Depth Perception in CAVE and Panorama

Michael Mullins, Tadeja Zupancic Strojan
Department of Architecture and Design, University of Aalborg, Denmark; Faculty of Architecture, University of Ljubljana, Slovenia.

This study compares aspects of spatial perception in a physical environment and its virtual representations in a CAVE and Panorama, derived from recent research. To measure accuracy of spatial perception, participants in an experiment were asked to look at identical objects in the three environments and then locate them and identify their shape on scaled drawings. Results are presented together with statistical analysis.
In a discussion of the results, the paper addresses the two hypothetical assertions – that depth perception in physical reality and its virtual representations in CAVE and Panorama are quantifiably different, and that differences are attributable to prior contextual experience of the viewer. The role of prior or tacit knowledge in these environments is established from the empirical data. It is concluded that the CAVE offers a higher potential for spatial experience and learning than the Panorama.
The results also suggests that knowledge gained in physical contexts is more readily transferred to its virtual simulation, while that gained in virtual experience is not reliably transferred to its equivalent physical context.
The paper discusses implications for spatial ability, learning and training in virtual environments; in architectural education; and participatory design processes, in which the dialogue between real and imagined space may take place in virtual reality techniques.

Keywords: *Virtual Reality; Perception; Spatial Ability; Learning; Virtual Context.*

Introduction

This study compares aspects of spatial perception in a physical environment and its virtual representations in a CAVE and Panorama[1].
Contemporary approaches to virtual representation span the metaphysical notion of parallel virtual worlds; the positivist paradigm in which representation looks like reality as closely as is technically possible; and thirdly, the view that emphasises the experiential facets of knowledge (Qvortrup, 2002). The basic aspects of virtual reality techniques - pas-

sive stereo, active stereo and interaction devices – can thus either be seen as: supporting the creation of virtual worlds; or detailed correspondence with the real world; or providing spatial experience of a fundamental nature.

The authors' research has previously been directed into a quantitative and qualitative description of differences in how the lay public and professionals perceive and understand architectural representations across a broad range of 2D and small-screen types of presentation. These results indicated that architectural intentions and lay public expectations coincide more closely through the means of "experiential media" (Mullins et al., 2003). Nevertheless, we found that both professional and lay public had difficulties defining geometrical shapes in space from 'experiential' presentations. As spatial experience is enhanced through movement and peripheral vision of context (see for example: Gibson, 1986), it can be inferred that CAVE and Panorama offer better means of architectural visual representation than 2D or small screen images for example.

A further issue of interest is the effect of simulated environments on spatial learning, and hence the spatial ability of students of architecture and related fields. It has been shown that students with low scores on tests of spatial ability, and in particular three dimensional spatial perceptions, are at risk as regards passing engineering graphics courses. After receiving training, their performance on tests of three dimensional spatial perception improved (Potter and Van Der Merwe, 2001). This would strongly suggest that learned spatial ability is an attribute of successful architectural students and thus a primary quality in differentiating 'professionals' and 'laypeople', in that the former are by definition in this study educated in the fields of architecture and related fields. This being the case, CAVE and Panorama are attractive tools in architectural training.

The notion that spatial knowledge has a learned or intuitive dimension may allow a deeper understanding of what happens in virtual environments. In relating Michael Polanyi's ideas to architecture, Chris Abel writes of tacit knowing: "It may be surmised that place identity itself is a function of tacit knowing, by which individuals come to dwell in a place not only physically but also by metaphoric extension of their own bodies" (Abel, 2000:117).

The interactive VRML models offered by CAVE and, to a lesser degree Panorama, suggests consideration be given to what they offer to architectural curricula. In considering that they simulate spatial experience of unbuilt buildings, what is the relation of these environments to their physical isomorph[2], and to each other?

The study seeks to apply empirical research methods to these issues. An experiment was designed to focus on aspects of depth perception of shape in three environments. Two hypothetical assertions were made – that depth perception in physical reality and its virtual representations in CAVE and Panorama differ measurably; and more accurate perceptions in virtual environments will be found where there is prior experience of the physical environment. Participants were asked to look at identical objects in the three environments, locating them and identifying their shape and size on scaled drawings. Results were then statistically compared for differences of accuracy.

Methodology

A digital model of the VRMedia Lab, Aalborg University, was used for the experiment. The model was converted for use in the Panorama and CAVE virtual environments, situated within the VRMedia Lab itself.

Test objects in the physical building were 3 shapes (triangle, square and circle) in 3 sizes (ex.100cm, 60cm and 30cm), with a departure point in Eric Granum and Peter Musaeus' set of static object properties (Granum and Musaeus, 2002). The shapes, chosen to reduce variables, represent clearly recognisable and 'value-free' objects.

The 9 objects were placed so that 3 were visible at varying depths from 3 different standpoints in the foyer. These shapes, positions and standpoints were simulated in the CAVE and Panorama by scaled representations in precisely the same virtual positions. Observation distances were measured in relation to the size of object, where the standard maximum dimension of 100cm of the object = 1 Standard Distance Unit (Sdu). Following Granum and Musaeus, a range of important characteristics like inter-object distance and observer-to-object-distance are thus related in a meaningful way to the size property of the objects. Objects had differing sizes to enquire into the effects of observation distance on shape recognition (this issue will be reported in more detail elsewhere). In order to be able to refer to the relevant shape descriptions, participants were given a scaled sketch drawing of the 9 shapes before starting the experiment. Questionnaires were developed as multiple choices, for example: " From standpoint 'A', do you judge the visible square shape to be: S1, or S2, or S3? (Choose only one shown on the sketch drawing)".

The participants in the experiment comprised 68 subjects in an age range of 20 – 65, and with an average age group of 25-35 years. Subjects were questioned individually. On completion of each presentation of each question, the relevant section of the questionnaire was filled out by the interviewer. These answers could be subsequently tested for accuracy, relative to actual shape positions recorded in the foyer.

Data Analysis

Hypothesis Test A: Less accurate perceptions will be made in virtual environments of CAVE and Panorama, when compared to perceptions in the original physical environment

Data collected from 68 questionnaires was analysed for correct and incorrect answers. For each participant, 9 questions were asked in each of the physical, CAVE and Panorama environments, giving a total of 27 answers per participant. Scores in each environment were examined for normality.

Means scores were found for each environment.

Figure 1
The foyer of the VR Media Lab with shapes in place for the experiment.

Figure 2
The Panorama simulation.

The error bar chart for these scores, see fig.3, shows only small areas of overlap and in the case of a Physical to Panorama comparison, no overlap at all. Confidence levels around the means of scores in the 3 environments are 95%. This suggested that there is a significant difference between the population means.

Since data were not normally distributed, a Friedman's one-way ANOVA, repeated-measures[3] test was performed on the three conditions. Results gave a chi-square of 34.36 with an associated two-tailed probability value of 0.001. These results confirm that significant differences in accuracy scores are related to the environment in which they are viewed.

3 pair-comparisons were then carried out between the conditions, physical – cave; physical – panorama; and cave - panorama. Wilcoxon tests on two-related samples show associated two-tailed probabilities as: p=.009; p=.001; and p=.001 respectively, with Z values of -2,603; -5,503; and -3,556 respectively.

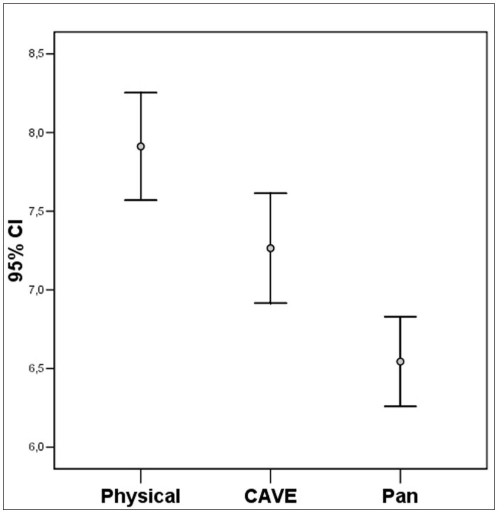
It can therefore be concluded that that participants made less errors in shape recognition in the physical environment, and more errors under the conditions of the CAVE and Panorama, with the level of error being highest in the Panorama condition. It can also be concluded that such differences are highly unlikely to have arisen by sampling error.

Hypothesis test B: More accurate perceptions in virtual environments will be found where there is prior experience of the physical environment

The data collected from the 68 questionnaires were grouped into two separate randomly assigned participant procedures:

- From Physical to Virtual (procedure P_V)
- From Virtual to Physical (procedure V_P)

In procedure P_V, participants answered questions starting in the physical environment, followed consecutively by the CAVE and Panorama environments. Procedure V_P was in reverse order. Procedure P_V tests the prior experience hypothesis by enabling a measurement of results in the Panorama when participants have already experienced the physical reality of the simulated environment. These results can be compared to Panorama results in



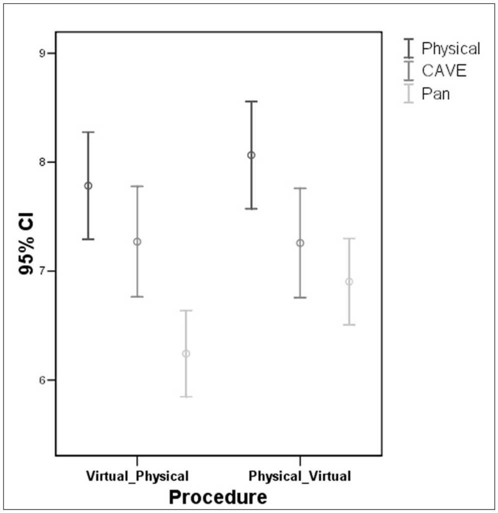


Figure 3
Error bar chart around mean accuracy scores in three different environments, showing 95% confidence levels.

Figure 4
Error bar chart around Means of Correct Answers in Environment by Procedure, showing 95% confidence levels.

procedure V_P, where participants started in Panorama and have not yet experienced the physical isomorph.

Confidence levels around the means of scores in the 3 environments, illustrated in the error bar chart below, show relatively large areas of overlap, particularly for the P_V direction. This was interpreted as showing that the 'procedure' independent variable has low influence on accuracy. However, in the case of the V_P variable, confidence levels overlap to a much lesser degree, suggesting that significant differences in means may be found there, and particularly between physical and Panorama. Overlap between the Panorama mean scores of both procedures, while showing some overlap, is also less pronounced than for the other environments. This was interpreted as showing that the differences in the procedures would be found to be greater in Panorama than in CAVE or physical.

Procedure V_P participants in the Panorama condition obtained fewer correct answers (Mean=6,24, SD=1,19) than did the Procedure P_V participants (Mean= 6,90, SD= 1,08). An independent t-test revealed that if the null hypothesis (stating equal means for Panorama scores in the two procedures) were true, such a difference between the two procedures would be highly unlikely to have arisen ($t = 2{,}381$, $df = 66$, $p = 0{,}02$). Results for the physical and CAVE environments were not statistically significant.

It can therefore be concluded that that P_V participants made less errors in shape recognition in the Panorama than did V_P participants. It can also be concluded that such differences are highly unlikely to have arisen by sampling error. Comparative differences between procedures for the foyer and CAVE are inconclusive.

Discussion of Results

Results indicate significantly better accuracy of response in the CAVE than in the Panorama. This is attributed to the relatively higher degree of immersion and movement possible in the CAVE or as Michael Polanyi wrote: "Our body is the ultimate instrument of all our external knowledge, whether intellectual or practical" (Polanyi, 1983). The CAVE conditions are measurably closer to the real conditions than Panorama, which in turn in many cases will offer better spatial simulation than small-screen models.

The experiment also indicates the clear directional difference, measured in accuracy scores, between moving from the physical to the Panorama, and the reverse. It may be objected that this improvement in scores may be expected as an affect of participants learning to recognise the shapes through repetition through 3 consecutive environments. However, the tests show that knowledge gained initially in Panorama and CAVE does not affect physical scores significantly, as would be expected if the 'learning hypothesis' were to hold true. This knowledge is not transferred. The virtual environment is inherently 'strange' and appears to be considered with a degree of disbelief by participants when comparing with its physical isomorph. Further tests may show that virtual spatial-learning, to avoid becoming virtual spatial-ability, maintain a close relationship with physical environments. Not least, in the case of architectural schools. However, the potential of virtual spatial learning in accelerating student spatial abilities are likely to outweigh such considerations.

The experiment has simulated knowledge gained via bodily immersion in virtual context. This study follows the positivist conventions of statistical testing of empirical hypotheses, yet will seek to relate its results to a broader context of experience. "There are wholes, the behaviour of which is not determined by that of their individual elements, but where the part-processes are themselves determined by the intrinsic nature of the whole" (Wertheimer, 1925). The generalisation of the results to describe attributes of the virtual context will be justified in the sense that the experiment describes repeated, part-processes in the context of different 'intrinsic wholes'. By comparing isomorphic part-processes, comparisons may be made regarding the wholes.

In this way, the present study supports the view that subjective experience is intrinsically related to the context of that experience and states that this is supported by changes recorded in response to the virtual environments. Depth perception is a measurable aspect of the 'metaphoric extension of the body' referred to by Abel which, taken as a whole, bestows spatial identity, and which is a function of tacit knowing.

Summary

Findings from the preceding analysis of conditions and variables created by the experiment can be summarised as follows:

Less accurate depth perceptions were made in the CAVE and Panorama, when compared to their equivalent in the original building. The Panorama is prone to give rise to more error and CAVE gives rise to less error. Thus, the CAVE offers a higher potential for spatial ability and learning.

More accurate perceptions in virtual environments will be found where there is prior experience of its physical equivalent. This implies for example, that while knowledge gained in virtual experience is not reliably transferred to its equivalent physical context, knowledge gained in physical contexts is transferred more readily to its virtual simulation.

Perceptions of shape and distance made in the 3D virtual contexts of the experiment display here fundamental conditions; not those of fortuitously chosen processes, but those that concern the character of the CAVE and Panorama.

The findings have implications for the use of virtual environments in architectural education, 3D city models and participatory urban renewal, in which the dialogue between the real and the imagined often takes place in virtual spatiality.

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Footnotes

1. www.vrmeadialab.dk/pr/facilities/panorama.html
2. Equality or sameness (iso) of form (morphism).
3. "Within-subjects effect": this is the possible effect of the environment on accuracy of answer for each individual participant. "Between-subjects" variables are the professional /layperson grouping (not included in this paper) and the process direction.