TOOLBOX

Human Factors research methods in the design and evaluation of applied virtual environments

The involvement of users and stakeholders in the design and evaluation of virtual environments (VEs) is critical to the success of the end solution. However, working with industrial partners on the development of VEs presents a number of challenges for the Human Factors (HF) researcher. Some of the issues (e.g. limited time of the industrial partners) are typical of any research project; others (e.g. simulator sickness, unreliability of prototypes) are more specific to ICT projects. This paper presents an overview of the requirements definition, design and evaluation methods adopted in the development of applied virtual environments. Recommendations are provided for overcoming the challenges, including: involve end-users and stakeholders throughout the VE development process; provide HF support to developers in understanding user/stakeholder requirements; and consider the availability of industrial partners when selecting HF methods.

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Virtual environments (VEs) are now well established in a variety of industrial applications, including product design, manufacturing planning, and training (Stone, 2001; Rebelo e.a., 2003; Mujber e.a., 2004). In each of these applications, they offer benefits which cannot be achieved using traditional approaches. For example, during design and manufacturing planning, evaluations can be made at an earlier stage of the development process before prototypes or physical mock-ups of the product or system become available (Halevi, 2001) thus reducing the costs associated with identifying issues at a later stage in the development process (Laughery, 2005). In training applications, trainees can be placed in situations which are too hazardous or inaccessible in reality, such as factory emergencies (Lawson e.a., 2007). However, to ensure that a VE is successful it is essential that proper consideration is given to Human Factors (HF) (Wilson & D'Cruz, 2006). Key HF activities include: definition and understanding of the context of use and user/stakeholder requirements; providing input to the development of the VE to ensure that it matches end-user needs and capabilities; and the selection and implementation of appropriate evaluation methods (Nemeth, 2005). Through these activities, the human factors researcher can ensure the VE is appropriate, effective and usable, and reduces the risks of simulator sickness or other ergonomics issues.

This article presents an overview of the typical Human Factors research methods in the design and development of VEs. The work is based on several industrial and European Commission (EC) funded research projects, including:

- DiFac (FP6-2005-IST-5-035079), Digital Factory for Human-Oriented Production System;
- IMOSHION (SME-2-243481), Improving Occupational Safety & Health in European SMEs with help of Simulation and Virtual Reality;
- VISTRA (FoF-ICT-285176), Virtual Simulation and Training of Assembly operations in digital factories;
- ManuVAR (CP-IP-211548), Manual work support throughout system lifecycle;
- VIEW of the Future (IST-2000-26089), Virtual and Interactive Environments for Workplaces of the Future;
- several industry-sponsored projects using driving simulators to understand driver distraction and support the development of driver user interfaces.

It is important to clarify that in this article the term virtual environment is used to describe any computer-generated environment experienced by a person. This encompasses the range from virtual environments presented on desktop computers to CAVEs in which participants stand inside a large cube and view stereoscopic/3D images projected onto the walls.

Human Factors input to the design of VEs

Figure 1 provides an overview of the main stages in the design and evaluation of a VE, as used on the DiFac, IMOSHION, and VISTRA projects. This process frames the main Human Factors activities shown in boxed text in Figure 1, which are discussed in the following sections.

It is important that end-users and stakeholders are involved at each step of the process (Neale e.a., 2002). This way, the development of the VE can continually move towards addressing their needs, as well as increasing their acceptance of the final design (Nemeth, 2005). This can also increase worker motivation to contribute to the development process through the understanding that their opinions will be taken seriously.

Note that this paper focuses on the pre-implementation work; the Human Factors researcher also has useful roles in post-implementation work (e.g. summative evaluation, feedback capture) which are beyond the scope of this paper.

Requirements definition

While many projects begin with an underlying idea of the proposed VE system, requirements definition is necessary to shape, refine and clarify the design of the VE such that it matches end-user and stakeholder requirements. VE developers can also be considered customers of the requirements definition process, as they need to know which aspects of the VE are critical and at what stage of the development process these features must be ready.

An important early step is *definition of the stakeholders*. While the terms end-user and stakeholder are often used interchangeably, the differences between these terms and groups are important. End-users can be considered as anyone who will use the VE (Stone e.a., 2005). Stakeholders are anyone who will be affected by the use or implementation

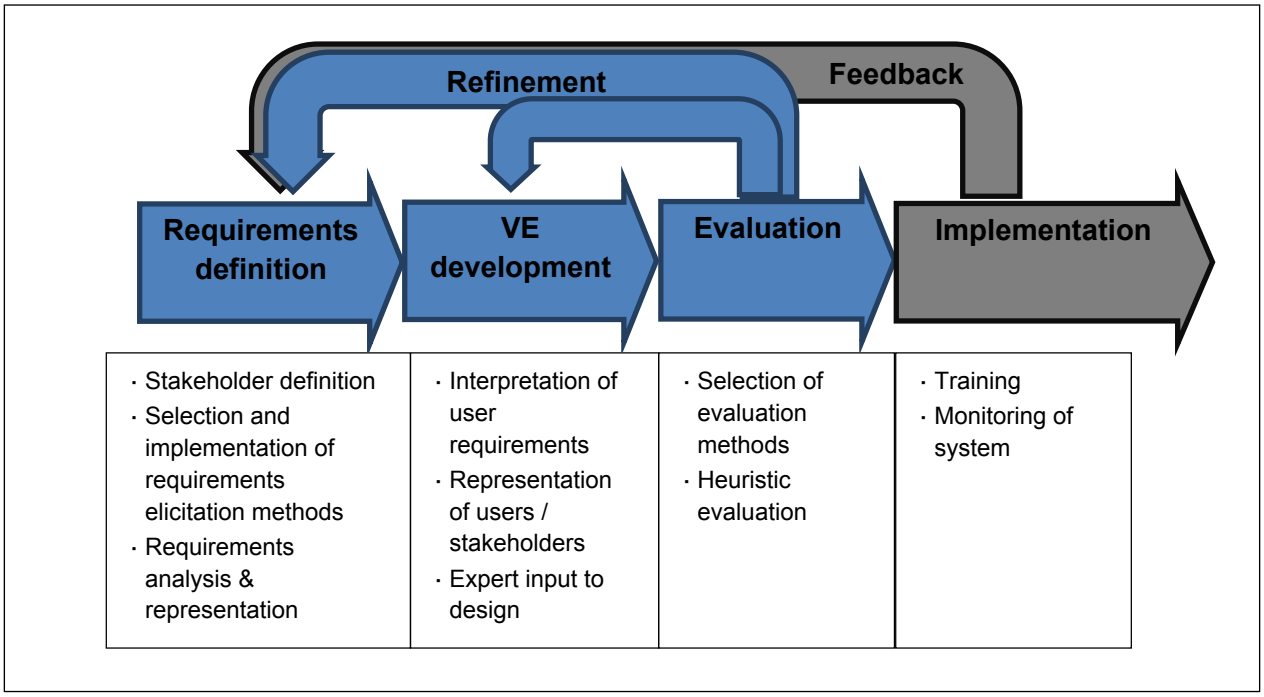


Figure 1. Schematic of a typical process used in the design and development of VEs. Boxed text indicates some of the key Human Factors involvement with each stage. The process is iterative (as indicated by the 'refinement' arrows) and may repeat several types before implementation

Table 1. Process used to generate a requirements gathering questionnaire in the VISTRA project

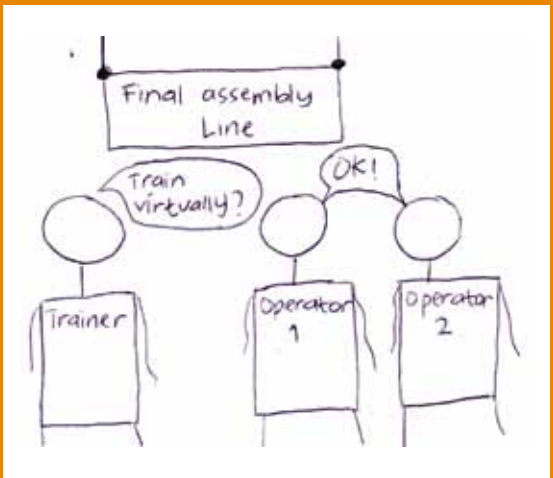
	Activity	Involved partners
1	Brainstorm all aspects about the work which are necessary to support the design of the VE	The entire VE development team: Human Factors researchers; VE development engineers; management; end user/stakeholder representatives etc.
2	Develop a questionnaire based on sound HF principles (e.g. use of unambiguous language, no leading questions, Oppenheim, 2005; Sinclair, 2005)	Human Factors researchers
3	Prioritise questions based on time availability of end-users and stakeholders	Human Factors researchers and end-user/stakeholder representatives

of the VE (Stone e.a., 2005). This could include: IT managers (for integration with existing systems); managers of existing virtual and CAD data; general managers and trainers. Thus, focusing on only end-users would neglect the requirements of a broad spectrum of people who must be considered during the design of the VE.

Another important stage in requirements elicitation is *selection of appropriate methods*. There are several different methods for requirements elicitation (e.g. interviews, questionnaires, observation, ethnography) as well as several good Human Factors texts providing guidance on their use and the types of data they produce (Kirwan & Ainsworth, 1992; Stanton e.a., 2004; Stanton e.a., 2005; Wilson, 2005). When selecting methods, it is important to consider the availability of stakeholders and end-users as their involvement in the design of the VE is likely to be in addition to their existing jobs. Thus, it may be necessary to consider methods which minimise their time input, or which can be conducted while they continue to do their jobs (e.g. verbal protocol, Newell & Simon, 1972; Kirwan & Ainsworth, 1992). When developing the methods, such as designing a questionnaire or interview questions, it is *important to capture all project partners' needs*. That is, the stakeholder and end-user requirements which are interesting to a Human Factors researcher may differ to those which are interesting to a technical developer. Yet both perspectives are necessary to support the design of the VE. The process which was successfully used in the VISTRA project is presented in Table 1.

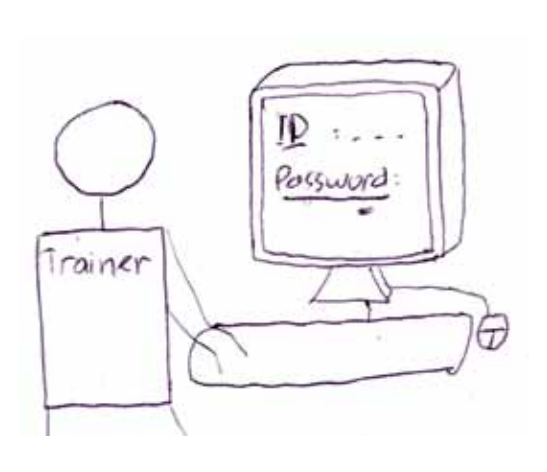
It is necessary at an early stage in the project *to define and agree upon specific terms*. Virtual reality, virtual environments, virtual training, augmented reality and simulation are some of the terms used within this area which can be applied differently, particularly among different disciplines. Clarifying and documenting agreed meanings at the start of a project can reduce confusion.
Another issue researchers may face during the requirements gathering phase is *commercial sensitivity* within the industrial partners. For example, on the VISTRA, ManuVAR and VIEW projects, video cameras were not permitted in the production facilities of some of the companies involved. This issue was easily overcome by using other approaches which did not compromise the industrial partners' requirements, such as note-taking during work observation. Furthermore, a clear process was defined within the project for the industrial partners to review any material before it was released into the public domain.
As mentioned above, requirements elicitation may involve some form of observation. However, *observing a worker is likely to affect their performance on a task*. For example they may work strictly according to procedure rather than how they actually work on a daily basis. The hidden tasks can in fact indicate problems with the job, and it can be useful to identify them through supplementary methods (e.g. interviews, ethnography). Workers may also play up for the observer, or behave as they believe their manager would like them to. While these effects can be difficult to avoid completely, there are measures which can be taken to minimize them, for example keeping senior managers away from the observation exercise, and clearly explaining the purpose of the investigation and level of anonymity afforded to the worker prior to the observation session.

As for requirements elicitation, there are many methods which can be used for *requirements analysis and representation*, such as hierarchical task analysis (Kirwan & Ainswoth, 1992), storyboarding (Preece e.a., 1994), link analysis (Kirwan & Ainsworth, 1992), personas (Cooper, 1995), and thematic content analysis (Taylor & Bogdan, 1984; Neale & Nicholes, 2001). Generally a mixed method approach is better (Neale e.a., 2003), as this can help reveal requirements which may have been missed if only one method is used. This approach also enables members of the development team to use the representation most appropriate or understandable to them.
Figure 3 is an example of how a requirements representation method has been used in the design of VEs. It shows a storyboard which was generated within the VISTRA project. Storyboarding bridges the gap between requirements and development in that it can be used to present ideas for the proposed solution, and the ways in which users/stakeholders may interact with the VE to conduct specific acts. It is accessible to the development team regardless of their level of technical knowledge.

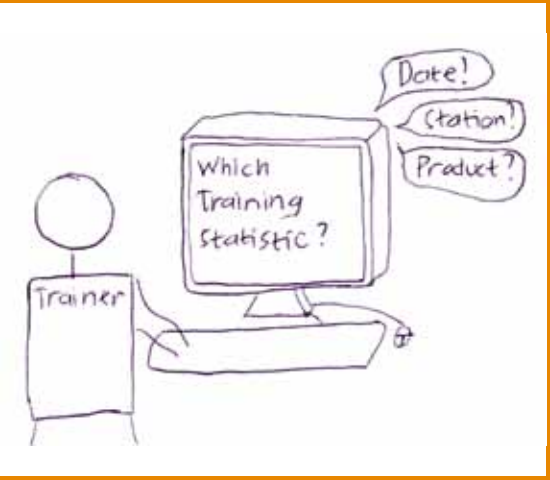


Trainer at final assembly line informs operators to train virtually

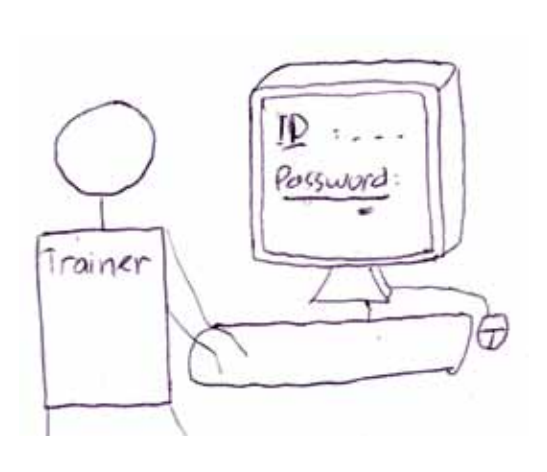
Operators train virtually in turn



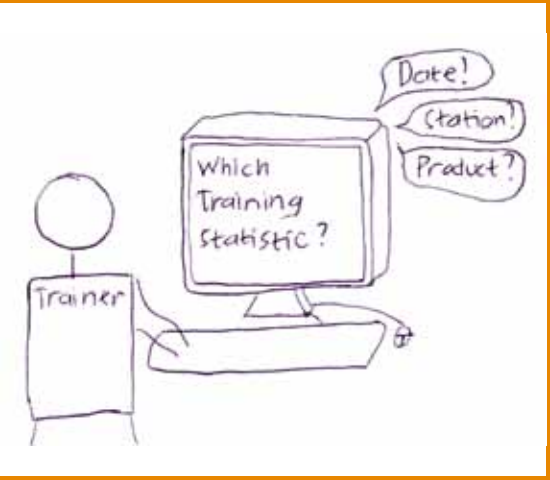
Trainer logs in to the VISTRA system



Trainer specifies training results to be viewed



Trainer views the training results



Trainer prints report on paper

Figure 3. Storyboard showing a scenario in which the trainer monitors operators' training on the VISTRA virtual training solution (VTS)

One of the difficulties is that requirements data are often rich, complex and sometimes unspecific, reflecting the variety and nature of human behavior, preferences, and characteristics. Unfortunately, these types of data do not lend themselves easily to ICT development, in which specific, procedural and ideally quantifiable data are often preferred. Thus, an important Human Factors role is in the translation of requirements into a format which is understandable by technology developers.

HF input to VE development

Moving to the VE development phase, the HF researcher continues to play an important role in helping developers to understand user/stakeholder requirements. Additionally, it is often useful to be proactive in steering the development work, rather than reacting to work produced by the developer. One approach to do this is sketch prototyping of proposed solutions. Figure 4 shows a sketch prototype for the user interface of the VISTRA training system, which indicated to the developer the required content for the user interface.

As well as interpreting the user/stakeholder requirements, it is the role of the HF researcher to ensure that these groups are considered throughout the development phase.

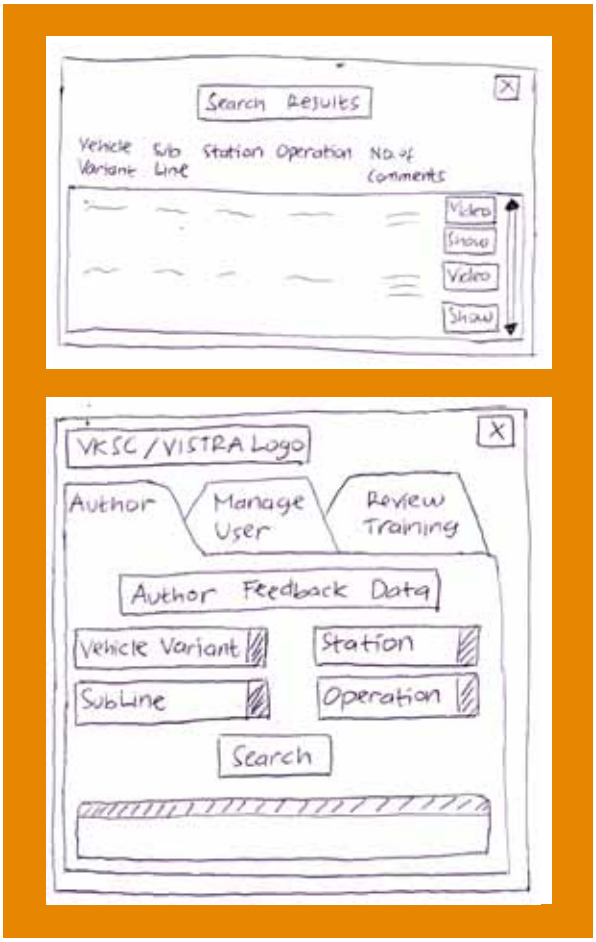


Figure 4. Prototype user interface from the VISTRA training system

This may be achieved by reiterating during meetings the end-users' capabilities and characteristics. Alternatively, and perhaps preferentially, a representative from the user/stakeholder group may actively participate in regular development meetings to keep the development work focused on their requirements.

Evaluation

As for requirements elicitation, *selection of methods should give consideration to the availability of end-users and stakeholders*. However, the methods should also be chosen based on performance/acceptance criteria (which are generally defined or derived from the user/stakeholder requirements) as well as the state of the technology development. As an example, the DiFac project used a video clip of a virtual training environment for factory evacuations as part of the evaluation. The video clip was created at a very early stage of the development phase, and showed a short video of how the virtual training environment may look. This clip enabled potential end-users and stakeholders to comment on the concept, and in particular how well it matched their needs. Furthermore, this solution overcame the difficulties of working over geographical dispersion as the evaluations could be conducted remotely. Also, the video could be watched and evaluated when convenient to the industrial partners.

It may not be possible or feasible to ask for user/stakeholder evaluation of every development iteration or every feature on a system. In these situations, *heuristic or expert evaluation is necessary*. There are number of tools to do this, for example the VIEW-IT heuristic assessment tool (Wilson & D'Cruz, 2006; Lawson & D'Cruz, 2011) which was based on HF literature and designed to be used for the evaluation of VEs.

Another issue worth considering during the evaluation of VEs is *the possibility of trial participants suffering from VRISE (Virtual Reality Induced Symptoms and Effects)* (Cobb e.a., 1999; Sharples e.a., 2008). Participants may be subject to a number of adverse effects, such as feeling sick, dizzy or fatigued. However, the Human Factors Research Group (HFRG) has conducted extensive research in this area (e.g. Cobb e.a., 1999, Nichols e.a., 2000; Sharples e.a., 2008), and adverse effects are usually mitigated through participant screening (i.e. people susceptible to motion sickness,) as well as procedures such as limiting the time spent in the VE.

Finally, in VE development projects (and any ICT project) the *technologies are typically unrefined during the evaluation stage*. It is important to discuss with developers what is required for the evaluation and when. For example, a developer may focus on the software functionality, whereas the ergonomics of the hardware of the prototype solution may be unacceptable and result in an overall reduction in feedback of the system. Furthermore, it is often the case that last minute developments are required and these should be factored into the evaluation schedule.

Conclusions

The Human Factors researcher can provide input throughout the design and evaluation of a VE. An important part of their role, particularly in the development of applied VEs, is to integrate the end-users and stakeholders into the design and evaluation process. This is not without problems, for example the limited time availability of end-users will impact the choice of methods for requirements gathering and evaluation activities. Another important role for the HF researcher is helping developers make sense of the requirements for the VE, as these are not easy to translate into technical development needs. However, there are methods such as personas and storyboards which produce data that are accessible to, and usable by, all members of the development team. Finally, the HF researcher should be prepared for specific issues during the evaluation of VEs such as simulator sickness and unreliability of prototypes.

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Summary

This article presents an overview of the methods used during the design and evaluation of applied virtual environments. It will inform practitioners of the general processes for the development of VEs, as well as highlighting issues which they may face. Recommendations are made to help the practitioners prepare for, and address, these issues should they be involved in VE development.

Keywords: Human Factors methods; virtual environments, design and evaluation.