on results the FOV analysis method can be regarded as promising, although further investigation is needed (Aromaa e.a., 2012b).

## Manual work support in ManuVAR

ManuVAR was the VTT-coordinated EU research and development project (ManuVAR, 2012; Krassi e.a., 2010). It focused on high-value high-knowledge manual work that cannot be offshored or automated because it constitutes the core of



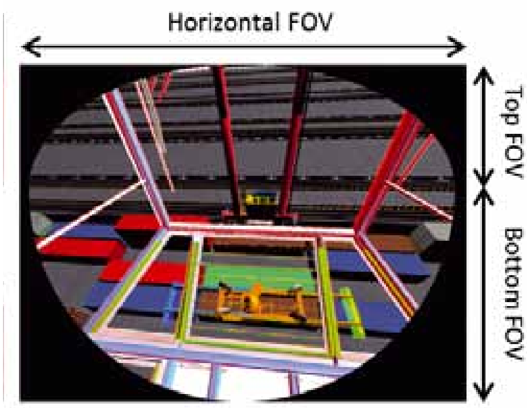



**Figure 3. On the left side is virtual environment test setup for the crane operator. On the right side is the operator's FOV which is fixed to 100° for the horizontal angle, 35° for the top angle and 50° for the bottom angle (Aromaa e.a., 2012a)**

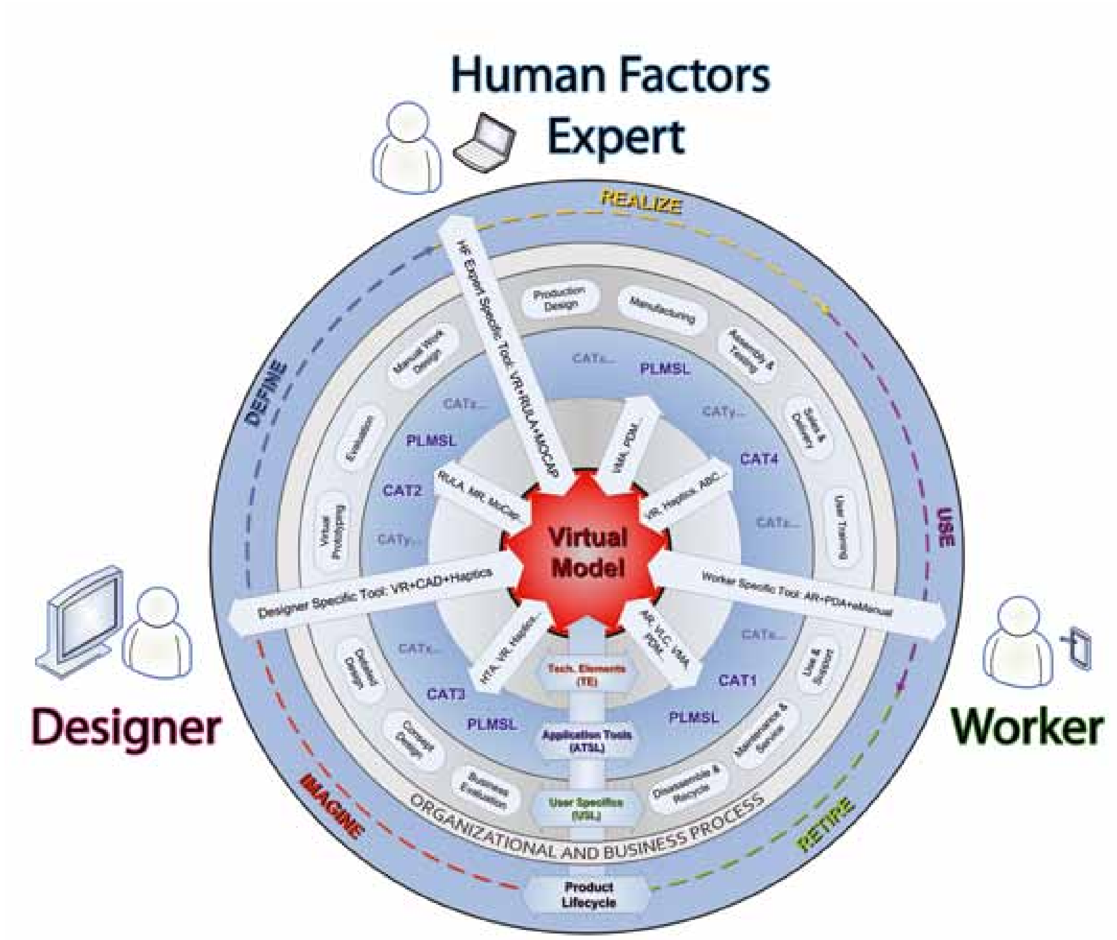



**Figure 4. ManuVAR PLM model (source: ManuVAR consortium)**

the business operation. ManuVAR developed a prototype solution combining PLM, virtual reality (VR) and augmented reality (AR) techniques and HF methods, and demonstrated its business potential in several industrial sectors: spacecraft assembly, assembly lines in small and medium enterprises, the maintenance of trains, training for power plant maintenance, and heavy machinery productization. The HF-VE framework of ManuVAR comprises two main results.

First, a grouping of HF methods for manual work support was proposed (Aromaa e.a., 2010). It is based on analogies with organisational knowledge creation (four modalities: internalization, externalization, socialization, and combination) and the cybernetic system (four main elements: input, plant, output, feedback and controller). The groups are as follows:

- workplace design (in analogy to 'plant', 'socialisation/combination'), e.g. hierarchical task analysis;
- instruction delivery (in analogy to 'input', 'internalisation'), e.g., reinforcement techniques, contextualization of instructions;
- ergonomics evaluation (in analogy to 'output/feedback', 'externalisation'), e.g. rapid upper limb assessment - RULA;
- training/learning (in analogy to 'feedback/controller'), example method: precision teaching.

While there are a lot of HF methods, the proposed grouping helps to make a knowledgeable decision in a given industrial situation on what type of support tools are required, and then to choose a particular method within a group.

Second is the ManuVAR PLM model and concept of bi-directional communication through the lifecycle (Krassi e.a., 2010), as in figure 4. Bi-directional communication throughout the system lifecycle is accomplished by means of the virtual model (VM). The VM acts as a communication mediator - a single systemic access point to the variety of PLM repositories (data, information, models) for all users in the lifecycle - which is accessed as an integral system by virtual experiments. Several actors (a worker, a designer, and a human-factors expert), located at different stages of the lifecycle (outer layer), communicate offline or online with each other via the VM (centre). Each actor has a customised view of the shared virtual model (Kiviranta e.a., 2010). As soon as one actor affects the virtual model, all the other actors are able to perceive the result. Compared to process-driven communication in a chain, this communication is more agile and it allows easier change management and synchronisation among multiple actors.

ManuVAR implemented and tested four application tools (figure 5), which could be further specialized with new elements and combined with each other on the basis of the VM to provide a solution to a given customer problem.

**Figure 5. The first tool (top left) provides real time contextualized work instructions with the use of AR. The second tool (top right) implements a real time physical ergonomic analysis with a motion capture system and it also allows an ergonomic specialist to handle the evaluation process. The third tool (bottom left) supports task planning and procedure validation in a VE by the designers and ergonomic specialists. The resulting tasks can be fed into the first tool for the instruction delivery. The fourth tool (bottom right) utilises a haptic device in a VE to support motor skill training in accordance with the precision teaching method**

### Illustration of the benefits of virtual environments for industry

From many years of experience with the use of VEs within industry, it has become clear that, although there are benefits to the use of VEs, it is really difficult to formulate these benefits in terms of cost, time, or effort. There was a study, presented in Aromaa e.a., (2012a), to classify the benefits of the use of VEs in design reviews and to describe the relation between benefits. In this study, questionnaires and observations were used to collect the benefits that emerged. As a result, a feature-benefit (F-B) pyramid was made (figure 6) to illustrate the classification of features and benefits in three different categories based on the findings: (1) VEs, (2) design, and (3) business. Additionally, the pyramid visualises the differences and dependencies between the features and the benefits.

Classification and categorisation of the benefits are important for industry, regarding the use of VE techniques in design reviews, especially to clarify their meaning in the human system context (use, assembly, and maintenance). The F-B pyramid can support companies' investment decisions regarding new technologies, implementation of technologies, or use of existing VEs more straight-forward. In particular, companies that operate in areas related to human-machine interaction, such as the automobile or machine industry, can benefit from the presented F-B pyramid (Aromaa e.a., 2012a).

### Future work

There are many challenges to tackle with the use of VEs in design for humans in the human-machine system context due to limited characteristics of the existing virtual reality technologies. This can cause inconvenience in use such as simulation sickness and invalidate HF evaluations due to the lack of natural feel of products. Additionally, machinery companies are starting to invest in their own VEs, so it is important to consider how to use VEs efficiently and as a part of the companies' practices. Here, information and

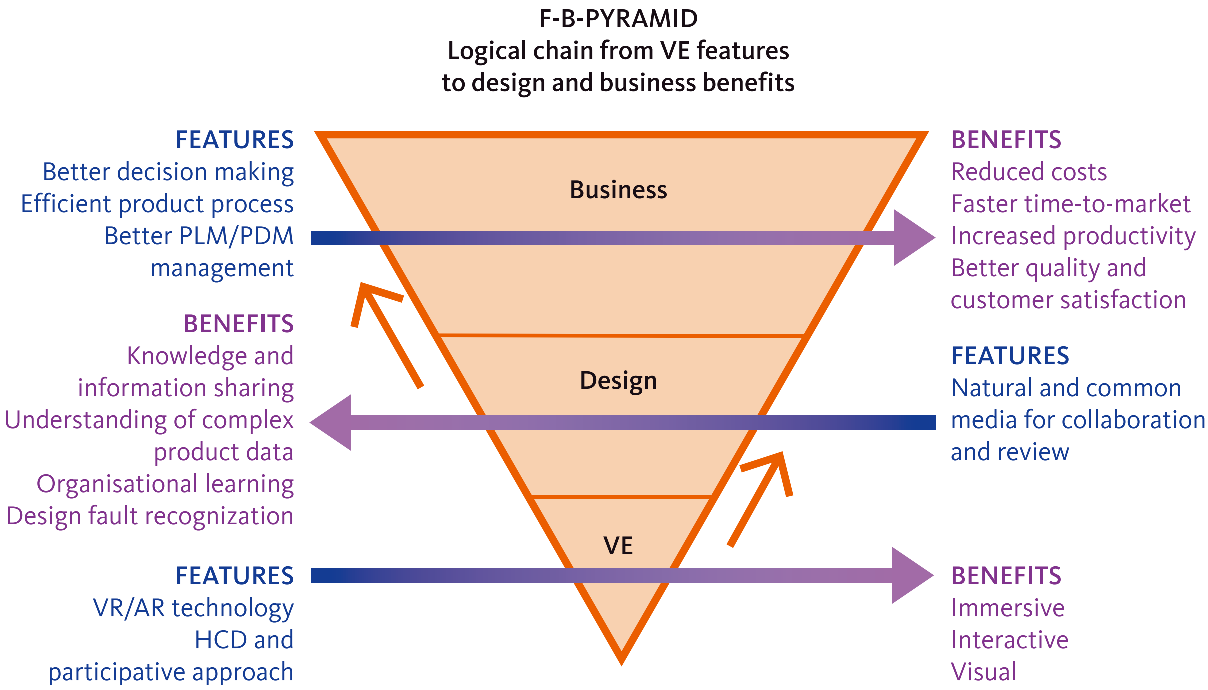



**Figure 6. Feature-benefit (F-B) pyramid illustrating the differences and relations between features and benefits in the case studies (Aromaa e.a., 2012a)**

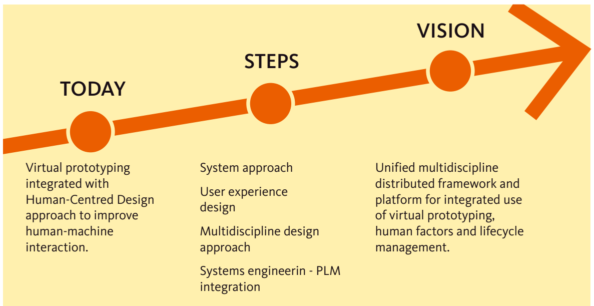



**Figure 7. The roadmap of the Human-Machine Interaction and Virtual Engineering team**

knowledge management and organisational factors are challenging.

The HMI-VE team has a vision to tackle these challenges and to develop this field of research further (figure 7). As of today, the team uses virtual prototyping (VP) combined with the HCD approach to improve the HMI. The next steps are based on the system approach, meaning that the human is an integral part of the systems. Additionally, the plan is take a step further to analyse not only, for example, physical ergonomics, but also to evaluate the holistic user experience. The multidisciplinary design approach means that many different parameters, such as psychoacoustics, thermal comfort, vibration, and musculoskeletal load, could be evaluated simultaneously in the VEs. In the future, the research context would be widened to include human comfort and the experience in a variety of interaction systems. This would be integrated with the PLM to ensure that fluent data, information, and knowledge flows in the organisation during the entire lifecycle of the system.

The vision is to develop a multidisciplinary distributed framework and platform for the integrated use of VP, HF, and lifecycle management. The distributed platform means that VEs could also be used for design and communication in many different locations and by many different experts working with it.

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## References

Aromaa, S., Leino, S.-P., Viitaniemi, J., Jokinen, L., & Kiviranta, S. (2012a). Benefits of the use of Virtual Environments in product design review meeting. International Design Conference, Dubrovnik, Croatia, May 21-24, 8 p.

Aromaa, S., Viitaniemi, J., & Philippon, N. (2012b). New task-related dynamic field of view analysis in virtual environment. Nordic Ergonomics Society Conference, NES2012, August 19.-22, Stockholm, Sweden (to be published 2012).

Aromaa, S., Viitaniemi, J., Leva, C., & Krassi, B. (2010). Integration of human factors methods to the ManuVAR PLM lifecycle management model. Proc. of the 3rd International Conference on Applied Human Factors and Ergonomics AHFE2010, Miami, Florida, USA, 17-20 July, 2010. 9 p.

Engeström, Y. (1987). Learning by expanding: An activity-theoretical approach to developmental research. Helsinki: Orienta-Konsultit.

Hubka, V., & Eder, E. (1988). Theory of Technical Systems: A Total Concept Theory for Engineering Design. Springer IEA. 2003. IEA Triennial Report, 2000-2003, IEA Press, Santa Monica, CA.

ISO 5006 (2006). Earth-moving machinery - Operator's field of view - Test method and performance criteria. ISO, Geneva.

ISO 9241-210, 2010. Human-centred design for interactive system, International Organization for Standardization, Geneva.

Kalawsky, R.S. (1993). The science of virtual reality and virtual environments: A technical, scientific and engineering reference on virtual environments. Addison-Wesley. 405 p.

Kiviranta, S., Poyade, M., & Helin, K. (2010). Virtual and Augmented Reality Technologies for Supporting Heterogeneous Multidisciplinary End-Users Across Product Lifecycle, Proceedings of the 3rd International Conference on Applied Human Factors and Ergonomics (AHFE2010), Miami, Florida, USA, 17-20 July, 2010, pp. 643-652. Published in 'Advances in Occupational, Social, and Organizational Ergonomics' (eds. Vink, P., Kantola, J.), CRC Press, ISBN 9781439835074.

Krassi, B., D'Cruz, M., Vink, P. (2010). ManuVAR: a framework for improving manual work through virtual and augmented reality, Proceedings of the 3rd International Conference on Applied Human Factors and Ergonomics (AHFE2010), Miami, Florida, USA, 17-20 July, 2010, 10 p. ISBN-13: 978-0-9796435-4-5. Published in 'Advances in Occupational, Social, and Organizational Ergonomics' (eds. Vink, P., Kantola, J.), CRC Press, ISBN 9781439835074.

Leino, S.-P., & Pulkkinen, A. (2012). Design for human-virtual engineering is a media for knowledge transfer. Proceedings of the 12th International Design Conference DESIGN 2012. pp. 1507-1514.

ManuVAR web site (www.manuvar.eu), accessed 15.6.2012.

Muller, M.J., & Kuhn, S. (1993). Participatory design. Communications of the ACM, 36:24-28.

Nonaka, I., & Krogh, G. (2009). Tacit Knowledge and Knowledge Conversion: Controversy and Advancement, Organisational Knowledge Creation Theory, Vol. 20, No. 3, May-June 2009, pp. 635-652.

Viitaniemi, J., Aromaa, S., Leino, S.-P., Kiviranta, S., & Helin, K. (2010). Integration of User-Centred Design and Product Development Process within a Virtual Environment. Practical case KVALIVE. VTT, Espoo. 39 p. VTT Working Papers: 147. http://www.vtt.fi/inf/pdf/workingpapers/2010/W147.pdf.

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| AR | Augmented reality |
| DHM | Digital human model |
| FOV | Field of view |
| F-B | Feature-benefit model |
| HCD | Human centred design |
| HF | Human factors |
| HMI | Human-machine Interaction |
| PDM | Product data management |
| PLM | Product lifecycle management |
| RULA | Rapid upper limb assessment |
| VE | Virtual environment |
| VM | Virtual model |
| VP | Virtual prototype |
| VR | Virtual reality |