Joint Virtual Reality Conference of EuroVR - EGVE (2011)
S. Coquillart, A. Steed, and G. Welch (Editors)

User Centred Methods for Gathering VR Design Tool Requirements

J.P. Thalen[1] and M.C. van der Voort[1]

[1]Laboratory of Design Production and Management
University of Twente, 7500 AE Enschede, The Netherlands

Abstract

This paper addresses the use of VR to facilitate design tasks in the early stages of a product design process. A preliminary exploratory study, involving over thirty interviews amongst four industrial partners, revealed only few occurrences of VR being used in the early stages of design. While the potential benefits of the applications are generally acknowledged, product designers lack the appropriate design tools that allow them to quickly and easily create the application. The research presented in this paper applies user-centred design principles to identify requirements for useful, usable and accessible VR design tools. The primary challenge in gathering such requirements is the lack of experience product designers generally have with VR technologies; product designers can not provide reliable requirements for tools they have never seen or used. We present a sequence of three concrete steps that provide product designers with sufficient information to express tool requirements, without developing extensive prototypes. The three methods have been developed and applied in an industrial case study, as part of a larger research project. The paper outlines this research context, the three methods and the lessons learned from the case study.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Methodology and Techniques—Ergonomics

Keywords: User Studies and Evaluation, Product Design

1. Introduction

The product development process *(PDP)* generally involves a sequence of gathering requirements, conceptual design, engineering and finally a market release. Especially during early stages, feedback from product end-users provides product designers with valuable information regarding usability, functionality or aesthetics. A challenge inherent to the early stage of the PDP however, is that end-users are asked to provide feedback on a product concept that does not exist yet. Tools such as sketches, mockups or functional prototypes are used as *boundary objects* [AF00] to facilitate this communication between designers and end-users.

Virtual Reality *(VR)* can extend this collection of early stage prototyping tools, for instance when the real world situation is too dangerous [TvdVvH08], when an environment needs to be controlled (e.g. in simulation and evaluation [KBS*01]) or when physical prototyping is too expensive or simply not possible yet (e.g. virtual prototyping [VSH07], [BKFT00]). However, a recent survey amongst design departments from four different companies, conducted as part of the current research, showed a very limited adoption of VR in the PDP, let alone the early stages of the PDP (section 2 elaborates on the results of this survey). While product designers generally acknowledge the potential benefits of *applying* VR in the early stages of the PDP, they consider the *tools* needed to create these applications to be either too complex, too task specific or not suitable for early stage design tasks.

In a series of three industrial case studies, of which the first is presented in this paper, we apply User Centred Design *(UCD)* methods to elicit relevant requirements from designers regarding VR design tools. The main contribution of the research is in showing how designers can explore various VR technologies, experience them in a familiar context and provide useful requirements without the researchers having to create extensive software prototypes. The resulting re-

DOI: 10.2312/EGVE/JVRC11/075-081

quirements, once validated across the three industrial partners, help with selecting appropriate tools from the existing range of tools, with integrating individual tools, or with the development of new tools.

2. Background

In a preliminary study a series of interviews (10 to 15 one-hour interviews per company) and site visits was conducted amongst four industrial partners involved in the current research. The industrial partners include multinational manufacturers active in automotive design, machine design, consumer electronics and office machinery design. The study investigated the adoption of VR in (early stages of) the PDP of these companies. The use of VR was found to be limited to one stereoscopic display and the use of CAD systems in advanced stages of the PDP. While the *applications* of VR were generally found useful (after explaining them verbally), designers indicated that the *tools* needed to create those applications should be easy to use (designers are no computer scientists), flexible (designers should be able to deploy VR applications in various design cases) and compatible with existing tool chains.
The findings of this preliminary study are similar to those of a study carried out over fifteen years ago, investigating the role of VR in integrated manufacturing [CDW95]. Here interviews and demonstrations showed appreciation of potential applications, but also doubts regarding the actual implementation of the applications within the design process. However, unlike fifteen years ago, doubts are no longer related to tool costs or computing power, but rather to tool usability and flexibility.
When we look at VR development tools from a designers' perspective (i.e. with a focus on usability and flexibility), three issues can be identified. Firstly, a significant part of the existing VR development tools consists of *toolkits* that extend programming languages with VR specific functions. An extensive review of such toolkits is provided in [WM09]. Well known examples include VR Juggler [BJH*08], OpenTracker [RS01] and ARToolkit [Hir02]. While these toolkits provide an excellent research platform, they are by no means usable by product designers who generally do not have the skills nor the time to invest in such tools. Secondly, user friendly alternatives such as ComposAR [WLBB09] or DART [MGDB04] do provide a more accessible authoring tool but reduce the tool's flexibility (e.g. the range of applications). Thirdly, more flexible VR design suites, such as *VRED Professional* or *Dassault Systemes' 3DVIA* primarily target later stages of the product development process such as engineering and simulation.
Despite the increased availability and diversity of VR tools, the lack of (awareness of) suitable tools still prevents designers from actually implementing VR applications. Our research therefore aims to determine whether the existing tools can be modified or new tools should be developed to better fit the needs, habits and capabilities of designers.

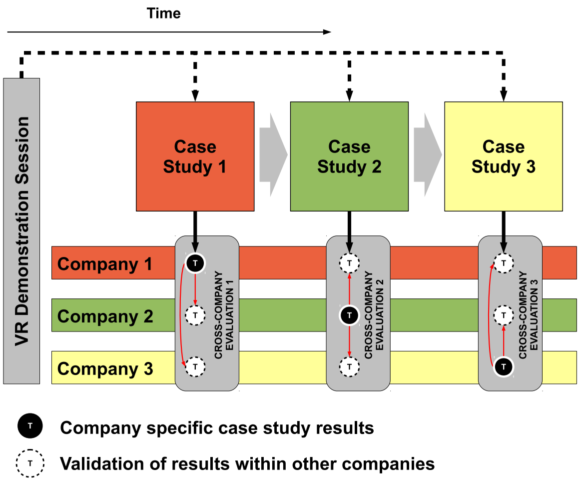

Figure 1: *The research approach starts with a company-wide VR demonstration session. Subsequent case studies focus on one company, and validate the case study results in three cross-company evaluations. This paper covers the initial demonstration session and the first case study.*

3. Approach

The approach presented in this section applies UCD principles to elicit relevant information from designers. UCD principles have succesfully been applied to VR application development, for instance to improve usability or user interactions [GHS99], [BGH02]. In our current work we apply UCD principles to identify relevant *tool* requirements; *what tools do designers need to create a specific application for use in their PDP?* The VR application, though important, merely serves as a frame of reference (i.e. a design task that is to be supported by VR) for designers to express their requirements. As such, the approach is comparable to the work of [SR01], where the development of a case-specific VR application is guided by UCD methods such as participatory design sessions and user studies with low fidelity prototypes. We intend to carry out a similar approach in three different industrial case studies. One particular challenge raised in the aforementioned work is time-consumption of UCD methods. Our approach aims to demonstrate that UCD methods can be carried out efficiently, even within industrial contexts.
The industrial context for this research is provided by three of the four companies that were also involved in the preliminary study. In a series of three sequential case studies we identify *1)* a VR application relevant for the company and *2)* VR design tools that match the requirements of designers. Each case study concludes with a cross-company evaluation and generalisation of the case study results prior to proceeding to the next case study (see figure 1). The resulting insights help with improving existing tools, with creating

new tools, or with merging existing tools, and consequently increase the adoption of VR in the early stages of PDP.

4. Demonstration Session

The first step in our research consists of a *VR demonstration session*. The session aims to create a shared understanding of VR by demonstrating various design related VR applications. An important difference with related work [CDW95] is the participation of four diverse companies and consequently four diverse VR applications. These demonstrators are relevant for the companies and span a significant part of the VR spectrum (e.g. immersive VR, mixed reality, desktop VR, etc.).

1. **AR Factory Layout (D1)** - This demonstrator uses AR to configure and review factory layouts. The application was designed to help machine designers with communicating their designs to customers. The demonstrator consists of simple 3D models of the company's products rendered and controlled in Blender [Ble11]. The scene objects are connected to AR markers through ARToolkit [Hir02] (see figure 2). Each marker contains a virtual model of a machine and also provides layered information, such as machine dimensions, machine input and output channels and hazardous areas.
2. **Virtual Usability Lab (D2)** - This demonstration consists of a 3D virtual office environment in which designers can walk around and operate virtual office machinery (e.g. printers, computers, etc.). The environment was created using Blender's game engine and projected on a large screen to create a semi-immersive experience. Designers control a first person perspective using a keyboard and mouse, and are able to carry out simple interactions with machines.
3. **Drive Simulator (D3)** - An immersive drive simulator available from [TvdVvH08], consisting of a physical car frame in front of a large semi-spherical screen, was demonstrated. The drive simulator allows participants to configure their own drive support system (e.g. lane change support, adaptive cruise control, etc.) and immediately experience it in a traffic scenario. In addition to this, the company also requested a demonstration of motion tracking, which was implemented by putting the driver in a motion tracking suit [Xse11] and showing the output on a screen next to the simulator.
4. **Virtual Playground (D4)** - The fourth demonstrator consists of a 3D interactive room, again created using the Blender game engine, designed to evaluate lighting and sound effects (e.g. real-time shadows, shading and ambient sounds). The layout of the room can be modified by moving around tangible furniture models on a *Surface Table* [Mic11], which was connected to the 3D environment. This provided lighting and sound designers with an intuitive tangible interface to change and review the room layout.

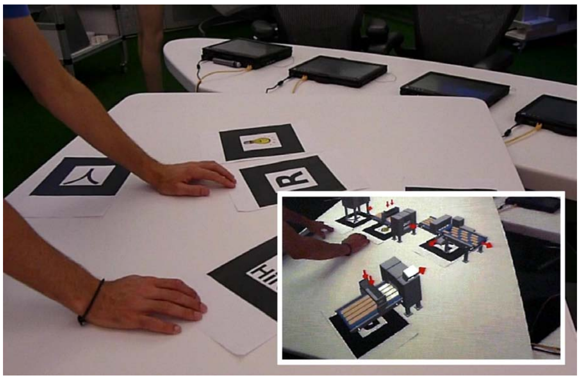

Figure 2: *The AR factory layout demonstrator. Designers move around tangible markers that represent machine configurations in a factory. The setup uses regular webcam and standard ARToolkit markers, connected to Blender game engine models.*

It should be noted that the aim of the above demonstrators is to create awareness and a shared understanding of VR amongst the participating companies. As the companies are not yet involved with actually using or building these applications, traditional development tools (e.g. ARToolkit, and game engines) are used to create the demonstrators.

4.1. Results

The demonstration session was held in a university VR facility and was scheduled to take one day. All four companies were represented by at least four participants, including designers, managers and researchers. The demonstrators were introduced by explaining how they had been developed, and how they were envisioned to fit the design process of the companies. Participants were invited to try out the demonstration. Upon completion of each demonstration, a brief round of discussion was held, and participants were asked to fill out evaluation forms.
The demonstrations describe the use of formerly unknown VR technologies in a design related context, such as *concept evaluation* or *idea generation*. Because designers are familiar with such contexts, it enables them to effectively reflect on the VR applications and consequently think of the tools that would fit the application. Compared to the demonstration session described in [CDW95], the applications presented in the current session are less extensive; designers can not really use the application, while in the aforementioned work participants could actually try out the application in a fictional test case. A benefit of the current work however is that, despite the relatively superficial demonstrators, the variety of applications and technologies triggers detailed discussions *between* companies, identifying potential opportunities and bottlenecks in a very early stage of the research,

Company	D1	D2	D3	D4
Machine design	**4.0**	3.5	1.0	4.0
Office machinery	4.0	**5.0**	2.3	3.3
Automotive design	4.3	4.0	**5.0**	4.0
Consumer products	3.5	3.0	3.8	**4.7**

Table 1: *Quantitative results of the demonstration session. Demos (D1/D4) were rated between 1 (not useful) and 5 (very useful) by each company.*

without major investments in application development.
Interactions between the participating companies are considered an important aspect of the demonstration session. Even though each demonstrator was designed for a specific design domain, participants were able to reflect on their company-specific application as well as the applications demonstrated for the other companies (see table 1). For example, the *AR factory layout* demonstration that was created for the machine design domain was also appreciated by the office machinery designers who envisioned to use the setup for workflow visualisations in an office environment. Subsequently, additional features for the application were proposed (e.g. *'it should also support...'*) and participants described feasible use cases for the demonstrated applications (e.g. *'we can use this for...'*). As such, the session provides the participating companies with a broad view of opportunities and familiarises them with translating technology opportunities into something they can use themselves.

5. Group Workshop

Following the cross-company demonstration session, the remainder of this paper describes results of the first company specific case study. This case study involves participants from the design department of a multinational manufacturer of professional printers and copiers.
The first part of the case study aims to define a VR application that facilitates early stages design tasks for this company. While the application shown during the demonstration session was found useful, we do not intend to force the company in pursuing this direction only. Identifying an advantageous VR application for the company should be a collaborative effort between the case study participants and the researchers.
The *group workshop* described in this section facilitates the exchange of domain expertise between product designers (design process knowledge) and the researcher (knowledge of VR technologies). The approach is inspired by participatory design methods such as Inspiration Cards [HD06], Pivots [UWZ*02] and in particular the Future Technology Workshop [VSR02]. The methods use tangible cards or artefacts to create and discuss future use scenarios. In our workshop we asked a group of designers to create future use scenarios in which VR technologies facilitate a specific design task. Small cards, called *frames*, with visual representations of design tasks and VR technologies were handed out to the workshop participants. Three types of frames are used.

1. **Regular frames** - Representing generic activities and events (e.g. meetings, presentations)
2. **Technology frames** - Representing the use of VR technologies (e.g. augmented reality, haptic devices, holographic displays, etc.)
3. **Empty frames** - Enable the participants to create custom frames

By (re)arranging these frames scenarios can be created. For instance, a participant can connect a *brainstorm meeting* to a *concept sketching* frame, followed by a *concept evaluation* frame. The resulting scenario can be extended with the technology frames, for instance by supporting the *concept evaluation* task with *virtual prototypes*. The use of these visual and tangible aids facilitates group discussions (everyone can modify storyboards) and lowers the threshold to talk about complex technologies because they are placed in a familiar context (e.g. a design-related scenario).

5.1. Results

The workshop was carried out with a group of twelve designers and engineers from the design department, and took about four hours to complete. The primary objective of the workshop was to let the participants create and discuss useful VR applications. The session involved the following steps.

1. **Present Example Storyboards (30 min.)** - The researcher first presented four example storyboards that were prepared for the workshop. The four storyboards are based on results of previous meetings and described four basic situations where VR could be applied.
2. **Create Individual Storyboards (60 min.)** - Participants were asked to create individual storyboards. These storyboards could be based on the examples (e.g. by adding or removing frames from the example storyboards) or created from scratch, using existing frames or newly created frames (see figure 3).
3. **Present & Select Individual Storyboards (60 min.)** - After forming three groups of four participants, the individual storyboards were presented within the groups. After discussing the storyboards, group storyboards were to be created by merging individual storyboards or by selecting a single one.
4. **Create Group Storyboards (60 min.)** - Each group was then asked to elaborate their storyboards by specifying the *objectives, tasks, tools* and *people* occurring in each frame. Special cards were prepared to facilitate this step.
5. **Present & Discuss Group Storyboards (30 min.)** - As with the individual storyboards, each group was asked to present their storyboard, highlighting their vision on the use of VR in the scenario. After presenting and discussing the storyboards, a final voting round concluded the session.

Three common themes emerged from the resulting storyboards.

1. *Augment evaluation environments* - A problem with evaluating new printers and copiers with real-life clients is that either a prototype is tested in a 'clinical' test environment within the company, or an expensive prototype is to be sent to the client for a 'field test'. With AR designers could turn the clinical test environment into a more realistic use context, or augment the client's use context with a virtual prototype.
2. *Visualise client data* - Designers often visit client sites to gather *contextual data*; information about workflows, work habits, practical issues, etc. Propagating this knowledge to fellow designers can be facilitated by visualising the information in a virtual environment, envisioned as a 'holo deck' where designers can walk around and explore the client's workspace.
3. *Support detailed design* - In advanced stages of design, engineers need to verify that all printer components fit the machine, and that certain components are still accessible for maintenance by trained or untrained users. In an early stage of design this could be done by letting end-users work on a virtual printer, for instance through head-mounted AR. Physical aspects, such as dimensions or tolerances could be included through haptic devices.

After reviewing and discussing the themes with the workshop participants, it was decided to focus the case study on the first application. Two storyboards describe this application and help with identifying several application characteristics. The purpose of the proposed application is to let product end-users (who are involved as test subjects in early stage product evaluations) feel 'at home' in the test environment; instead of being in a clinical test room, it should feel like they are working in a familiar workspace. Designers indicate that they should be able to easily create and modify the test environment, and to let the test user carry out certain tasks with (virtual) future products.
The contribution of the workshop lies not in the novelty of the application. Similar virtual review and evaluation applications have already been published [KBS*01], [BD03] and [BCCP09]. The workshop however allows us to review such applications from the designer's perspective. Designers position the application in a logical sequence of design tasks, and indicate how much time they would spend on it, which relevant skills they have and how the application should cooperate with other design tools.
While the workshop offers a time efficient and low-threshold solution for technology exploration, it does not result in concrete application specifications. The storyboards describe *what* should be achieved, but not *how* this should be done. The next stage of the case study translates the application outline into more concrete tool requirements.

Figure 3: *An individual storyboard. This example shows regular frames, empty frames (filled out by participant) and technology frames. Most of the participant added text captions and arrows to clarify the storyboard.*

6. Hands-on Workshop

The *Hands-on Workshop* described in this section facilitates the translation of application characteristics into tool requirements. For example, when the application requires a high *level of realism*, certain tools can be ruled out because they do not support the specific level of realism, or exceed the limited programming skills or time constraints imposed by designers.
While there are numerous relevant application characteristics, the following two are selected (in consultation with the designers) because they are difficult to assess without experiencing their effect on the application.

1. *Level of realism* - How does the level of realism affect the outcomes of a concept evaluation in a virtual environment?
2. *Level of virtuality* - How does the type of virtual environment (e.g. mixed reality or fully virtual) affect the outcomes of the concept evaluation?

In order to let designers experience the effects of changing these application characteristics, a virtual environment was created by the researcher. In accordance with the application outlined in the group workshop, this virtual environment provides a realistic 'printshop' environment, in which designers and test users can move around, interact with printers and carry out product evaluations. To properly represent the two application characteristics, the level of realism and the level of virtuality are configurable.

- The level of realism can be high (HR) or low (LR). The HR environment features textured 3D objects, real-time shading, full 3D audio, and animated objects (e.g. a printer tray can be opened). The LR environment features simple shading, no textures, limited audio and no animations (e.g. printer tray status is communicated through a simple icon).

Figure 4: *The hands-on workshop allowed participants to experience the application with two different levels of realism (the upper right and lower right pictures) and in two levels of virtuality (the upper left and lower left pictures).*

- The level of virtuality can be fully virtual (FV) or mixed reality (MR). The FV environment consists of a 3D first person walk-through environment, projected on a 3x2m rear-projected screen. The designers operate the first person perspective with keyboard and mouse. The MR environment is implemented on a tablet PC equipped with a camera. Pointing the tablet on a visual marker will display the corresponding 3D models on the tablet's display.

Together these configurations allow for four different virtual environments to be experienced; HR/FV, HR/MR, LR/FV and LR/MR (see figure 4). To make the VR application more concrete, the workshop featured a fictional use case in which designers are to evaluate new product concepts in the virtual environments.

6.1. Results

The hands-on workshop involved four designers who also participated in the previous group workshop. The results of this session are twofold.
Firstly, experiencing the four different environments helped designers with refining application requirements. For example, instead of simply requiring the highest level of realism, it was found that reduced realism does not necessarily reduce the effectiveness of the application. Furthermore, the fully virtual environment was considered more effective for fully representing the use context. While the augmented reality environment did allow for physical interactions (e.g. walking around an object), it failed to keep the designers 'immersed' in the virtual environment. The fully virtual environment provided a more integral experience.
Secondly, insights regarding how to integrate the applications with the existing tool chain of the company emerged during a concluding discussion. After experiencing the virtual environments, the designers were introduced to the tool chains used for creating the four different implementations. The tool chains comprise three tasks, namely *Geometry Modeling* (modeling 3D objects), *Behaviour Modeling* (adding interactivity to objects) and *Scene Integration* (putting the objects in a 3D scene). Having experienced the effects of these tool chain components on the VR application, designers were able to identify integration opportunities and bottlenecks. For instance, the Geometry Modeling task could be combined with a CAD database already available within the department. The Behaviour Modeling task, which was expected to be a bottleneck for designers, turned out to be similar to the function of one of the dedicated *prototypers* (an expert on creating interactive GUI prototypes) available within the department. For Scene Integration, designers require an application that would simply allow them to create an office environment, and import the appropriate 3D objects (e.g. furniture, office machinery, etc.) either from the existing CAD databases, on-line resources or interactive models provided by the prototyper.
The results of the hands-on session were used to finalise a more detailed description of a tool chain that supports the envisioned VR application. The tool chain integrates with various resources from the existing tool chain, such as a model database, and skills provided by the prototyper. A follow-up project will further implement these findings within the company.

7. Discussion & Future Work

The paper presents ongoing research addressing the introduction of VR technologies in the early stages of a PDP. Our preliminary study identified the limited availability and awareness of suitable VR design tools as a bottleneck for successfully deploying VR in this setting. The research aims to determine whether existing tools can be modified to better fit design contexts, or new tools should be developed.
We organised a demonstration session in which designers from various design domains were introduced to different VR applications. The inclusion of four different design domains turned out beneficial for feeding discussions between companies. Even with four relatively simple demonstrators, designers were able to assess the applicability of the applications to their own PDP, but also to translate unfamiliar applications into something they could deploy in their own setting. Especially in such exploratory stages of research it is interesting to see that low fidelity demonstrators, once given a relevant (domain specific) context, provide sufficient grounds for detailed discussions. Using low fidelity demonstrators also prevents participants from being biased towards one specific application (e.g. there is room for exploration and design iterations).
In the subsequent company specific case study we again used low fidelity participatory design methods to first let the company participants create a relevant use case for VR (the *VR application*), and then identify requirements for the tools needed to create this application. The group workshop fa-

cilitated the collaborative effort of connecting technological opportunities to relevant design cases. Without actually using or creating software, this session resulted in a clear outline of a desired VR application. To our knowledge this is the first example of applying this method to the field of VR. It should be noted that the context in which the workshop took place (e.g. a design department) probably contributed to the outcome; professionals in other fields may be less willing to participate in such workshops. After experiencing the envisioned application and discussing the required tool chains in the hands-on workshop, designers became aware of formerly unrelated resources, such as the CAD database and the prototyping expert. Combining existing resources and making designers aware of the resulting opportunities is considered an important lesson for future case studies.

While the first cross-company evaluation is still due, the study already skews interesting insights, mainly regarding applying UCD in VR related research. The key finding, especially compared to [SR01], is that we demonstrate how low-fidelity design steps (e.g. storyboards and simple prototypes) provide sufficient grounds for eliciting requirements, while remaining time efficient in an *industrial* setting. The methods will be further refined for other industrial contexts in the upcomming case studies.

8. Acknowledgements

The authors gratefully acknowledge the support of the Innovation-Oriented Research Programme 'Integral Product Creation and Realization (IOP IPCR)' of the Netherlands Ministry of Economic Affairs, Agriculture and Innovation.

References

[AF00] ARIAS E. G., FISCHER G.: Boundary objects: Their role in articulating the task at hand and making information relevant to it. 1

[BCCP09] BORDEGONI M., CUGINI U., CARUSO G., POLISTINA S.: Mixed prototyping for product assessment: a reference framework. *International Journal on Interactive Design and Manufacturing (IJIDeM) 3*, 3 (July 2009), 177–187. 5

[BD03] BULLINGER H., DANGELMAIER M.: Virtual prototyping and testing of in-vehicle interfaces. *Ergonomics 46*, 1 (2003), 41. 5

[BGH02] BOWMAN D. A., GABBARD J. L., HIX D.: A survey of usability evaluation in virtual environments: Classification and comparison of methods. *Presence: Teleoperators & Virtual Environments 11*, 4 (2002), 404–424. 2

[BJH*08] BIERBAUM A., JUST C., HARTLING P., MEINERT K., BAKER A., CRUZ-NEIRA C.: VR juggler: a virtual platform for virtual reality application development. In *ACM SIGGRAPH ASIA 2008 courses* (Singapore, 2008), ACM, pp. 1–8. 2

[BKFT00] BALCISOY S., KALLMANN M., FUA P., THALMANN D.: A framework for rapid evaluation of prototypes with augmented reality. In *Proceedings of the ACM symposium on Virtual reality software and technology* (Seoul, Korea, 2000), ACM, pp. 61–66. 1

[Ble11] BLENDER: Free and open source 3D modeling, animation and game engine software. http://www.blender.org, July 2011. 3

[CDW95] COBB S. V., D'CRUZ M. D., WILSON J. R.: Integrated manufacture: A role for virtual reality? *International Journal of Industrial Ergonomics 16*, 4-6 (1995), 411–425. 2, 3

[GHS99] GABBARD J. L., HIX D., SWAN J. E.: User-Centered design and evaluation of virtual environments. *IEEE Computer Graphics and Applications 19*, 6 (1999), 51–59. 2

[HD06] HALSKOV K., DALSGARD P.: Inspiration card workshops. In *Proceedings of the 6th conference on Designing Interactive systems* (University Park, PA, USA, 2006), ACM, pp. 2–11. 4

[Hir02] HIROKAZU K.: ARToolKit: library for Vision-Based augmented reality. *IEIC Technical Report (Institute of Electronics, Information and Communication Engineers) 101*, 652(PRMU2001 222-232) (2002), 79–86. 2, 3

[KBS*01] KUUTTI K., BATTARBEE K., SÃĎDE S., MATTELMÃĎKI T., KEINONEN T., TEIRIKKO T., TORNBERG A.: Virtual prototypes in usability testing. In *Hawaii International Conference on System Sciences* (Los Alamitos, CA, USA, 2001), vol. 5, IEEE Computer Society, p. 5029. 1, 5

[MGDB04] MACINTYRE B., GANDY M., DOW S., BOLTER J. D.: DART: a toolkit for rapid design exploration of augmented reality experiences. In *Proceedings of the 17th annual ACM symposium on User interface software and technology* (Santa Fe, NM, USA, 2004), UIST '04, ACM, pp. 197–206. ACM ID: 1029669. 2

[Mic11] MICROSOFT: Microsoft surface table. http://www.microsoft.com/surface, July 2011. 3

[RS01] REITMAYR G., SCHMALSTIEG D.: An open software architecture for virtual reality interaction. ACM, pp. 47–54. 2

[SR01] SCAIFE M., ROGERS Y.: Informing the design of a virtual environment to support learning in children. *International Journal of Human-Computer Studies 55*, 2 (Aug. 2001), 115–143. 2, 7

[TvdVvH08] TIDEMAN M., VAN DER VOORT M., VAN HOUTEN F.: A new product design method based on virtual reality, gaming and scenarios. *International Journal on Interactive Design and Manufacturing 2*, 4 (Oct. 2008), 195–205. 1, 3

[UWZ*02] URNES T., WELTZIEN Å., ZANUSSI A., ENGBAKK S., RAFN J. K.: Pivots and structured play: stimulating creative user input in concept development. In *Proceedings of the second Nordic conference on Human-computer interaction* (Aarhus, Denmark, 2002), ACM, pp. 187–196. 4

[VSH07] VERLINDEN J., SUURMEIJER C., HORVATH I.: Which prototype to augment? a retrospective case study on industrial and user interface design. In *Virtual Reality*. 2007, pp. 574–583. 1

[VSR02] VAVOULA G. N., SHARPLES M., RUDMAN P. D.: Developing the'Future technology workshop'method. In *Proceedings of the International Workshop on Interaction Design and Children, Aug* (2002), pp. 28–29. 4

[WLBB09] WANG Y., LANGLOTZ T., BILLINGHURST M., BELL T.: An authoring tool for mobile phone AR environments. In *Proceedings of New Zealand Computer Science Research Student Conference* (2009), vol. 9, pp. 1–4. 2

[WM09] WRIGHT T. E., MADEY G.: A survey of technologies for building collaborative virtual environments. *The International Journal of Virtual Reality 8*, 1 (2009), 53–66. 2

[Xse11] XSENS: 3D motion tracking software and hardware. http://www.xsens.com, July 2011. 3