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BENEFITS OF THE USE OF VIRTUAL ENVIRONMENTS IN PRODUCT DESIGN REVIEW MEETING

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1. Introduction

Design review meetings are important milestones within a product development process. They ensure that the design is evaluated against various sets of criteria e.g. requirements, consistency and usability during several stages of the design process. The review meetings are efficient tools for sharing information about the product and for managing knowledge exchange [Huet et al. 2007]. Knowledge can be embodied in the individuals or embedded in the processes or practices of organisations. Knowledge can be expanded on and enriched through the spiral, innovative amplification of tacit and explicit knowledge joint creation [Nonaka and Krogh 2009]. Thus it means both cultural, behavioural and organisational issues and not merely technological innovations. Consequently the knowledge process has to be incorporated into the work processes specially focusing on the knowledge work processes such as how to (1) create, (2) gather, (3) store, (4) share and (5) apply knowledge, and all this while taking into account the way people work on a daily basis. The modes of knowledge creation are contributed by collaborative interactions between individuals, teams, and information systems.
Nowadays the design review meetings lack demonstrative and interactive interface between the reviewers and the design model to be able to test manual work tasks in a natural way. Additionally, procedures for gathering, recording and sharing knowledge are usually not well organized [Huet et al. 2007], [Verlinden et al. 2009] or not even arranged because the importance of the reviews for the quality, usability, manufacturing and costs of the final product is not clearly seen. According to [Seth et al. 2011] expert assembly planners today typically use traditional approaches in which the three-dimensional (3D) CAD models of the parts to be assembled are examined on two-dimensional (2D) computer screens in order to assess part geometry and determine assembly sequences. For the final verification, physical prototypes are assembled by workers who identify issues with either the assembly process or the product design [Seth et al. 2011].
Although traditional tools are still used in industry there are several studies about the use of Virtual Environments (VEs) in the review meetings e.g. [Bordegoni et al. 2009], [Kremer 1998]. The use of the VEs addresses to the natural feel of the task and illustrative presentation of the model. According to [Ma et al. 2011] the collaborative virtual assembly environment is a useful computer-aided tool for supporting complex product design where each designer can bring into their special advantages and communicate with each other. Importance of the VEs comes up specifically in allowing communication for those who are not familiar with 3D CAD tools, e.g. for the assembly workers.
According to [Bordegoni et al. 2009], virtual prototyping is particularly useful in the assessment of interaction systems used by users. This means that by engaging users to the design reviews based on Human Centred Design (HCD) approach [ISO 9241-210 2010] and participatory design improve and deepen communication, knowledge transfer, collaboration and user participation in the design process.

The participatory approach in design and development is a procedure in which the users, workers of a production process or a machine operation have the opportunity to influence the content of the design target.

Although VEs and HCD approach are beneficial for the review meetings, unfortunately the potential of the VEs (and exploited VR technology) in product design are still not fully taken in to practice in industry. Based on a literature review [Leino et al. 2012a], which summarizes the recent progress on virtual-engineering-based human-centred design and product lifecycle management, the main gaps are related to lack of practical and adapted implementations of HCD, integration of virtual engineering to product processes, bi-directional data and information flow between virtual engineering applications and data management systems (PDM/PLM), and lack of sufficient methods, tools and infrastructure of managing company content and knowledge.

This study was made within the EU project ManuVAR (Manual Work Support throughout System Lifecycle by Exploiting Virtual and Augmented Reality). The ManuVAR industrial requirements, which can be viewed as the most prominent problems of the European industries in the context of high knowledge high value manual work, were found out to be: (1) problems with communication throughout lifecycle; (2) poor interfaces; (3) inflexible design process; (4) inefficient knowledge management; (5) low productivity; (6) lack of technology acceptance, and (7) physical and cognitive stresses. Project goal is to find out methodologies and solutions to improve manual work by utilising Virtual Reality/Augmented Reality (VR/AR) technology systems. [Krassi et al. 2010]

From these observations and many years of experience of the use of VEs within industry, it has become clear that although there are benefits of the use of VEs in design reviews, it is really difficult to formulate these benefits in terms of cost, time or effort. The research questions are “How the benefits of the use of the VEs in the design review meetings can be classified?” and “What is the relation between benefits?”. These questions guide the research made in two industrial case studies presented here by describing methods, approaches and technology used for investigating the benefits in the cases. Then, results are described, discussed and finally conclusions are drawn out.

2. Methods

2.1 Human centred design approach

The following HCD approaches were used: (1) the design is driven and refined by user-centred evaluation; (2) the process is iterative; (3) the design addresses the whole user experience, and (4) the design team includes multidisciplinary skills and perspectives. From the iterative HCD activities in [ISO 9241-210 2010] (Figure 1), “Evaluate the design against requirements” was the one performed in this study. The participatory approach was implemented in this study in such a way that different stakeholders were actively involved.

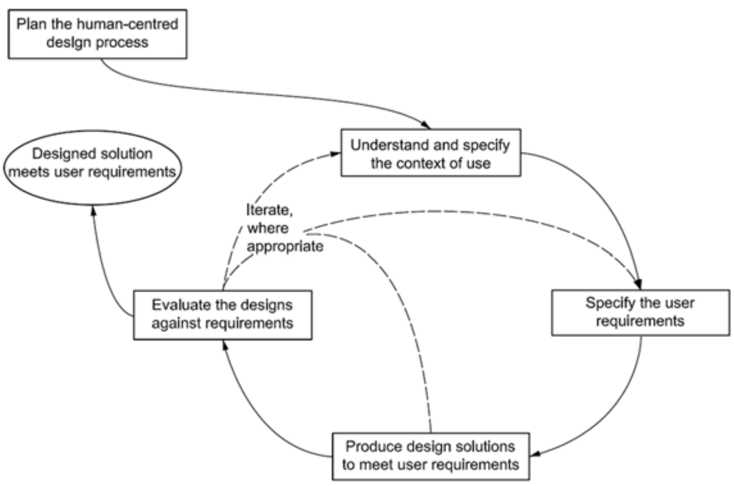

Figure 1. Interdependence of human-centred design activities

Previously mentioned HCD and Participatory Design can be considered as methods of “Design for Human” (DFH). One major principle of DFH highlights the importance of taking all manual work including lifecycle stages (manufacture, logistics, operation, maintenance, recycling, etc.) into account during the product or system design phase.

2.2 Virtual environments

VE system (Figure 2) that was used in review meetings consists of several subsystems: (1) main visualization system with active stereographic rendering in three screens powerwall setup; (2) secondary visualization system with Head Mounted Display (HMD); (3) marker-based optical motion capture system to capture worker point of view; (4) user interface (UI) system that is a combination of gesture control, gaming controllers and basic keyboard/mouse interaction, and (5) surround audio system. The review board was provided with an overview to the system on powerwall to understand the specific context. Additionally the HMD view for the worker was also projected on one extra screen for the review board observation.

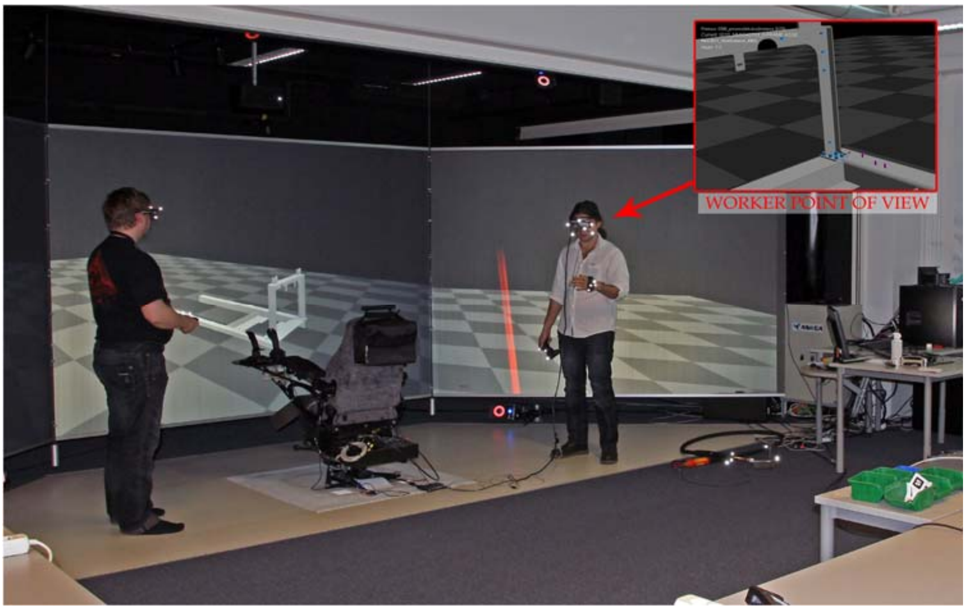

Figure 2. Virtual reality system

2.3 Product design review meeting procedure

The procedure includes three steps (1) preliminary-work, (2) actual review and (3) post-work. Before each review meeting, the preliminary work was defined and processed paying attention to the needs concerning the participants, software, hardware and other information. In the VE review meeting, the review board members gathered together to work out the actual review meeting. Following phases were conducted during the meeting:

1. A short introduction was given of the review meeting process, VR/AR tools and how to act in VE;
2. The goal, task/scenario and participants were introduced and discussed. Also role of the participants was defined (e.g. who takes notes, who uses HMD);
3. The test users were asked to perform tasks and to test the required case. The review board had free discussions. Notes were taken and small changes were made to the product model following iterative stepping;
4. Design decisions were made based on the information obtained during the meeting and expert evaluation. The meeting was documented (notes, video, pictures), saved and informed to the key persons not present in the review meeting.

Both review meeting case studies were executed at the research centre’s premises in VEs laboratory.

2.4 Review meeting case studies

2.4.1 Case study 1

The purpose of the first review meeting was to present a new concept which was additional module to the existing product. There had been product design review meetings beforehand to iteratively improve the concept before this particular meeting, which was organised for the customers. Therefore, the nature of the review was about introducing the concept and how it would be assembled on site than finding out problems. The review board consisted of one product company representative, a few experts (VE system and Human Factors) and customer representatives from six different companies. One expert was using the HMD to assemble the new module and to present the idea of the concept to the customers. Although it was not the main purpose, customers were able to make comments and to suggest improvements. Customers were also allowed to try the VE system.

2.4.2 Case study 2

The purpose of the second review meeting was to show the forthcoming engine module to the productization and production experts (Figure 3). The purpose was to evaluate the assembly, maintenance, safety and structural problems, and also to discuss possible solutions. The review board consisted of an assembly worker, design engineers (mechanical/hydraulics/etc.), a manufacturing manager, assembly foremen and product development engineers - all from the same company. Also a VE expert, HF experts and the review meeting chairman were present. The assembly worker was using the HMD to observe the step by step assembly and review board was discussing and making comments. The meeting was recorded by taking pictures and notes from the discussions.

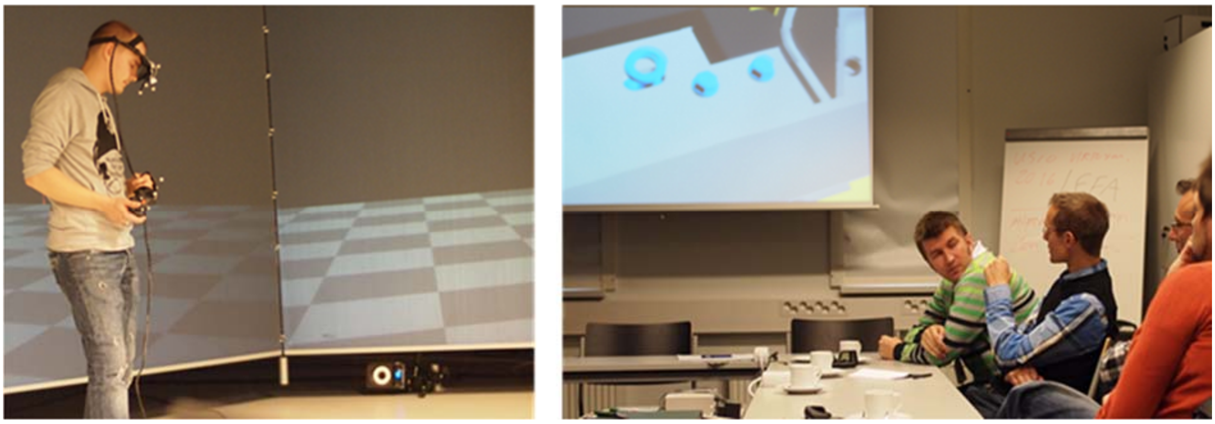

Figure 3. Engine module review meeting

2.5 Questionnaire and observation

Questionnaires and observations were used to collect information about the benefits emerged from the use of the VEs in the review meeting. Questions were related to issues e.g. how the review meeting felt as an experience, how the new VE based review process felt like when compared to the old practises, did it affect to the information transfer and whether the level and maturity of the used VEs was sufficient. The questionnaire was web-based and it was sent to the participants after meeting. A total of ten filled questionnaires were received. The observations and notes were taken during the meetings on the use and usability of the VE system, function of the review meeting process and also the product development issues in question.

3. Results

In general, the results from the interviews and observation show that the participants felt the review meeting was interesting and useful experience for them. The results based on the observations and interviews in case 1 and case 2 are presented in Table 1. The results are categorised in three key topics: (1) VE system; (2) Communication and knowledge transfer, and (3) Design process and lifecycle. In each topic, there are described main positive and negative feedback collected.

Table 1. Key results from the interview and observation on the use of the VEs in the review meeting

Key topics	Positive feedback on the use of VEs in the review meeting	Negative feedback on the use of VEs in the review meeting
VE system	• The use of VEs was illustrative • Easier to understand dimensions and functionality • User interfaces (controls) were sufficient • The implementation level of VE system was good enough for the review meeting • In general, the depth of details was sufficient for the product review	• Visualisation could have been better • Easier modified models were requested • Hide/unhide parts feature in model were requested • Simulation of the surrounding environment could improve the immersion • Zooming feature in the HMD could be good
Communication and knowledge transfer	• Increases collaboration between stakeholders, customers and manufacturing company • Enables better communication and discussions on a specific detail • Information was shared between design engineers and production/productization	• Better information recording tools needed
Design process and lifecycle	• Possible to test and to modify the design before manufacturing • Decreases need of expensive prototypes • Fewer corrections needed during the life-cycle because errors could be removed at the beginning of the process	• The review meeting process should be more systematic • Good preparations advance would make the review meeting more efficient

The improvements for the product are listed on Table 2. The improvement suggestions were collected from Case 2 review meeting's discussions and observation. Many of the improvements suggested to the product were made by the worker while walking through the assembly.

Table 2. Key findings for the product development

Findings for the product development	
Product development	• Three errors in the geometry of reviewed 3D model were found • Change request related to component layout • Change request related to dimensions of two supporting structures to give more space for assembly • Change request related to the form of one supporting structure to enable the attachment of a component • Four different change request related to needs in assembly order/methods • Change request related to one safety related issue • Some feedback was collected about assembly tools and methods • Some discussions were kept about the buildup-level and module variations

4. Discussion

4.1 Benefits of the use of VEs in design review meeting

4.1.1 Emerged benefits from the two case studies

The results are generally positive and they encourage the use of VEs in the review meetings. Most of the comments were related to the quality of the VE system, communication and the product itself. It was noticeable thought that it was easier for the participants to comment on the technology improvements needed in VE/VR than the review process or the review content itself.

It was seen that one major benefit that comes from the use of the review meeting is gathering together people with different knowledge and getting them to communicate their knowledge in the way that all of them can understand. Therefore, the *information and knowledge sharing* is a key benefit. The use of VEs enables knowledge sharing because it establishes an environment, where everyone has the same visual understanding of the current situation. The same understanding that comes from the 3D environment cannot be achieved from the 2D pictures on a projector: because only in the VEs it is possible to walk around the real-size 3D model.

In the second review meeting, the information was shared between the design engineers and the production engineers, which was positive because the discussions between the departments are usually too challenging due to time limitations. The increased assembly worker-engineer communication was also valued in the results as many of the improvement remarks for the product were made by the worker. This *user participation and requirements* recognition are in-line with the HCD [ISO 9241-210 2010] principles. Additionally, by using this participative approach it is possible to extend good practices and to improve benefits in using VEs in manual work prototyping. Now, the existing computer-based tools to support virtual assembly either (1) concentrate on representation of the geometry of parts and evaluation of clearances and tolerances or (2) use digital human models to approximate human interaction in the assembly process [Seth et al. 2011]. The participatory approach supports also *design decision making and learning*.

Other major benefit that emerges from the use of VEs is the *visualisation and immersion*. It is relatively easy to immerse the worker into to the task without any previous experience. The worker can concentrate on the task and work naturally. Also, the user interface controls were gaming-controls, so it was easy to use them after a short instruction. According to [Bordegoni et al. 2008], the use of VEs in the review meeting is especially beneficial when assessing interaction systems (human-machine interaction) and we confirm this finding. In the review meetings, it is also possible to *enhance designers' experience* of what the workers really experience while doing their tasks.

The two case studies also proved that it is possible to use the VE review meeting to achieve various goals in *different lifecycle phases*. The VEs make it possible to have an efficient review meeting (to verify human/worker/user/customer requirements) already at an early phase of the concept design when usually no illustrative material exists. The benefits also arise from *time and money savings* achieved later on in lifecycle e.g. (1) company can build preliminary assembly instructions based on the review meeting; (2) user acceptance will be better if based on the participatory approach; (3) assembly and maintenance will be more efficient; (4) it is possible to plan the delivery dates for sub-contractor parts; (5) bottlenecks can be found out and removed from production; (6) alternative assembly orders can be defined, and (7) the amount of physical prototypes can be decreased.

Based on these results, the use of VEs in the review meetings can also address all the manual work gap presented in the ManuVAR project [Krassi et al. 2010]: (1) communication; (2) interfaces; (3) design process; (4) knowledge management; (5) productivity; (6) technology acceptance, and (7) human factors.

4.1.2 Benefits from the second case study

By changing the assembly order and adding a simple supportive structure it was possible to give the assembly worker more working space (Figure 4). The initial plan was to put the tank to its place as early as possible. This would cause the worker to do the assembly in a limited space between tank and engine.

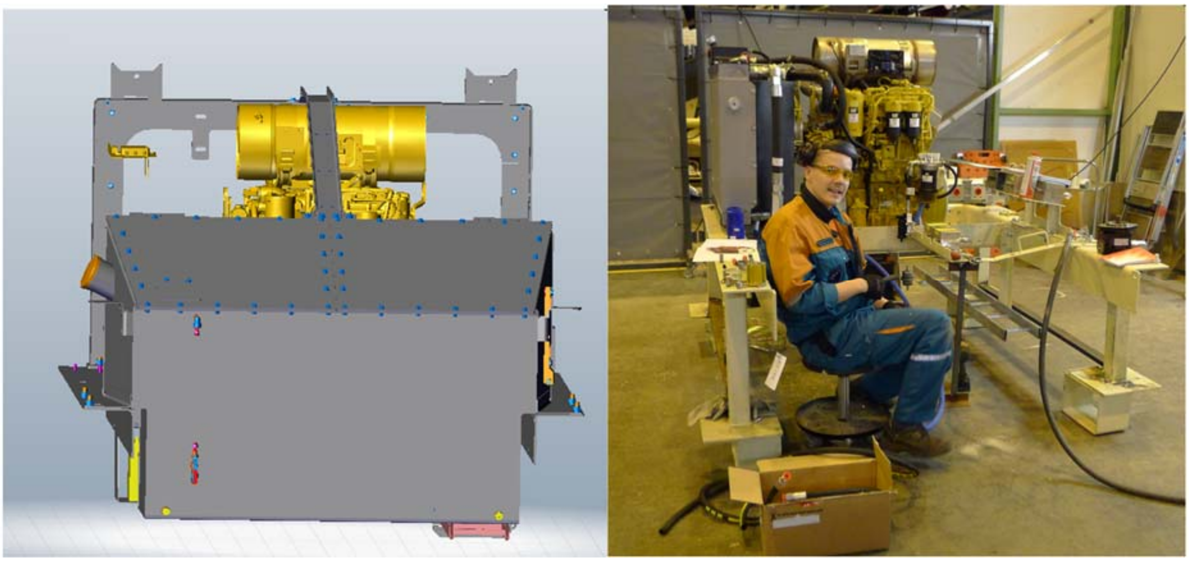

Figure 4. More working space for assembly worker by changing the assembly order

An example of what eight small design faults spotted in the review meeting mean in terms of assembly time are shown in Figure 5. Following the time line, the first bar represents the prototype manufacturing process with the VE review meeting, while the second bar represents the process where errors are spotted during the assembly instead of the early design review.

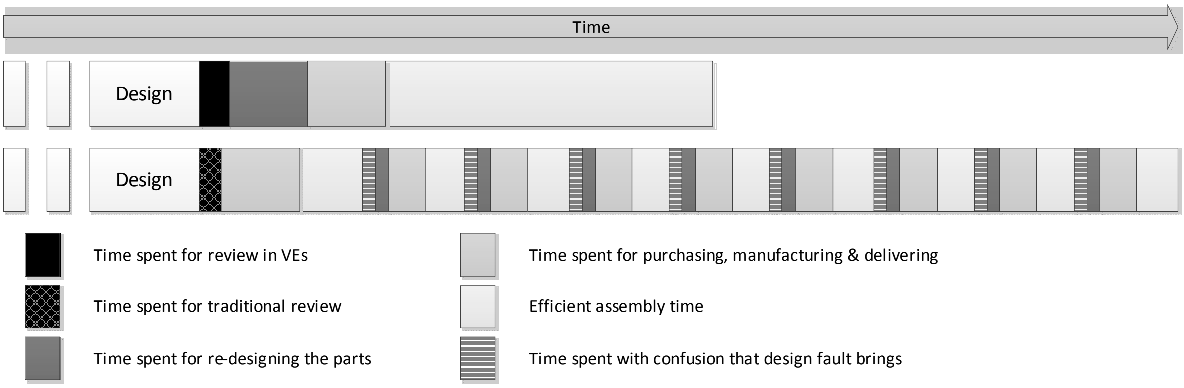

Figure 5. An example of the assembly time spent when detecting eight design errors early in VE design review meeting compared to the worst case scenario of the use of the traditional review meeting

4.1.3 Benefits' classification and relations

Even though there are many studies done on VEs' use in the design reviews, the benefits of this use are not described sufficiently. [Bordegoni et al. 2009] mentioned a few benefits from the virtual prototyping, but for evaluating effectiveness they suggested further investigation where building a virtual prototype should be compared with building a physical prototype in terms of required time, cost and tests. Also [Kremer 1998] and [Verlinden et al. 2009] are concentrating more on describing technology development in the design reviews. Additionally, the review processes are investigated e.g. [Huet et al. 2007] describes how to record knowledge in reviews effectively. This paper emphasizes the emerging benefits from the use of the VEs in the review meeting than describing yet another technology used.

When analysing the previously listed benefits it was clear that there are different types of them. The benefits are described in Figure 4 in Feature-Benefit (F-B) pyramid. Benefits are classified in three different categories based on findings: (1) VEs; (2) design, and (3) business. Additionally it is important to consider the difference and dependence between the features and the benefits. In Figure 6, VR/AR technology and HCD approach features are the enablers for achieving the benefits (immersive, interactive and visual) from the VEs use. These benefits then direct to the natural and common media for collaboration and review which forms a feature for the design. Finally, the business benefits are gained e.g. reduced costs or shorter time-to-market.

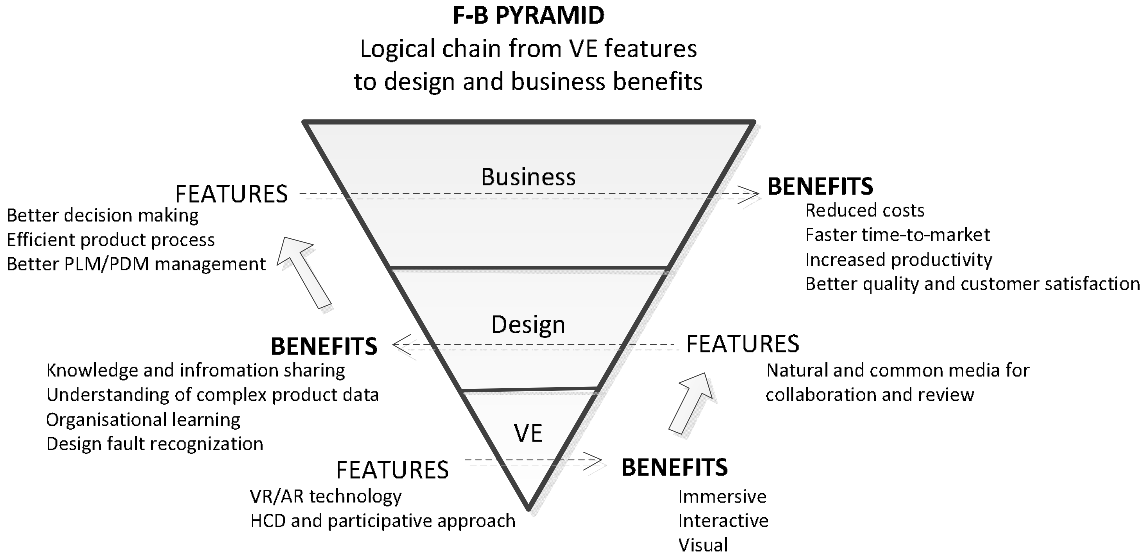

Figure 6. Feature-Benefit (F-B) pyramid describes difference between features and benefits in the case studies

This type of classification and categorisation of the benefits from the use of VEs technology in design reviews are important for the industry especially in the human –interaction context (use, assembly and maintenance). The F-B pyramid is a way to make the benefits more tangible in the theoretical and industrial context. It can also make companies' investment decisions regarding new technologies, implementation of technologies, or use of the existing VEs more straightforward. Especially the companies that operate in the areas related to human-machine interaction such as automobile or machine industry, can benefit from the presented F-B pyramid.

4.2 Challenges

When using the VEs, it is always important to consider restrictions that arise from the use of VE technology e.g. simulation sickness. It needs to be taken account how long it is possible to be in VEs (either VR or AR based) especially when using the HMD. It is also important to acknowledge the differences between each users' individual characteristics concerning eye vision, stereoscopic visual capabilities and simulation sickness. Thus need to be informed beforehand to the participants and monitored during the review.

One challenge is to decide the level of details when working within the VE system. The more details and functionality are needed, the more time it will take to do virtual models. It also means more development costs and longer time-to-market. It was also seen that technology still has constrains that affect to the immersion e.g. visualisation, simulation, haptics, challenge with large and heavy parts, and realistic forces. [Seth et al. 2011] lists same type of technical challenges to be overcome to realize virtual assembly simulations, namely: accurate collision detection, inter-part constraint detection and management, realistic physical simulation, data transfer between CAD and VE systems, and intuitive object manipulation (inclusion of force feedback).

One often neglected challenge is how to integrate the VE review meetings to the company processes in a way that will make the design work more efficient. Companies are investing money for their own VE systems, but they are often inefficiently used because they do not implement the new system their design process. We found out that more systematic practises in the VEs review meetings process needs to be implemented at the company level. Nowadays feedback is recorded usually into participants' minds or personal notes, and reported to the designers verbally or through an email. Due to insufficient communication, knowledge about design defects and feedback will not be shared among organisation.

There are studies about the review meeting activities, procedure and knowledge management [Huet et al. 2007], but the challenge is how companies can adapt these good practises to their processes. The review board might also need training to fully understand the system and to be able to work with it.
One issue is how to link the VEs use and the information management (PDM, Product Data Management) and PLM (Product Life-cycle management) processes together. CAD-VE data exchange is one of the most important issues faced by the virtual prototyping community, especially translating identified design changes back to CAD and other CAE systems [Seth et al. 2011]. Design data is typically managed in EDM (Engineering Data Management) systems, to which, for instance, production department does not have access. Additionally, engineering structure of a product is in many cases very different to assembly or maintenance structure and task hierarchy, which causes difficulties for design evaluation from production or service point of view.

5. Conclusions and future work

This paper describes and categories benefits of the use of VEs in design review meeting collected from two industrial case studies. Main benefits are: (1) the information and knowledge sharing; (2) the user participation and requirement management; (3) the design decision making and learning; (4) the visualisation and immersion of VE systems; (5) the enhancement of designers' experience of the use of product; (6) the evaluation of different lifecycle phases, and (7) the time and cost savings. Based on this and other studies it has become clear that there are different types of benefits and classifying and defining them in e.g. cost, time or effort is difficult. This paper classifies these benefits in three categories: (1) VEs; (2) design, and (3) business, and describes relations between them.
This paper is the first step for the classifying emerged benefits. In future, more companies will be interviewed and better measurement and categorising for benefits will be developed. Another issue for the future research is to find out how to describe the benefits in a more tangible way to the industry. Finally, the VEs review meeting processes and the integration to knowledge and information management will be further investigated.

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