The Effect of Stereovision on the Experience of VR Models of the External Surroundings and the Interior of a Building

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Abstract. *Virtual reality offers considerable promise with regard to facilitating the building process. A good example is the facilitation of communication between architects and building companies, sellers and buyers or between community planners and the general public. It is often thought that in order to utilise the potential of VR in, for example, the above-mentioned contexts, it is necessary to use fully fledged versions of VR, including stereovision and the possibility of controlling the VR show. However, if a model can also be presented on less advanced equipment and still interpreted in a way that is useful to the viewer it will be possible to distribute the model simply and effectively. This would make it easier to create a more democratic urban planning process compared with if specialised equipment needed to be used and special shows needed to be arranged.*
In this study we compared the experience of two VR models (a large indoor exhibition hall and an outdoor street in Gothenburg, Sweden) when presented with and without stereovision. When the experience was measured using the Semantic Environmental Scale (the SMB scale, developed by Küller, 1975, 1991), questions on the experience of presence and six other questions on the experience of the models, the results only revealed one indication that stereovision made a difference. This indication was the result for the SMB factor Enclosedness. Suggestions are presented for future research in this area.

Keywords. *Design Process; Virtual Environments; Human-Computer Interaction; 3D City Modelling; Environmental Simulation.*

Introduction

Stereovision and 3D visualisation have been of interest for a long time and have been the topic of many studies. Atkins et al. (2003) found that when depth cues from visual stereo cues and haptic cues were inconsistent, people tended to see the haptic cue as a reference and adjusted their interpretation of the stereo visual cue. Naepflin et al. (2001) asked subjects to track lines in a situation where other confusing lines were also presented. The task was to combine the starting point of a line with its endpoint. They used three depth cue conditions: stereo view, movement parallax and a combination of these. The authors found that movement parallax and the combination of stereo view and movement parallax produced a higher percentage of correct answers to the task. There are many other examples of studies conducted using a similar small-scale approach. Such research also exemplifies much of today's research on Virtual reality (VR), which often addresses small, well-defined issues. Although of great interest, the questions are often constructed for the research situation itself and are not always clearly connected to a real-life situation. In experimental studies dealing with stereovision in VR, it is crucial that there is as much control as possible. Sometimes this means that the studies are done in VR models with very little in-built information, e.g. perhaps only a few geometrical objects and just one plane of reference. On many occasions studies are conducted using specialised equipment that is not common or easy to use in practical work situations. Head-mounted displays, for example, are still not common and may disrupt discussions between colleagues at the workplace either because they cannot see one another while looking at the model or because only one person at a time is looking at the model and the same information cannot be shared.

In the virtual environments that are used to evaluate planned areas in cities or other built areas there is a lot of information and the VR shows that are presented to decision-makers often make use of equipment that makes it possible to look at the model and communicate with each another at the same time. There are a lot of depth cues at hand (some consistent with each other and some not) and it is not obvious how much a stereoscopic view contributes to how the environment is experienced. Dinh et al. (1999) found that additional types of sensory inputs were more important than increasing visual fidelity in order to improve the sense of presence. A stereoscopic view perhaps does not influence the experience of the environment to any great extent if there are already depth cues at hand.

The aim of this study is to explore how a stereoscopic view influences the way in which a virtual environment is experienced when using a model with quite a lot of visual information and depth cues. Both the models used in this study have been used in real urban planning settings, where they were part of the total information that formed the basis for decisions on future changes in a city or a building of great importance in the same city. The presentation equipment that was used did not emphasise immersion but was more of the kind that could be used in a real decision-making situation.

Method

Participants: Ninety-six students on the building engineering programme and the business strategy and entrepreneurship programme at Chalmers University of Technology participated in the study. However, 13 persons were removed from the study after a test was conducted to determine whether the respondents had stereoscopic view. Of the remaining 83 persons, 64 were men and 18 were women (one participant did not state his/her gender). The average age of the 83 persons was 23.5 years (range 19 – 40). All participants had previously seen VR shows on at least one occasion.

Table 1. Means (SD) for age, computer experience and level of education and gender frequency in the four groups.

	Group 1 Indoor VR model *with* stereo	Group 2 Indoor VR model *without* stereo	Group 3 Outdoor VR model *with* stereo	Group 4 Outdoor VR model *without* stereo
Age	24.93 (4.30)	23.42 (4.34)	22.13 (3.54)	23.40 (5.07)
Computer experience	4.12 (1.20)	4.35 (0.78)	4.38 (0.62)	3.87 (0.97)
Level of education	2.25 (1.06)	2.11 (0.99)	2.50 (0.89)	1.91 (1.08)
Gender (Frequency)	F = 2, M = 14	F = 4, M = 24	F = 5, M = 10 Missing = 1	F = 7, M = 16

Design

The effect of stereo was studied in an indoor and an outdoor VR model using a between-subjects design with four groups. The first group saw, in stereo, an indoor VR model of the possible future appearance of a conference centre, the Swedish Exhibition Centre ("Svenska Mässan") located in the centre of Gothenburg, Sweden. The second group saw the same model without stereo. The third group saw, in stereo, an outdoor VR model of the possible future appearance of a large street in the centre of Gothenburg (Västra Hamngatan), and the fourth group saw the same model without stereo. Fourteen men and two women participated in the first group, 24 men and four women in the second group, ten men and five women and one person who did not report his/her gender in the third group, and 16 men and seven women in the fourth group.

The four groups' means and SDs for age, computer experience, level of education and frequencies for the two genders are shown in Table 1. The reported computer experience was measured on a scale of 1-6, where 1 represented no computer use and 6 represented persons who were involved in developing computer software. The reported level of education was also measured on a scale of 1-6, where 1 represented no university studies and 6 represented a PhD degree.

One-way ANOVAs with four levels showed that the groups did not differ with regard to age, com-

Figure 1. Examples from a) the indoor VR model showing the future appearance of Svenska Mässan, Gothenburg, Sweden, and b) the outdoor VR model showing the future appearance of Västra Hamngatan, Gothenburg, Sweden. In both models (exemplified in Figures 1a and 1b) we used cars, buses, trams and in-house developed walking people (in the indoor model the cars, buses, trams and people can be seen when looking through the windows).

puter experience or level of education. A Kruskal-Wallis test showed no significant difference in gender frequency between the four groups.

Materials

The VR models. The two VR models were developed at the Visualisation Studio at Chalmers University of Technology. The VR model of Svenska Mässan shows the interior of the future planned rebuilding of Svenska Mässan, with a restaurant area, shopping area, exhibition area and furniture. The outdoor VR model of the possible future appearance of Västra Hamngatan shows much of the current street as a channel, surrounded by the existing buildings. The indoor VR model of the future Svenska Mässan is shown in Figure 1a and the outdoor VR model of the future Västra Hamngatan is shown in Figure 1b.

Technical equipment used for programming the model and for the shows. The technical equipment used at the shows was a PC computer with a Quadro FX 3000 graphic card supporting Genlock and Quadrobuffer stereo, and a powerwall, 2 x 4.8 metres, powered by two Barco projectors. A stereo-effect was achieved in two of the groups by using Crystal Eyes, i.e. stereo glasses. The programs used for the construction of the model were MultiGen Creator and 3D Studio Max. The model was then visualised in a program, MRViz, which has been developed in-house and is based on OpenSceneGraph.

The lighting effect in the VR models was achieved by using an ambient and diffuse light source. Some local shadow effects were achieved using photos and pre-rendered images. In the external VR model, simply modelled shadows were used for shadow casting from the trees.

The SMB scale (The Semantic Environmental Scale). In order to measure how the participants experienced the VR model, the SMB scale, developed by Küller (1975, 1991) was used. The purpose of the SMB scale is to describe systematically how individuals experience their environment, not to measure the characteristics of individuals. Initial work established that when sets of a large number of adjectives were factor-analysed the adjectives clustered into eight factors, which are used in the SMB scale and are presented in Table 2. The SMB scale has 36 single-adjective, seven-step scales. When used to judge real-world environments, the SMB reaches a high degree of stability in group sizes of 15-20 individuals (Küller 1975, 1991).

The SMB scale has mostly been used in real environments although Küller (1975) suggested that it offers potential for future city planning in model

Factors	Definition
Pleasantness	The environmental quality of being pleasant, beautiful and secure.
Complexity	The degree of variation or, more specifically, intensity, contrast and abundance.
Unity	How well all the various parts of the environment fit together into a coherent and functional whole.
Enclosedness	A sense of spatial enclosure and demarcation.
Potency	An expression of power in the environment and its various parts.
Social status	An evaluation of the built environment in socio-economic terms, but also in terms of maintenance.
Affection	The quality of recognition, giving rise to a sense of familiarity, often related to the age of the environment.
Originality	The unusual and surprising in the environment.

Table 2 The eight factors of the SMB scale (from Küller 1991, p. 132).

form. For this reason, we chose the SMB scale to measure the experience of the VR models.

VR experience questionnaire. A questionnaire was developed which included 16 questions about VR experience at the VR shows. Three of the questions are, for reasons of space, not reported here. Four questions concerned the extent to which the model or various aspects of the model felt real. One question asked whether the participants would have liked to walk on their own in the VR model [have control of the VR model]. Seven of the questions are related to various aspects of the participants' feeling of presence in the model. One question asked whether the participants had become bored with the model during the show. Most of the questions in the VR questionnaire were answered on a seven-point scale with 1 = "Not at all" and 7 = "Totally". However, five of the questions on presence were taken from Dinh, et al (1999) and for possible comparison the same 5-point scales were used as in that study (with 1 = very weak/unrealistic/small extent to 5 = very strong/realistic/large extent). The questions reported are presented in Table 4.

Stereoscopic depth cue test. In order to establish whether the respondents could use the stereoscopic depth cue, we used a method developed in-house based on the suggestions of an optician. The respondents were first asked to look at a picture in mono on the concave without stereo glasses. They were then asked to put on the stereo glasses and we showed the same picture in stereo. The respondents were then asked to answer the question whether their experience of the picture had changed. If the answer was yes the respondent was asked to write down a description of the change he/she experienced. Depending on the answer, it was assessed whether the respondent was seeing in stereo or not. Most of the categorisations were very clear; in doubtful cases the participant was categorised as not having stereovision and was excluded from the study, as were the other clear cases of non-stereovision. The stereoscopic effect is achieved by displaying two digital images, horizontally separated. In order to really know whether the participant had stereovision we enhanced the stereoscopic effect by separating the two images to a greater extent. This makes people who have stereovision more aware of it. On the other hand, for people who are stereo-blind the effect will remain the same. When showing the VR models for measuring the influence of stereoscop-

Factor	Group 1 Indoor VR model *with* stereo	Group 2 Indoor VR model *without* stereo	Group 3 Outdoor VR model *with* stereo	Group 4 Outdoor VR model *without* stereo
Pleasantness	4.97 (0.40)	4.74 (0.95)	5.62 (0.74)	5.55 (0.75)
Complexity	4.20 (0.74)	4.32 (0.87)	4.11 (0.74)	4.26 (0.87)
Unity	5.17 (0.47)	4.97 (0.99)	5.05 (0.88)	5.20 (0.77)
Enclosedness	2.89 (0.70)	2.52 (1.05)	3.38 (1.00)	3.01 (0.90)
Potency	4.30 (0.44)	4.18 (0.72)	4.42 (0.55)	4.35 (0.50)
Social status	4.89 (0.67)	4.83 (0.91)	5.08 (0.66)	5.02 (1.00)
Affection	2.95 (0.51)	2.65 (0.83)	3.51 (0.78)	3.18 (0.93)
Originality	4.08 (0.84)	3.45 (0.90)	4.20 (0.88)	3.98 (0.97)

Table 3. Means (SDs) for the SMB scale. The rating scale for the factors ranged from 1 to 7.

ic view, a more normal stereoscopic view was used (distance between eyes were then 6 cm).

Procedure

All VR shows took place at the Visualisation Studio at Chalmers University of Technology. Each VR show was introduced by the researchers, who first welcomed the participants and gave instructions for the experiment. The participants were then shown the appropriate VR model for five minutes, after which the groups completed the SMB questionnaire. After the SMB questionnaire had been completed the participants filled in the VR experience questionnaire. As they completed the questionnaires the VR model was still being shown in front of them in the form of a rotating picture. Finally, the participants did the Stereoscopic depth cue test.

Results

First the results for the SMB are presented, followed by the results for the questions relating to the experience of presence and finally the other questions regarding the experience of the models. The results for the SMB scale are shown in Table 3.

When tested with a between-subjects MANOVA with stereo/not stereo and the "type of model" as independent factors and the eight SMB factors as dependent, support was found for effects of both the stereo and the "type of model" factor but no interactions were found. A main effect was found for stereo/not stereo for the SMB factor Enclosedness ($F = 5.70$, $df = 1$, $p<0.019$) and for the SMB factor Originality ($F = 5.45$, $df = 1$, $p<0.022$). For the "type of model" factor a main effect was found for the SMB factor Pleasantness ($F = 16.73$, $df = 1$, $p<0.000$), for the SMB factor Enclosedness (F

Question	Group 1 Indoor VR model *with* stereo	Group 2 Indoor VR model *without* stereo	Group 3 Outdoor VR model *with* stereo	Group 4 Outdoor VR model *without* stereo
How strong was your sense of "being there" in the virtual environment?	3.31 (0.74)	3.26 (0.94)	3.06 (1.06)	3.22 (0.90)
Overall: how realistic did the virtual environment seem to you?	381 (0.54)	3.61 (079)	3.56 (1.15)	3.96 (0.56)
How realistically were you moved around in the virtual environment?	3.19 (0.75)	3.11 (0.92)	3.75 (0.7)	3.52 (0.85)
To what extent did you feel that you could have reached into the virtual environment and grasped an object?	3.25 (0.86)	2.61 (0.99)	2,81 (1,22)	2.83 (1.11)
To what extent were there times during the experience when the computer-generated world became a reality for you, and you almost forgot about the "real world" outside?	1.87 (0.89)	1.82 (0.82)	1.81 (0.91)	2,00 (1,07)
To what extent do you agree with the following? The objects in the virtual environment moved in a natural way.	2.62 (0.89)	2.64 (0.95)	2,87 (0,81)	2,13 (0,81)
How strong was your sense of presence in the virtual environment?	3.38 (0.72)	3.39 (0.88)	3,38 (1,09)	3,22 (1,00)

Table 4. Means (SDs) for the questions related to presence. The scale on these questions ranged from 1 to 5.

= 6.08, df = 1, p<0.016) and for the SMB factor Affection (F = 10.51, df = 1, p<0.002).

The results for the questions related to the experience of presence are presented in Table 4. The results were tested with a between-subject MANOVA with stereo/not stereo and the “type of model” as independent factors and the presence-related questions as dependent. No significant effects were found for the factor “stereo/not stereo” for any of six of the questions related to presence topics. The “type of model” factor only showed a significant difference for the question “How realistically were you moved around in the virtual environment?” (F = 7.25, df =1, p<0.009).

The results for the six remaining questions in the questionnaire are shown in Table 5. In order to test the effect of the two factors stereo/not stereo and “type of model” , a between-subjects MANOVA was computed with stereo/not stereo and the “type of model” as fixed factors and the general questions as dependent. The factor stereo/not stereo did not have any significant main effect for any of the questions. However, the “type of model” factor showed a significant main effect for the questions “real shading” (F = 8.77, df = 1, p<0.004) and “Correct lighting” (F = 7.34, df = 1, p<0.008).

Discussion

The present study investigated the effect of stereoscopic vision in the two VR environments, an indoor and an outdoor model.

The results showed a significant difference in the SMB factor Enclosedness depending on whether the model was presented with stereoscopic view or not. This indicates that it may be important to include stereovision in VR presentations, at least in certain contexts.

None of the environments depicted in the VR models exist in reality and so we could not mea-

Question	Group 1 Indoor VR model *with* stereo	Group 2 Indoor VR model *without* stereo	Group 3 Outdoor VR model *with* stereo	Group 4 Outdoor VR model *without* stereo
To what extent do you feel the virtual environment has given you an understanding of what the environment is going to look like?	5.50 (0.97)	5.39 (1.07)	5.50 (0.73)	6.08 (0.67)
Was your experience that the surfaces (such as walls) felt real in the virtual environment?	4.69 (1.08)	4.07 (1.51)	4.44 (1.63)	4.96 (1.15)
Was your experience that the shading in the virtual environment felt real?	3.44 (1.36)	3.43 (1.91)	4.62 (1.31)	4.35 (1.40)
Was your experience that the lighting was realistic?	4.25 (1.24)	4.21 (1.62)	5.00 (0.97)	5.13 (1.32)
Would you have wanted to walk on your own (have control yourself) in the virtual environment?	5.75 (1.39)	5.50 (1.75)	6.25 (1.3)	5.86 (1.55)
Did you get bored with the VR model during the show?	3.25 (1.34)	2.64 (1.66)	2.69 (1.89)	2.78 (1.76)

Table 5. Means (SDs) for the questions on the experience of the VR models. The scale for these questions ranged from 1 to 7.

sure whether the experience of Enclosedness comes closer to the experience of reality with or without stereoscopic view. In reality, our use of stereoscopic cues decreases when looking at objects from further away. If a person just used his/her experience from reality to determine which depth cues he/she would rely on, it would be expected that the results should have shown an interaction effect between stereo/not stereo and the “type of model” factor when measuring Enclosedness. The study offered no support for this hypothesis.

Overall, no significant differences were found for the questions related to the concept of presence depending on whether the presentation was presented with stereoscopic view or not. This is in accordance with the results reported by Dinh et al. (1999). The authors in that study found that increasing visual fidelity did not increase the feeling of presence to any great extent compared with adding other types of sensory input. The conclusion that the stereo factor did not affect the VR experience, expressed as presence, to any great extent is also supported by the fact that the results for the questions related to various aspects of the experience of the VR models did not differ depending on whether the model had been presented in stereo or not.

In conclusion, we found few indications that a stereoscopic view influences how virtual building environments are experienced and evaluated. These results need to be replicated and extended in future research in order to improve our understanding of how a stereoscopic view influences the experience of different types of environment. If possible, such research should also include studies of how the experience of a virtual environment, when presented with and without stereo, compare with the experience of the same real environment. Another interesting line of research would be to study how different strengths in the stereoscopic effect influence VR experience.

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