PsychNology Journal, 2005
Volume 3, Number 1, 35 – 73

# Responsive Environments, Place and Presence

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**ABSTRACT**

This paper examines the effect that changing arena (i.e. an immersive CAVE or head mounted display) and adding an augmented barrier has on the sense of place and presence in two photo-realistic virtual environments. Twenty eight subjects (17 male, 11 female) mainly undergraduate students or staff took part. The paper summarises two experiments that used a range of data capture methods including the place probe, semantic differentials, distance estimates and the MEC Questionnaire. The results indicate that in non-interactive photo-realistic environments the choice of arena has an impact on the perceived ability to undertake actions, and hence sense of place and presence; with the CAVE providing a lower sense of spatial presence for certain aspects than the HMD.

Keywords: *presence, place, CAVE, HMD.*

Received 18 February 2005; received in revised form 09 April 2005; accepted 11 April 2005.

## Introduction

This paper explores how sense of place and presence is altered by changing the arena in which a virtual environment is displayed and how it is affected by the use of graphical augmentations. An empirical study was undertaken that compared two arenas: a fully immersive, six-sided cubicle (a CAVE) and a Head Mounted Display (HMD). Both displayed a variety of scenes using a photo-realistic display known as image based rendering (IBR).

The technology explored in this study is based around the idea of capturing photographic images of a real world location or place. The photographs are then processed and rendered in a virtual environment arena. A key part of the user experience of such an environment is an individual's sense of place (Relph, 1976; Tuan, 1977). Our previous work explored the comparison of sense of place between real and virtual environments (McCall et al., 2004) and how to capture the sense of

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place (O'Neill et al., 2004; McCall et al., 2004) so that designers can better design the virtual experience. As a result we became interested in how sense of place changes when the arenas are changed, or when aspects of the scene are changed, for example through the use of graphical augmentations of the photo-realistic scene. Our research was also driven by the need to provide information that could help the system developers in selecting appropriate scenes and in improving the technology.

According to Relph (Relph, 1977) sense of place is related to physical properties, activities and meanings. These are very high-level issues and in this paper we have chosen to further break these categories down adopting a framework proposed by Bentley, Alcock, Murrain, McGlynn and Smith (Bentley et al., 1985) known as 'responsive environments'. The concept of responsive environments shares many of the basic aspects of environment legibility developed by Lynch (Lynch, 1960). By focussing on what features make an environment responsive to the needs of its users we can then begin to explore how properties of virtual environments (such as arena used for the display and scope for movement) may alter the responsiveness and ultimately sense of place and presence.

The paper begins with an introduction to the concept of responsive environments (Bentley et al. 1985), place and presence. From there it discusses the nature of the studies in this paper, including information on the arenas, augmentation (a barrier) and data capture methods. It then presents results, discussion and a conclusion.

## Responsive environments

Bentley et al. (1985) have developed a set of guidelines which they claim make an environment responsive to the needs of its users. They do this using the following concepts: permeability, variety, robustness, visual appropriateness, richness, personalisation and legibility.

Permeability is a property of how easy it is to move through an environment and depends heavily upon the paths and objects placed within the space. There are two types of permeability: physical properties (e.g. a path) and visual appearance. For example although a path may exist in some environment, if it is not visually obvious it may remain unused. This in turn affects the sense of place people experience in the environment. Permeability is also influenced by the nature of spaces, for example whether they permit private or public access.

Variety refers to the range of activities, people and building forms which can be found in a space. The varied nature of people, forms and activities will create a range of meanings and in turn the meanings may influence the variety of options available. For example in a museum people can buy gifts, view exhibits, talk to other visitors and perhaps visit a café. However a virtual version of the same museum may concentrate only on aspects related to viewing exhibits, thereby altering the sense of place. As well as being shaped by the range of activities which are built into the space, variety is a product of the location of features and paths of movement.

Robustness explores how a single space can be put to multiple uses. An example would be a room where changing the configuration of the furniture may lead to it becoming a lecture room, dining room or place for a Christmas party. Robustness is also influenced by temporal aspects. For example a museum exhibit may be open only at specific times, with people queuing in order to gain access. If large groups of people are queuing then the queue may act as a meeting point, social space (as people may begin to converse) or as an area to relax prior to seeing the exhibits. However as soon as the exhibit opens then the queuing area may simply return to its original use, that of channelling and controlling movement.

Visual appropriateness is how the provision of cues can support variety, robustness and legibility, it is vital if people are to correctly interpret how to make appropriate use of an environment. Examples of poor visual appropriateness are when buildings are identical in colour and appearance making it difficult to differentiate them.

Richness relates to the range of sensory experiences available, for example sight, smell, touch and sound. It is also concerned with how the experience can have an effect on the emotional state of those visiting the place. A visual example would be the use of paths to provide a heightened sense of awareness of the environment and that something important is going to happen. Therefore in the visual sense it is important to consider how long something can be viewed and where it can be viewed from.

Personalisation is the ability we are given to customise an environment on a large or small scale. Small scale personalisation can include moving a chair in a room, large scale personalisation being the ability to change the appearance of a building.

Legibility is how easy it is for a person to construct a mental map of their environment and depends to a large extent to the form of the environment and the activities people undertake. Lynch (Lynch, 1970) discusses many features such as paths, nodes, landmarks, districts and edges.

Although these concepts are drawn from the real world they are relevant to the development of virtual environments. For example paths play a key role in nearly all of the properties of a responsive environment, due to the fact that they are a predominant part of the mental image a person possesses (Appleyard, 1970; Kuipers, 2001; Lynch, 1970). They shape the activities of people and are shaped by the activities people undertake. Paths also provide a rich sensory experience, as they act as a means to walk by and through features of a space. This results in them playing a critical role in the development of a sense of place. In real world environments they suggest and provide a means of movement. However in the virtual environments discussed in this paper technical restrictions prevent people from moving. Although the environments suggest that paths are available using them is not possible. Moreover, virtual environments often restrict several aspects of the experience such as richness, variety, robustness and personalisation; therefore reducing the potential cues available that may help people in developing their sense of place.

**Place**

Researchers in the field of environmental psychology and more recently virtual environments have explored the idea of place in order to understand the whole experience people have of locations (spaces) that they visit (Spagnolli & Gamberini, 2005). The work has often taken a phenomenological perspective (Relph, 1976; Tuan, 1977) with the objective of uncovering the core aspects of a space that result in it becoming a place. In basic terms a space is the physical manifestation of a location, for example a room, its walls and furniture etc. Whereas a place contains higher level aspects such as the activities people undertake, any meanings they attach to it, as well as the physical properties (Norberg-Schultz, 1976;Relph, 1976).

**Presence**

Assuming that an environment is responsive to the needs of its users and that our sense of embodiment allows people to experience the range of activities, people and forms provided, we contend that they are likely to experience a strong sense of place and presence. Therefore in a virtual environment presence can be seen as ‘the subjective experience of being in one place or environment even when one is physically situated in another’ (Witmer & Singer, 1998). If the sense of place is strong and the technology provides a high quality experience then people will experience the 'illusion of non-mediation’ (Lombard & Ditton, 1997). Presence also manifests itself in three ways: physical, social and co-presence (Ijsselsteijn & Riva, 2003). Physical presence is the focus in this paper and deals with feeling as if one is physically located in a mediated environment. Social presence is when there is a feeling of being with others, either locally or remotely and co-presence is where one feels a sense of being co-located somewhere with others and combines aspects of social and physical presence. This paper focuses on physical presence as both virtual environments studied are for single users only.

A contrasting view of presence is offered by Floridi (Floridi, 2004) as the 'successful observation' of entities in our surroundings. This view creates two ideas of presence: forward and backward. Forward presence is where we seek to extend our boundaries of experience to a remote location, for example by manipulating a robot at a remote location such as the moon (also known as tele-presence). In contrast backward presence is where the environment is brought to the participant, for example by placing someone in an immersive CAVE and projecting images of a given location. The experiments in this paper focus on backward presence as the environments used seek to bring another environment to the user.

**Contributing Work**

The approach adopted from the outset of the research has been to understand presence in relation to place. Initial studies explored a number of different techniques for eliciting data, ranging from questionnaires; such as the immersive tendencies Questionnaire (ITQ) (Witmer & Singer, 1998), the Sense of Presence Inventory (SOPI), structured interviews, talk-aloud protocols and the subsequent development of our own method the Place Probe (O'Neill et al., 2004; McCall et al., 2004a)

The effectiveness of these methods has been explored through a variety of data analysis techniques such as grounded analysis, peer reviewing, semiotic analyses and various forms of coding. Furthermore, the utility of these techniques has been studied in a variety of settings such as environmental architecture (Smyth, 2003), real and virtual representations of botanical gardens, a university stairwell and a city view of Prague (McCall et al., 2004a; McCall et al., 2004b; O'Neill & Benyon, 2003).

One of the motivations underpinning this research has been to compare virtual representations of places against their real counterparts. Such comparisons can be made at many different levels of abstraction. The comparison of the Prague botanical gardens and the Edinburgh botanical gardens (O'Neill & Benyon, 2003) was considered to be valid at the level of general characteristics i.e. the virtual gardens did not feel hot and humid which was a key characteristic of the real gardens. However, the representational quality of many of the plants provided an overall feel of 'being in' a botanical garden.

Similarly, the virtual viewpoint study (O'Neill et al., 2004) allowed for the comparison between a real viewpoint in Prague and a virtual representation of that same place. Of course it is very difficult for the real and the virtual places to ever be exactly the same. The impossibility of making a detailed and exact replica must always be kept in mind when considering the data. However, for the purposes of informing the design of a virtual place that is as faithful as possible to the real place, focusing on key emergent themes does appear to be useful. The comparisons made by probing participants' sense of place in both real and virtual versions of the viewpoint highlighted similarities in participants experiences, as well as significant technical problems that tended to interfere with their sense of place and ultimately presence.

**Study**

**Equipment**

The virtual environments in the study used a photo-realistic rendering technology developed within the EU funded BENOGO project. Firstly a digital camera is used to capture a set of images at a given location. The images are mapped onto a concave sphere and are displayed in a HMD or CAVE. The actual image seen by the user is a composite of those previously captured and is based on their position and a software algorithm.

Unlike certain other photo-realistic technologies the BENOGO system lets people move freely within a specified area and provides horizontal parallax. However the level of movement is limited, for example in the system used in this study people can only walk within a 60cm diameter (in the horizontal plane). Moreover, when looking at the top and bottom (of the world or sphere) there are some graphical distortions. The system does not allow interaction with others or photo-realistic objects.

In addition to the rendering technology used the environments were displayed in two arenas; a HMD and an immersive CAVE. The HMD had a resolution of 640x480 pixels and displays 14 pixels per degree of view. In comparison the CAVE has a resolution of 1024x1024 pixels but only displays 11 pixels per degree of view. The lower number of pixels per degree combined with the fact that the images in the CAVE are stretched across a larger surface area results in the images appearing at a much lower resolution.

Head tracking was used within the HMD in order to calculate the position of the user and hence to render the scene from an appropriate point of view in real time. In the

CAVE the images are projected on to each wall (or surface) with tracking provided via a head sensor.

**Environments**

In order to carry out the studies two environments were chosen. The first was a view from a balcony within the Czech Technical Museum in Prague (see figures 1a & 1b). This environment was used to conduct the evaluation of place and presence as it contains interesting content. The second environment was an office within the Czech Technical University (figures 2a & 2b), it was chosen as it was used high resolution graphics and all relevant distances within the space were known.

We were also interested in exploring the effect of augmentations on the sense of place, presence and distance in both arenas. Hence we implemented a computer generated augmented barrier (see figures 1a and 2a). A barrier was chosen since at the time of the studies movement of the users was restricted to a 60cm disc and it was felt that the barrier may discourage people from venturing out with the disc area and hence experiencing blank displays and other technical problems. It is our intention to explore the effect the barrier has on movement in future publications. The barrier is computer generated and when compared to the photo-realistic virtual environment there are a number of noticeable differences, namely the resolution appears different, it is brighter and the textures appear less natural.

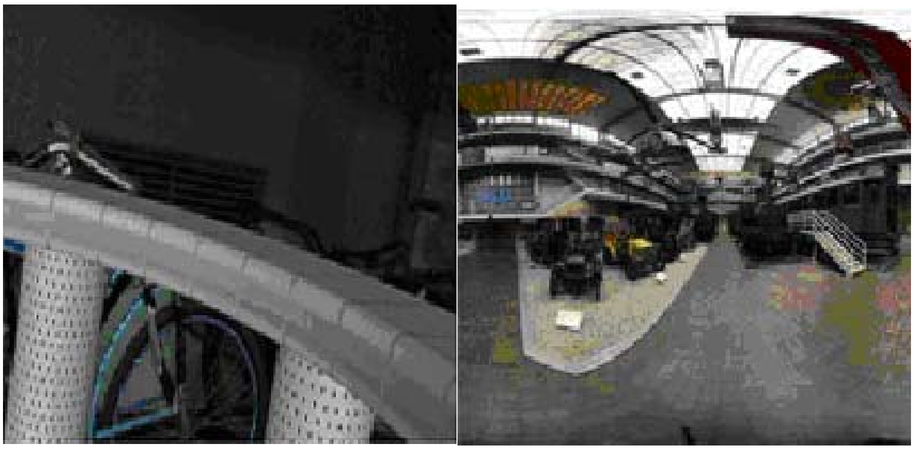

**Fig. 1(a) and 1(b):** The technical museum with the augmented barrier and a view from the balcony in the technical museum.

**Fig. 2(a) and 2(b):** The augmented barrier in the box world and the box world without the augmented barrier.

### Data Capture Methods

The objective throughout the study is to combine qualitative and quantitative data sources and to look for corroboration within the results. It was felt that while measures such as the MEC questionnaire may provide numerical scores for the varying conditions, they do not shed light on the higher level experiences which may be related to the sense of presence; for example the ability to understand content or feelings of space and size. Moreover the objective of the work was to provide feedback to the system developers hence there was an interest in relating specific features of the technology to feelings of place and presence.

### The Place Probe

During prior studies it became apparent that using any single method to capture aspects of place and presence was insufficient. Consequently we began to explore a variety of methods that would be capable of capturing rich information about places; from technical aspects through to higher level issues such as meaning and activities. The result was the development of an en-situ tool known as the 'Place Probe' (O'Neill et al., 2004; McCall et al., 2004a).

Probes have been used in two main contexts. Cultural probes (Gaver, 1999) for the capture of rich data about the context in which a technology was being used, or where it was likely to be used. The probes were not intended to simply elicit some objective data, they were intended to provoke responses. In a similar vein Technology probes (Westerlund, Lindquist, & Sundblad, 2001) have been used particularly in the domestic setting to explore new uses of technologies. The probe which they developed used methods that were intended to inform the design of a prototype system which would provide a common interface where different generations within a family could communicate, even if they were are at different physical locations. They used probes to capture information about the nature of communications between family members. The probes contained a communication diary, notebook, two disposable cameras, address envelopes and a pen. Other probes have been used by (Eggen et al., 2002) and by Baillie (Baillie et al., 2002).

The probe reported here differed in that it was designed to capture experiences at a specific point in time or a particular place rather than over an extended period of time. Drawing on the experiences of the previous empirical studies our place probe included several key elements; a visitors book, sketch maps, semantic differentials and a six word summary. Earlier experiences of the probe found that it was capable of identifying a rich range of data about real and virtual places, in particular attributes which were relevant to exploring the concepts behind responsive environments.

The place probe is completed by each participant after they have completed a relevant part of the study, for example after they have experienced the CAVE or HMD. The probe takes approximately ten to fifteen minutes to complete and the participants can request assistance if they are unsure what they must complete for each section.

*Part 1: The Visitors Book*

Research undertaken by Turner and Turner (2003) has highlighted the written reports contained in visitor's books as a source of rich data about place. Indeed such reports have the advantage that they are often ask open-ended questions e.g. 'Please tell us about your experience' rather than 'Tell us about the lighting', hence they do not prompt people to provide answers on specific topics.

*Part 2: Sketch Maps*

Sketch maps provide information on the layout and key features of a location. In this case accuracy of the map is not of prime concern, rather it is the depiction of those aspects of the place that people remember; for example a tree, building or seating area. They can also be used to provide additional information such as where people are standing or their paths through the environment.

*Part 3: Semantic Differentials*

Semantic differentials are sets of descriptors of the place on a bi-polar scale. For example, people are asked to indicate where they would position the place on a scale of attractive-ugly, big-small, colourful-colourless, noisy-quiet, and so on. Eleven characteristics have been used (O'Neill et al., 2004). The results presented later do not include data from this element of the probe. However, a similar instrument was included in the experiments.

*Part 4: Six Words*

The final part of the probe asked people to write down six words which best described their experience of being in a particular place.

**Semantic Differentials**

A set of semantic differentials which are identical to those found in the place probe were used. In this instrument participants were asked to rate various features of the environment (see tables s1-s4 at the end of this paper). The differentials combine Osgood's (Ogood, Suci, & Tannenbaum, 1957) semantic differentials and Relph's three aspects of place (physical features, activities afforded and affect engendered). For example people are asked if the environment is attractive or ugly, with the rating ranging from Very Attractive, through neither (i.e. not attractive or ugly) to Very Ugly. Prior to each set of differentials a question is provided so that participants will concentrate on the relevant area. The differentials build on the aspects of place developer by Relph (Relph, 1976) by adding a section specifically designed to explore the effects of the mediating technology. The objective of the semantic differentials is to develop maps of the connotative associations people have with certain words and the environment, which in turn allows the abstraction of information on their feelings towards it.

**Semi structured Interview**

The semi-structured interviews were conducted within a relaxed framework, which allowed for the retrieval of both general and focused qualitative information. Five questions were formulated before the interview (see

Table 1 : Interview questions) with some random questions materialising during the interview. All the questions were discussed in an informal manner with the interviews lasting between ten and twenty minutes. The first question is an open-ended question while the preceding questions are more specific. The method of questioning was quite flexible and each question was designed and phrased to probe for relevant details. Each participant experienced the virtual technical museum, either through the HMD or the CAVE and each interview was recorded using a DAT recorder.

1. Can you tell me your general feeling and thoughts on your experience in the VR environment?
2. Did anything in the environment trigger your curiosity?
3. Was there anything odd or unusual in the environment?
4. Where did you think you were?
5. What did you think you were doing there?

**Table 1 :** Interview questions.

**MEC Spatial Presence Questionnaire**

The MEC questionnaire (Vorderer et al., 2000) is designed to measure the experience of spatial presence. The questionnaire is derived from a solid theory of spatial presence and is divided into a number of different sections:

- Attention allocation.
- Spatial situation model.
- Spatial presence: a) self location, b) possible actions.
- Higher cognitive involvement.
- Suspension of disbelief.
- Domain specific interest.
- Visual spatial imagery.

It is designed for immediate use after media exposure and the scoring system consists of a five point scale. Depending on the requirements of the study, the questionnaire can contain 8,6 or 4 items per section. Data from studies conducted during the development of MEC pointed to the 4 item set being suitable for our work and it was chosen for use throughout both experiments. A list of the questions used in this study can be found at the end of this paper in tables M1-M7.

**Distance Estimate Test**

For an environment to be responsive its users must feel as if they have the ability to move around and interact with objects in their personal and action spaces. An action space is usually categorised as a distance of greater than arms length (which is personal space) but less than 30 metres (Loomis & Knapp, 2003). In the box world environment chosen for this study all objects existed within the action space.

Prior work on distance estimates within virtual environments has found that users of HMD's typically underestimate distance relative to the real environment, with the display being the problem area not the weight of the HMD (Willemsen, Colton, Creem-Regehr, & Thompson, 2004). However image quality or realism was found not to have any significant impact (Thompson, Willemsen, Gooch, Creem-Regehr, Loomis, & Beall, 2004). Other aspects such as depth cues play a critical role, and in the BENOGO technology some issues remain such as the lack of horizontal occlusion or reflections.

Early experiences of the BENOGO technology and the different arenas suggested there may be a variation in the feeling of being able to touch objects. Furthermore anecdotal evidence pointed to objects in the CAVE feeling further away, hence reducing the feeling of being able to act within the space. Consequently the focus of this part of the study was on how estimation of distance changes between each arena. Moreover the augmented barrier became an additional aspect to explore as it was built specifically to make participants feel as if there were less actions available.

In order to conduct this study a box world was used (see figures 2a & 2b) where the exact distances to the specified points were already known. The box world was chosen as at the time of the study it offered the highest resolution available and the distances were known. The participant experiences the environment from the perspective of the camera (see the black spot marked camera in figure 3), giving then an egocentric view of the space. In this study the focus was on exploring distance measures within the action space of the user. It should be noted however that the objective of exploring the distance measurements is to compare the different arenas (CAVE vs. HMD) and the effect of adding the barrier, rather than to compare them to the actual distances.

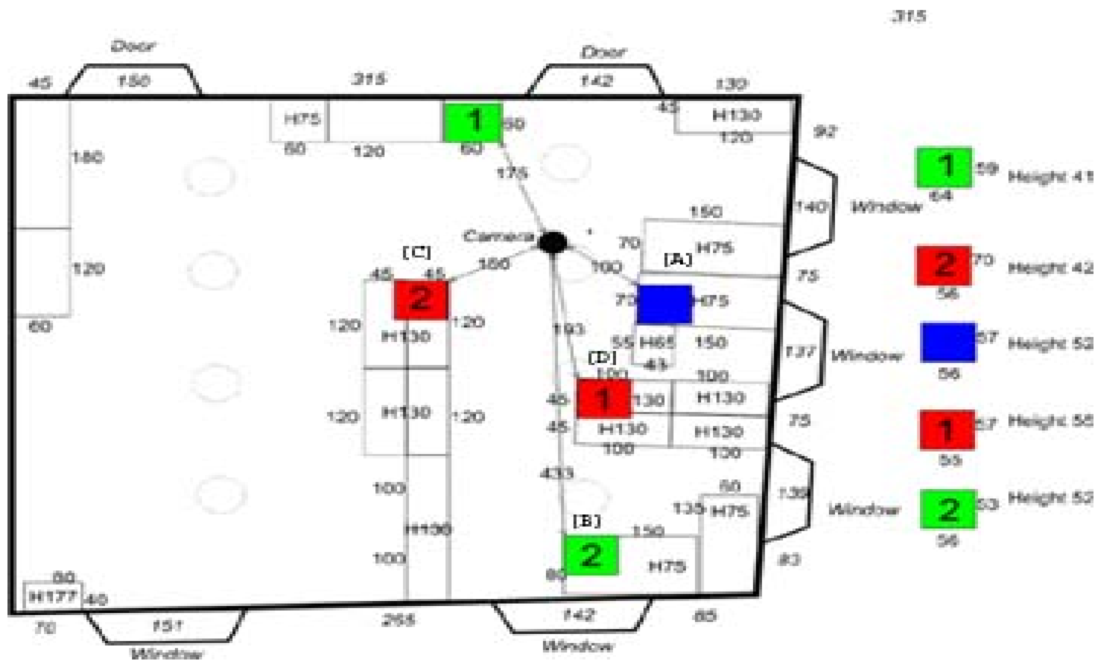

**Fig. 3:** Box World Map. The black dot indicates the position of the user, each coloured block represents a point they were asked to measure.

Prior to being asked for distance measures of the virtual environment, each participant was asked to estimate a relative distance of something in the real environment and for their own height. On entering the virtual world they were asked how they felt relative to their normal height. The distance estimates explored feelings of absolute distance (i.e. from themselves to a given point) and relative distance (i.e between two points), the questions are outlined below:

1. How tall are you?
2. Relative to your normal height do you feel short, tall or normal in the scene?
3. Which box is nearest you?
4. Which box is furthest away?
5. What is the distance of the blue box?
6. What is the distance of the far green box?
7. What is the distance between the two red boxes?
8. Facing the near green box, what is the width of the room?
9. Facing the blue box what is the length of the room?

## Procedure

The experiments were conducted during a two day workshop at Aalborg University, Denmark. Two sets of experiments were conducted on consecutive days using different sets of participants and varying methods as described in Table 3. They are not intended to be comparative studies but instead are intended to explore the use of different methods and to capture as diverse and large a set of data as possible.

<table>
<tr><th></th><th>Experiment 1</th><th>Experiment 2</th></tr>
<tr><td rowspan="2">CAVE</td><td>Museum:<br>With Vs Without Barrier<br>(Semantic differentials, MEC)</td><td rowspan="2">Museum:<br>No Augmentation<br>(MEC, Place probe, Semi-structured Interview)</td></tr>
<tr><td>Box world: distance estimates<br>With Vs Without Barrier</td></tr>
<tr><td rowspan="2">HMD</td><td>Museum:<br>With Vs Without Barrier<br>(Semantic differentials, MEC)</td><td rowspan="2">Museum:<br>No Augmentation<br>(MEC, Place probe, Semi-structured Interview)</td></tr>
<tr><td>Box world: distance estimates<br>With Vs Without Barrier</td></tr>
</table>

**Table 2:** Structure of the studies carried out during the workshop.

Experiment 1 was conducted with another team of researchers who were interested in exploring sound augmentations. Due to the number and nature of tests being conducted during experiment 1 it was felt that participants may get bored if they were asked to complete the place probe on several occasions. Hence the experiment used only the semantic differentials element of the place probe. The MEC questionnaire was used during both experiments simply to allow for maximum data collection.

On being assigned to an arena the participants were then informed of the structure of the test, the range of environments and that they would be asked to complete a series of questionnaires. The order in which participants experienced the environments and barrier conditions was chosen at random. After each of the museum test conditions they were asked to complete a MEC questionnaire and set of semantic differentials (from the place probe). Prior to starting the box world tests the participants were asked to provide a distance estimate of an aspect of the real environment. After the initial test they asked to complete the two augmentation conditions, after which they were asked to provide a series of distance estimates.

Experiment 2 was intended to compare the difference in sense of place and presence when comparing the CAVE and HMD. For this the only variable which was changed was the arena. This resulted in there being more time available for each participant once they had completed the task. Hence they were encouraged to complete the Place Probe, MEC questionnaire and take part in a short semi-structured interview.

There were no complex tasks involved in any of the test conditions, hence it was felt that only basic instruction on how to use in the CAVE or HMD should be provided. These included telling people that they could move around or adjust the positioning of the HMD.

**Participants**

A total of 28 subjects took part in the study, for the most part they were students and staff from Aalborg University and ranged from those in computing to those from an Arts and Social Sciences background. During experiment 1, 10 males and 4 females took part. While during experiment 2, the group consisted of 7 females and 7 males.

**Statistics Used**

The nature of the study resulted in only a small number of participants experiencing each condition and as a result the data was not always normally distributed. Accordingly non-parametric statistics were used to permit comparison between the different data sets. The primary statistic used was the Mann-Whitney u-test which allows for comparison of two data sets in order to ascertain whether there is a genuine statistically significant variation in the data. The confidence interval used was set at 95% which translates into their being less than a 5% chance of the result being due to a random factor ($p<=0.05$). Therefore where the data indicates $p=0.03$ this indicates the result has a 3% chance of being due to a random factor.

**Results**

The results presented focus on the order in which the studies were conducted (see the experiment breakdown in table 1), and the data capture method used. The semantic differentials and distance measures apply only to the studies carried out as part of experiment 1. Data from the MEC spatial presence questionnaire covers findings from both experiments. Data from the place probe applies to studies carried out during experiment 2 only. The results do not report the findings from the semantic differentials component of the place probe during experiment 2.

**Semantic Differentials (Experiment 1)**

The full list of attributes of the various measures used are presented in Appendix 1. However, there were few statistically significant differences when comparing the different arenas and barrier settings which may be due to the small sample size (approximately 6) and the course nature of the questionnaire. Data is presented where it is most relevant. Where statistics are reported they relate to a confidence interval of 95% or $p<0.05$.

HMD: adding an augmentation made the environment feel:

- Bigger (p=0.0023)
- More permanent (p=0.0027)

CAVE: adding an augmentation made the images in the environment feel:

- Grainy (p=0.0329)

When comparing the effect of adding augmentations to both arenas:

- The objects in the HMD felt more touchable (p=0.0051)

When both arenas did not contain augmentations

- Images in the ***CAVE*** were ***less believable*** (p=0.0165)
- Images in the ***CAVE*** felt ***slower*** (p=0.011)
- ***CAVE*** made users feel ***less free*** (p=0.0301)
- ***CAVE*** made the environment feel ***bigger*** (p=0.0026)
- ***CAVE*** made the environment feel ***more permanent*** (p=0.009)
- ***CAVE*** *made the environment feel* ***less responsive (p=0.004)***

A further analysis using correlations was carried out in order to ascertain the links between semantic differentials. In the information presented later in this section the words such as 'meaningful' relate to an individual semantic differential (see appendix 1). Although the correlations suggest links between the semantic differentials they should not be taken to indicate causality, instead they should be viewed as areas of future study.

On exploring the correlations it was found that how ‘meaningful’, ‘interesting’, ‘exciting’ and ‘memorable’ the environment was, depended to large degree on the overall image quality, with ‘meaningfulness’ being correlated to ‘realism’ and ‘nearness’ of objects. ‘Accuracy’ correlated with ‘believability’, which affected the feeling of ‘orientation’, with ‘orientation’ being correlated to the ‘colourfulness’ and ‘lightness’ of the scene. As a result ‘accuracy’ is related to the ‘colour’ and consistency of images when a person moves.

The CAVE and HMD both present the scenes in different ways with objects in the CAVE appearing further away. The perception of distance and the ability to touch objects appears important in making the environment feel responsive to the needs of the users. Further examination of the correlations found that the perceived ability to touch objects has a direct impact on the sense of ‘mobility’, ‘freedom’ and ‘activity’.

The sense of being inside the environment was positively correlated to the perceived ability to ‘touch’ objects, the ‘lightness’ of the scene (arena) and how ‘beautiful’ the environment felt. ‘Beautiful’ correlated with feeling of being ‘oriented’ and the environment feeling ‘full’ rather than ‘empty’. In turn ‘fullness’ of the space was directly related to ‘realism’, ‘accuracy’ and how ‘believable’ the environment felt. The sense of scale (or ‘bigness’) of the environment had a direct impact upon how ‘meaningful’, ‘memorable’ and ‘interesting’ the scene was.

**Distance Measures (Experiment 1)**

The distance measures have been calculated for both arenas and augmentation settings, the sample groups are approximately 6 or 7 for each condition. The table headings refer to the objects in the distance estimate tests (see table 3), with the blue box [A], green box [B], W & L room relate to the width and length of the virtual room and between is the difference between dark boxes C & D. Correct is the measured distance of the objects or distances from the standing point in the real world equivalent of the virtual environment. A map of the blocks used in the study can be found in figure 3.

| | | Absolute Distances | | Relative Distances | | |
|---|---|---|---|---|---|---|
| | | Blue Box | Green Box | W Room | L Room | Between Objects |
| | Actual | 100 | 433 | 782 | 658 | 115 |
| CAVE | Mean | 113.33 | 558.33 | 950.00 | 950.00 | 250.00 |
| Barrier | Median | 90.00 | 500.00 | 850.00 | 800.00 | 200.00 |
| | St Dev | 51.25 | 307.27 | 339.12 | 388.59 | 173.20 |
| | | | | | | |
| CAVE | Mean | 126.00 | 560.00 | 920.00 | 900.00 | 186.00 |
| | Median | 100.00 | 500.00 | 900.00 | 800.00 | 200.00 |
| | St Dev | 48.79 | 304.96 | 349.28 | 353.55 | 21.90 |
| | | | | | | |
| HMD | | Blue Box | Green Box | W Room | L Room | Between |
| Barrier | Mean | 66.67 | 358.33 | 641.67 | 783.33 | 250.00 |
| | Median | 60.00 | 350.00 | 700.00 | 800.00 | 250.00 |
| | St Dev | 19.66 | 91.74 | 185.52 | 213.70 | 70.71 |
| | | | | | | |
| HMD | Mean | 48.78 | 266.69 | 509.06 | 599.01 | 190.24 |
| | Median | 60.00 | 350.00 | 641.67 | 783.33 | 250.00 |
| | St Dev | 25.43 | 151.57 | 281.71 | 333.79 | 103.51 |
| | | | | | | |

**Table 3:** Comparative distance estimates for the CAVE and HMD, with and without the barrier.

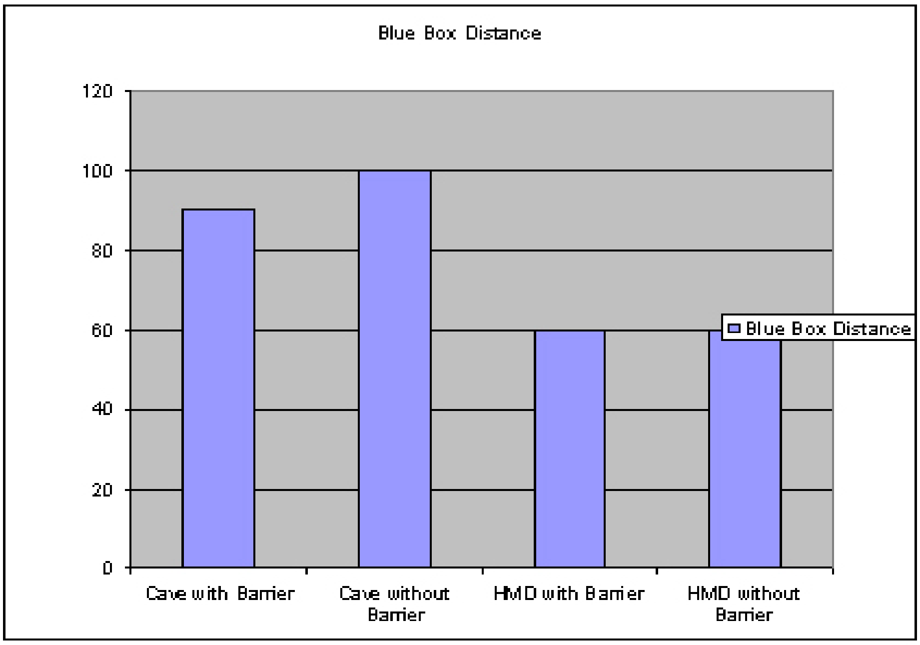


**Fig. 4a:** Median distance measures for blue box task.

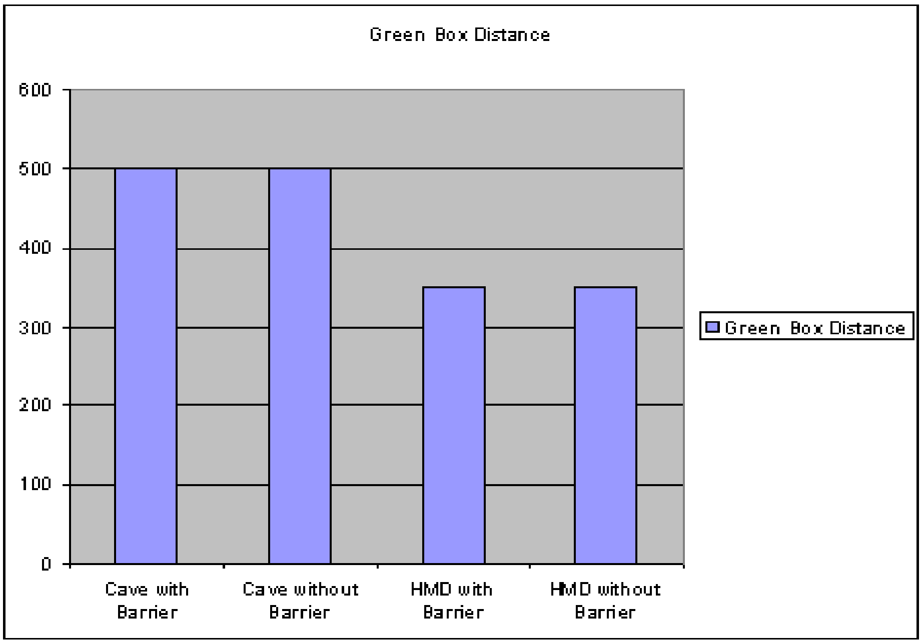


**Fig. 4b:** Median distance measures for the green box task.

The results in table 3 indicate that people thought the distances for the location of objects and room dimensions were larger within the CAVE than the HMD, this applied irrespective of whether the barrier was present (see figures 4a&b and 5a&b). However there were no such variations when comparing between object distances. At this stage these findings are only indicative as the only statistically significant result related to the distance of the blue box; many others came close to being significant and hence warrant further investigation. However we found no link *between object* distance estimates and the presence of the barrier (see figure 6).


**Fig. 5a:** Comparing median length of room measurements task.

The absolute distance estimates of blocks in the CAVE and HMD varied substantially, but were not statistically significant. At this stage it is possible to speculate that for the distances of objects people consistently underestimated them in the HMD, and were approximately accurate or over estimating them in CAVE. With the distance estimates in the HMD increasing when an augmentation is added. There was also a consistent overestimation of room size in the CAVE, and underestimation in the HMD. Interestingly though the between objects score for both environments appeared to be consistent and more accurate in the CAVE.

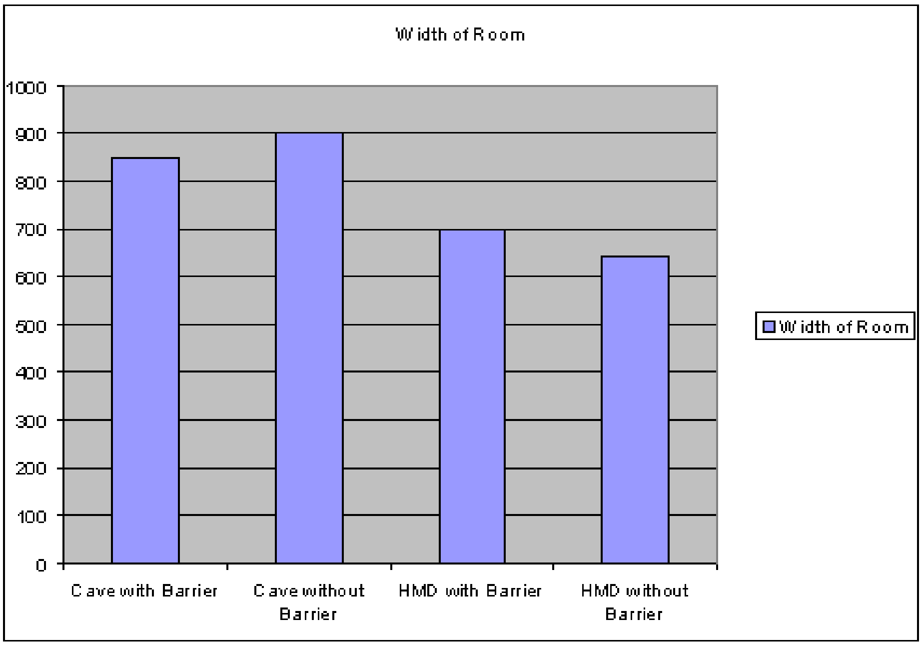


**Fig. 5b:** Comparing median width of room measures.

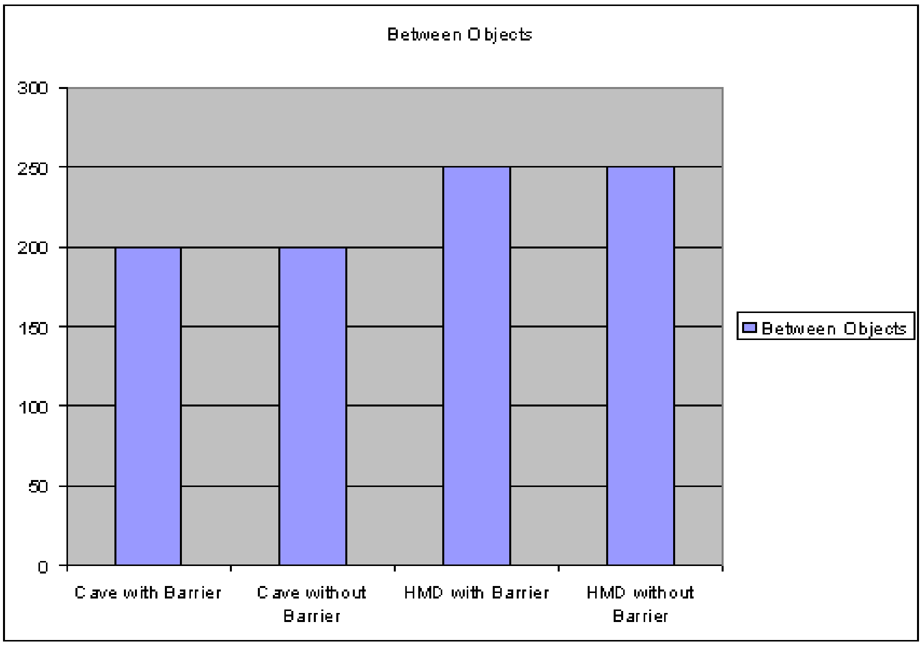


**Fig. 6:** A graph illustrating the median between objects distances.

The data partially confirms some findings from prior work (Willemsen et al., 2004) that people consistently underestimate distances in HMD's. However it also points to some variations, in particular with absolute distance measures when comparing the CAVE and HMD.

**MEC Spatial Presence Questionnaire (Experiments 1 & 2)**

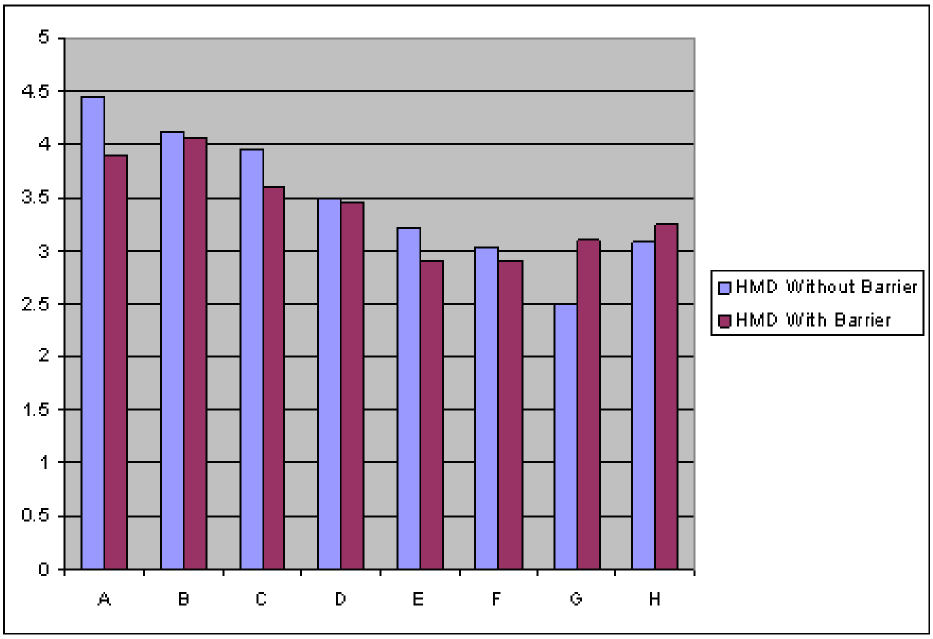


**Fig. 7:** A chart comparing the results from the MEC questionnaire in the HMD. (A) Attention allocation (B) Spatial Situation model (C) Spatial Presence: Self location (D) Spatial Presence: Possible Actions (E) Higher cognitive involvement (F) Suspension of Disbelief (G) Domain Specific Interest (H) Visual Spatial Imagery.

The data from the HMD study (see figure 7) without the barrier shows a high average score for spatial presence (self location, C, scoring 3.958 and possible actions, D, scoring 3.499). The level of participants' attentiveness is quite high (A, score of 4.458) and as is the spatial situation model (B, 4.12). The participants' ability to suspend disbelief is average as is their cognitive involvement and ability to visualise the space. The participants' interest in the environment is low. On adding the barrier there appears to be a drop in the scores for spatial situation model, spatial presence (self location), cognitive involvement and suspension of disbelief but an increase in domain specific interest and visual spatial imagery.

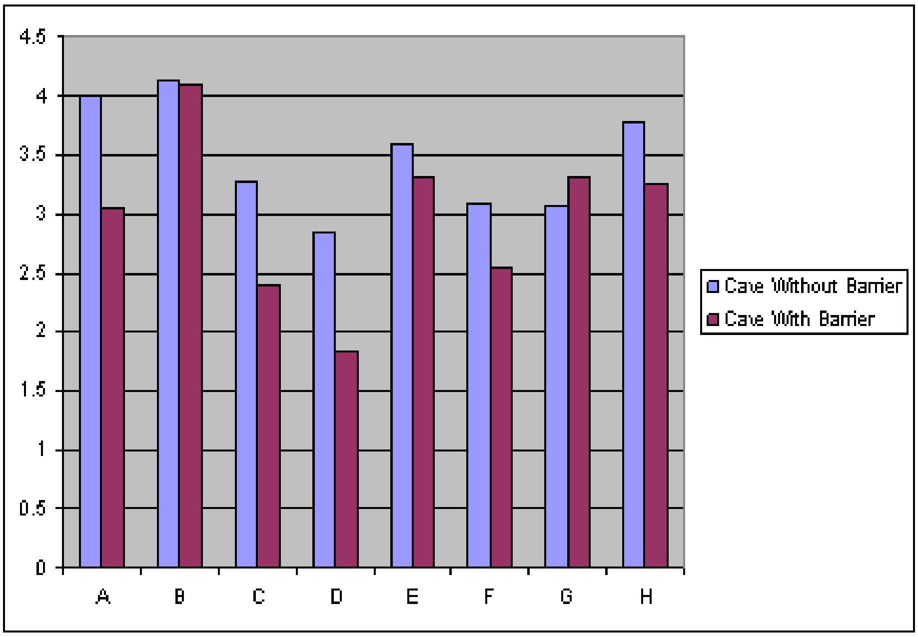


**Fig. 8:** MEC data when comparing the CAVE with and without the barrier.

There are similar trends in the data when exploring the effect of adding the barrier to the CAVE condition (see figure 8); with the only difference being the level of domain specific interest which marginally increases when the barrier is added to the CAVE. Also on a quick examination of the data the drop in scores when the barrier is added to the CAVE is much higher than in the HMD condition. One very interesting finding is that the scope for possible actions drops substantially when the barrier is added.

On comparing the arenas without the barrier the results are somewhat mixed (figure 9). Interestingly though the HMD performs better with respect to spatial situation, spatial presence (self location and possible actions). With the CAVE appearing only to materially enhance aspects such as cognitive involvement, domain specific interest and visual spatial imagery. The scores for the CAVE for attention allocation, spatial presence (self location and possible actions) are much lower than for the HMD. However the barrier (see figure 10) appears to make little effect on issues such as spatial situation, domain specific interest and visual spatial imagery.

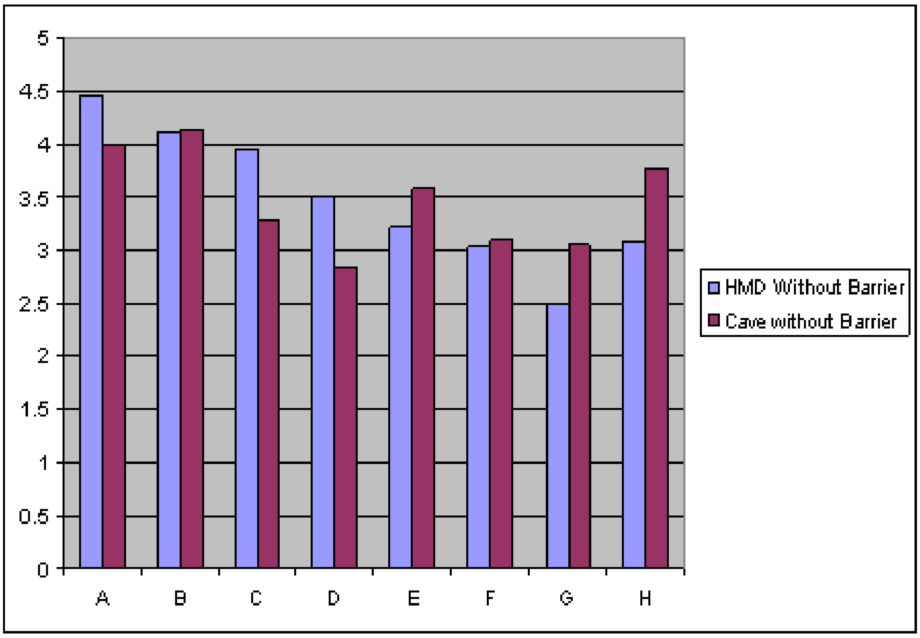


**Fig. 9:** MEC data when comparing the HMD and CAVE without the barrier.

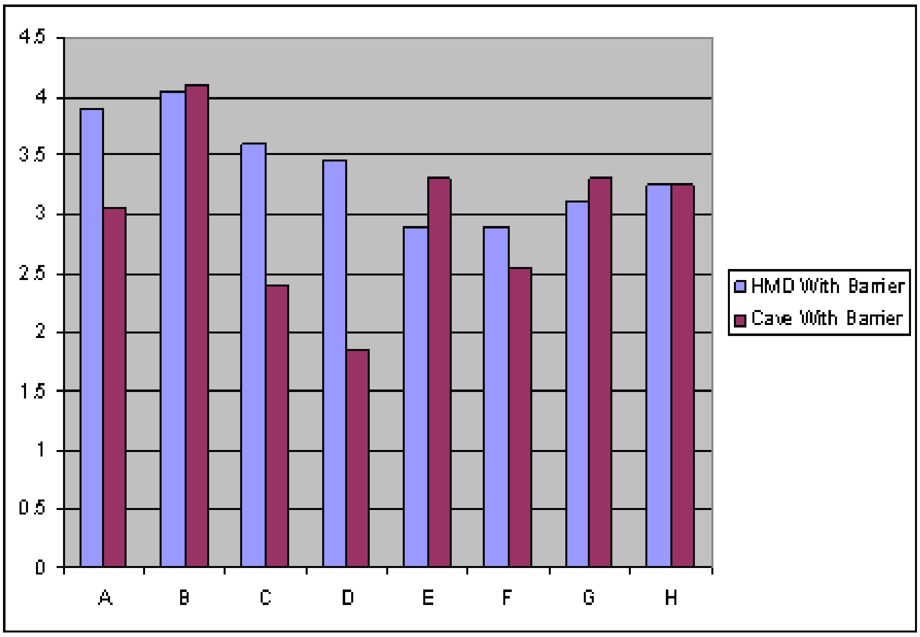


**Fig. 10:** MEC data comparing the HMD and CAVE with the barrier.

**Place Probe: Descriptions and Keywords (Experiment 2)**

The place probe was given to fourteen participants after they experienced the virtual technical museum (HMD=6, CAVE=8). The following are the overall key themes from the data from both arenas obtained from the descriptive section (visitors book) and six words of the probe:

- Restrictiveness
- Size
- Oldness
- Strangeness
- Fun
- Impressiveness
- Emptiness
- Negative feelings
- Physical objects
- Technology

The action space of both arenas was restricted and this recurring theme emerged from the data leading to the participants feeling disappointed as their ability to explore the environment was curtailed.

- *'I missed that I couldn't move around.'* (Female, 28, CAVE)
- *'I would have liked to see more of the museum, not just turn around and see the things placed in a circle around me.'* (Female, 30, HMD)
- 'Better movement capabilities would take the experience to a higher level.' (Female, 47,HMD)
- *'The restriction of the movement seemed annoying.'* (Male, 25, CAVE)

Legibility and visual appropriateness remained a problem within both arenas, with more technical problems being noted in the CAVE. This was highlighted by words such as 'stereo', 'real', 'VR', 'science fiction' and 'technic' being used to refer to the CAVE, while these terms were not used with respect to the HMD.

- *'Impressive stereo – effect though the resolution leaves something to be desired.'* (Male, 25, CAVE)
- *'Also when looking down the image and the experience was pretty bad.'* (Male, 32, CAVE)
- *'I had a problem with errors.'* (Female, 28, CAVE)

Physical objects were noted from both experiences i.e. trains, planes , cars, bikes, railing, ceiling, balcony (the planes were noted 10 times, motorbikes were noticed 4 times, bikes were noted 3 times, trains were noted 4 times, railing were noted 3 times). However, problems with resolution meant that legibility was a problem with participants being able to see objects yet not able to identify them.

- *'I found it quite hard to actually see things clearly at all times.'* (Female, 25, CAVE)
- *'I tried to read the information in the museum.'* (Female, 47, HMD)

In both arenas they got the sense of the size of the room, with words like large, huge, big, and great used to describe experiences. In the CAVE the word 'large' tended to be used more while in the HMD they used the word 'big'.

From both arenas, the feelings that were emerging varied from scary, spooky to an interesting, nice and very good experience. People in both, found it scary because they felt if they moved too far, they would fall down while a person in the HMD also felt spooked because it was so realistic they could 'almost smell the dust and oil from the old machines'.

Participants in both arenas described it as a nice and good experience. Words like 'old', 'history' and 'vintage' were used to describe the environment. The words 'vintage' and 'old' being used more in the CAVE while the words 'vintage' and 'historical' being used in the HMD arena. People in the CAVE arena got more of a strange, surreal, confused, curious feeling while those in the HMD got more of a mysterious feeling. People in both mentioned it was fun and a person in the CAVE described it as an 'interesting' experience while those in the HMD described it as an 'exciting' experience.

The CAVE experience was noted as being dark and was described as empty, deserted, scary and bad while the HMD was described as boring, melancholy and silent. Nevertheless, people in both arenas have started to make certain connections with the environment and the real world. For example, in the CAVE arena, they described the experience like being inside a ship or inside a computer game while in the HMD it was more like the feeling of being back in the twenties/thirties.

- *'It sounded like the inside of a ship.'* (Female, 38, CAVE)
- *'I had the impression of being inside a computer game.'* (Female, 25, CAVE)
- 'I had the feeling of being back in the twenties/thirties.' (Female, 24,HMD)

### Place Probe: Sketch Maps (Experiment 2)

The sketch map section of the probe provided some interesting information about what people considered to be the most salient aspects of the environment they encountered. In both the HMD and the CAVE participants identified the same kinds of objects, the most common of which were:

- Motorbikes
- Planes
- Trains
- Cars
- Hanging planes

Individual preferences revealed examples of specific objects such as the 'gold motor bike' or 'the yellow plane' but none of these were common across participants or environments.

The tables 4 & 5 illustrate the specific counts for map goodness, objects, total position of objects and the position of the most significant objects. They also show the position ratios of all objects and significant objects.

| No | Goodness | Object Count | Total Position | Significant Position | All Pos Ratio | Sig Pos Ratio |
|---|---|---|---|---|---|---|
| 8 | 2 | 7 | 4 | 4 | 0.13 | 0.8 |
| 9 | 1 | 9 | 4 | 4 | 0.13 | 0.8 |
| 10 | 1 | 4 | 4 | 2 | 0.13 | 0.4 |
| 11 | 1 | 4 | 0 | 0 | 0 | 0 |
| 12 | 1 | 3 | 1 | 1 | 0.03 | 0.2 |
| 13 | 3 | 22 | 22 | 5 | 0.73 | 1 |

**Table 4:** HMD with 6 participants.

| No | Goodness | Object Count | Total Position | Significant Position | All Pos Ratio | Sig Pos Ratio |
|---|---|---|---|---|---|---|
| 8 | 2 | 5 | 4 | 3 | 0.13 | 0.6 |
| 9 | 2 | 5 | 4 | 4 | 0.13 | 0.8 |
| 10 | 2 | 3 | 0 | 0 | 0 | 0 |
| 11 | 3 | 28 | 28 | 5 | 0.93 | 1 |
| 12 | 3 | 11 | 11 | 4 | 0.36 | 0.8 |
| 13 | 1 | 7 | 5 | 3 | 0.17 | 0.6 |
| 14 | 2 | 10 | 8 | 2 | 0.27 | 0.4 |
| 15 | 3 | 14 | 14 | 5 | 0.47 | 1 |

**Table 5:** HMD with 6 participants.

According to Billinghurst and Weghorst, (1995) an ANOVA must be conducted across the significant position ratio of all the maps in each world and over the All position ratio. Significant ratio produces results regarding how well oriented participants were in both environments, whereas all position ratio identifies if either of the worlds had more clearly identifiable landmarks. However the lack of participant numbers in these tests meant that using an ANOVA is not very reliable.

Mann-Whitney tests were used instead to look for significant differences between both all position and significant position ratios. The test results suggest that there are no significant difference between the two versions of the worlds.

We also compared the object count and Map Goodness scores across the worlds. Billinghurst and Weghorst, (1995) suggest that these aspects of data only be used to compare across maps of the same environment. While we were comparing across two different arenas we felt that the environment was rendered using the same images and experienced spatially in largely the same way according to the lack of significant differences in the ratio tests. Therefore we felt that it might be relevant to compare map goodness and object count statistics.

In employing statistical analysis to look for differences between the data, nothing was found to distinguish between the two different groups of maps. The data from the sketch maps appears to show that the level of cognitive mapping is indistinguishable between both the HMD and CAVE.

**Semi structured Interview (Experiment 2)**

Data from the semi-structured interviews covers experiment 2 only, i.e. the CAVE or HMD without the augmented barrier. The findings from the semi structured interviews show that even though many of the participants got a ‘sense of the place’ in both arenas, they still were not achieving a strong ‘sense of presence’. Many participants could identify the place as a museum and recognise the objects:

- *‘I thought it looked real, it was …I got the feeling it was a museum… Oh it was the way it was …the things were planted in the room with signs (Female,28, CAVE)*
- *‘Ya I had the feeling it was a large room and I could identify the main objects in it …(Female ,35, HMD)*
- *‘It was like a tech museum, ya there was sights of aeroplanes, bicycles and transportation.’ (Female ,38, CAVE)*
- *‘‘I really felt I was standing in a room and looking at this old museum. ‘*(Female, 21,HMD)

Despite the positive comments made by the participants they were not experiencing a true complete sense of being there. This lack of being there can be attribute to the breaks which they experience in the sense of place (such as feeling as if they were in a movie) and technical aspects (such as occasional blackness) as outlined below:

- *‘… but I don't think I got the feeling I was there I was kinda of looking into it so… It was kinda like being in the environment …ya I would describe it like …Kinda like looking into the movie about it ’ (Female,28, CAVE)*
- *‘It was quite real and then again it felt like I was inside a computer game’ (Female, 38, CAVE)*
- *It was quite a sensation it really felt like being there …well until you turn the other side or went out of the sensory frame’ (Male,25, CAVE)*

While the content of both arenas visually engaged the participants, they felt disappointed in that although they could see paths and other objects they restricted movement range prevented them from doing so. This is outlined in the comments below:

- *“But the …I felt there was some restrictions in the movement because you couldn't move out very much,”* (Male,32, CAVE)
- *“I could look over the fence but of course I was limited in the …I think it was a metre /a square metre where I could move around”* (Male,25, HMD)

- *"I also felt restricted, I felt I couldn't walk very far and if I turned too much it would go black"* (Male, 25, CAVE)

Problems also arose in relation to visual appropriateness and legibility, namely that although participants could identify objectives such as hanging planes, motorbikes, vintage cars, it was not possible to find out more about the exhibits. For example signs and pictures on the wall were difficult to read, this would often result in people suddenly becoming accurately aware of the technical issues and hence detecting the medium. Some examples are provided below:

- *"The things were planted in the room with the signs …I tried to see if I could read one but…"* (Female, 28, CAVE)
- *"I would have been much more satisfied if I could have got closer to see more specific details. Ok"* (Female, 30, HMD)
- *"And there was some text but it was unreadable but I could easily identify the object ….I could easily identify planes and cars"* (Male,25, CAVE)

**Discussion**

The premise of this paper is that an environment which is responsive to the needs of its users will exhibit a stronger sense of place than those that are not responsive. This is primarily based around the idea that many aspects of responsive environments are critical to models of place. For example activities play a key role within a sense of place and the responsiveness of an environment. Hence if a virtual environment adequately provides relevant cues (such as people, paths and forms) it should lead to more activities being available to users and hence a heightened sense of place. Moreover, by drawing the users' attention away from technical issues or limitations it is suggested that the sense of presence will also increase as people are focussing on the content not the medium. To this end the discussion will examine how the virtual environments used in this study respond to the needs of their users and ultimately shape their sense of place and presence.

**Comparing Arenas**

In general the participants found the CAVE less responsive than the HMD. This may initially be due to the lack of permeability; the ability to move around an environment and for the movement channels to be clearly visible. In terms of the study presented here the semantic differentials point to movement being related to the ability to touch, and senses of freedom, mobility and activity. Taking these as a starting point both arenas do not compare well to the real equivalent as movement is restricted thus reducing the ability to touch objects, as well as freedom and mobility. Data from the interviews and probe back this up with participants indicating they found movement restrictive through comments like “you couldn't move around very much” and “the restriction on movement seemed annoying”. In addition, people felt they could move around less in the CAVE, this was noted in both the MEC questionnaire and semantic differentials.

Variety is the range of activities, people and forms which exist within an environment. In the context of the study here it would be expected that the real version would afford more variety when compared to its virtual counterpart. On closer examination there are variations between arenas, for example the semantic differentials indicate there is a link between the feeling of being inside the environment, and how the ability to undertake activities is related to nearness and ability to touch objects. Additionally the CAVE seems bigger, thus reducing the nearness, ‘touchability’ of objects and the feeling of being inside. The sense of things being further away from the participant is reinforced in the CAVE by the increased estimates of distance. Further evidence can be found within the interviews with one person saying the CAVE made them feel like they were in a movie, which implies they are passive and not active within the scene. Another participant commented on trying to touch the railing to prevent falling within the HMD. This connection between touch and objects in the scene was not prevalent within the CAVE. The perceived inability to carry out even basic tasks such as holding the railing may be due to the increased sense of scale within the CAVE which in turn may provide an indication as to why objects felt less touchable. The MEC spatial presence data confirmed the feeling that there seemed more scope for activities within the HMD than in the CAVE. At this stage there appears to be no difference in the sense of variety when related to forms and other people, this may be due to the same images being used in both arenas.

A robust environment is one which affords many uses through small or simple changes, such as moving furniture or through temporal and social changes. As this is also related to the ability to make changes it will be discussed alongside the ability to personalise the environment. In this study neither arena offered the participants the ability to customise any part of the environment. Moreover, there was no social interaction, which may have brought about a change of use or temporal changes (except for sound cues). Aspects discussed earlier such as the lack of ability to touch objects clearly have an effect on robustness, however beyond the issues already discussed it is not possible to make meaningful comparisons between the arenas.

We would contend that the change in aspects such as variety and permeability between arenas has an effect on sense of place. For example there were variations in the descriptive attributes of the place probe and semantic differentials, to the extent that the same environment appeared to have different meanings between the two arenas. For example in the HMD people commented on it making them think of the 20's and 30's whereas the CAVE felt like a ship. There were also variations the nature of descriptions with more technical aspects predominating from those using the CAVE. Furthermore the levels of spatial presence (self location and possible actions) (columns C & D, figures (9 &10) were lower for the CAVE than the HMD.

### Comparing Augmentations (The Barrier)

The barrier appears to have had some effect on place and presence but not as much as the choice of arena. There was some indication that the barrier caused people to feel the CAVE was more grainy, possibly leading to problems with visual appropriateness and legibility. The barrier also lowered the degree of spatial presence. Anecdotal evidence would point to this being caused by the different light intensities and resolution of the augmentation in comparison to the rest of the scene. Adding the barrier to the CAVE had by far the largest impact, with the MEC scores for spatial presence (possible actions and self location) and attention allocation falling substantially. The drop in the score for possible actions appears to confirm the theory that the barrier reduces the scope for actions but the affect on attention allocation requires more research.

### General Findings

From the perspective of real environments visual appropriateness and legibility are how the appearance of the environment helps people identify its uses. There were clear issues with image quality which had a direct impact on the ability to read signs or gain more information from other content. Within the probe data the issue of resolution in the CAVE (legibility) was noted by a number of participants, and seemingly on a more regular basis than for the HMD. However for both environments the lack of resolution made it difficult to read signs and hence gain a greater understanding about the content of the exhibition.

For both environments if people experienced a sense of place, this was exhibited in the data found in the structured interviews and many aspects of the place probe. It was frequently noted that people felt they were in a museum, with the main negative points being they felt they were in a computer game and that the screen resolution wasn't always very high. These combined with the general awareness of other technical issues would point to people being distracted by the medium.

## Conclusion

The studies presented in this paper have looked at the effect of changing arena and adding the graphical augmentation of a barrier to two virtual environments, a technical museum and a box world. Further work is required for example in exploring the correlations within the semantic differentials and improving the sensitivity of the measuring techniques. There is also a need to further refine how the concept of responsive environments can be used to evaluate virtual environments, and the links to place and presence.

In contrast to anecdotal evidence the CAVE did not provide the heightened sense of presence or place that we would have expected. This is especially surprising given that we would expect its immersive nature to have improved both areas. While this in part can be put down to basic technical limitations, such as the different size of pixels and lightness much of the findings can be explained in terms of the lack of how the properties map onto responsive environments. One of the major reasons being that the environment felt more distant and hence less easy to touch. The other problem area for all arenas being the implied range of movement options (paths) when in fact none were available. Both of these had the effect of implying more opportunities for movement and activities than actually existed.

The findings point to the choice of arena being an important factor in the sense of place and presence, primarily on account of the increased sense of size which people experienced in the CAVE. This points to the need to carefully consider the nature of the tasks which are likely to be undertaken in the environment and the importance of accurate distance measures. A core aspect of the expected sense of place is the ability to touch items and hence the HMD would appear to offer a better solution.

The idea of responsive environments provides a clearer method of looking for specific features within an environment and how they impact upon the sense of place, in particular aspects such as paths, activities and legibility. It clearly does not cover all aspects of the place experience but does provide a useful framework upon which arenas and environments can be explored.

**Acknowledgements**

We acknowledge the assistance of other members of the BENOGO project, in particular the staff at Aalborg University Denmark. We would also like to thank Trevor Jones and Matthew Leach for their comments on early drafts of this paper. Funding for this project was provided by the European Union under grant number IST-2001-39184.

## Appendix 1
## Semantic Differentials Tables

### 1 Technology differential (for virtual environments only)

**Did the images that were displayed seem?**

| | Very | Quite | Neither | Quite | Very | |
|---|---|---|---|---|---|---|
| Grainy | | | | | | Clear |
| Realistic | | | | | | Unrealistic |
| Unbelievable | | | | | | Believable |
| Distorted | | | | | | Accurate |
| | | | | | | |

**Table S1:** Differentials relating to image quality

**Did the movement of the images seem?**

| | Very | Quite | Neither | Quite | Very | |
|---|---|---|---|---|---|---|
| Smooth | | | | | | Jerky |
| Broken | | | | | | Unbroken |
| Slow | | | | | | Fast |
| Consistent | | | | | | Erratic |
| | | | | | | |

**Table S2:** Differentials relating to how images behaved when moving

### 2 Activity differential

**Did you feel that you were?**

| | Very | Quite | Neither | Quite | Very | |
|---|---|---|---|---|---|---|
| Passive | | | | | | Active |
| Free | | | | | | Restricted |
| Disorientated | | | | | | Oriented |
| Inside | | | | | | Outside |
| Mobile | | | | | | Immobile |

**Table S3:** Differentials relating to user activities

## 3 Space differential

**Did you feel that the environment was?**

| | Very | Quite | Neither | Quite | Very | |
|---|---|---|---|---|---|---|
| Small | | | | | | Big |
| Empty | | | | | | Full |
| Light | | | | | | Dark |
| Enclosed | | | | | | Open |
| Permanent | | | | | | Temporary |
| Colourless | | | | | | Colourful |
| Static | | | | | | Moving |
| Responsive | | | | | | Inert |
| Far | | | | | | Near |
| Untouchable | | | | | | Touchable |

**Table S4:** Differential relating to the sense of space

## 4 Affective/Meanings differential

**Did you feel that the environment was?**

| | Very | Quite | Neither | Quite | Very | |
|---|---|---|---|---|---|---|
| Ugly | | | | | | Beautiful |
| Pleasant | | | | | | Unpleasant |
| Stressful | | | | | | Relaxing |
| Harmful | | | | | | Harmless |
| Exciting | | | | | | Boring |
| Interesting | | | | | | Uninteresting |
| Memorable | | | | | | Forgettable |
| Meaningful | | | | | | Meaningless |
| Confusing | | | | | | Understandable |
| Significant | | | | | | Insignificant |

**Table S5:** Differentials relating to meanings and affect

| |
|---|
| **Q1** I devoted my whole attention to the [medium]. |
| **Q2** I concentrated on the [medium]. |
| **Q3** The [medium] captured my senses. |
| **Q4** I dedicated myself completely to the [medium]. |

**Table M1 MEC:** Attention Allocation Questions

| |
|---|
| **Q1** I was able to imagine the arrangement of the spaces presented in the [medium] very well. |
| **Q2** I had a precise idea of the spatial surroundings presented in the [medium]. |
| **Q3** I was able to make a good estimate of the size of the presented space. |
| **Q4** Even now, I still have a concrete mental image of the spatial environment. |

**Table M2 MEC:** Spatial Situation Model (SSM)

**Q1** I felt like I was actually there in the environment of the presentation.
**Q2** It was as though my true location had shifted into the environment in the presentation.
**Q3** I felt as though I was physically present in the environment of the presentation.
**Q4** It seemed as though I actually took part in the action of the presentation

**Table M3 MEC:** Spatial presence: Self Location (SPSL)

**Q1** I had the impression that I could be active in the environment of the presentation.
**Q2** I felt like I could move around among the objects in the presentation.
**Q3** The objects in the presentation gave me the feeling that I could do things with them.
**Q4** It seemed to me that I could do whatever I wanted in the environment of the presentation.

**Table M4 MEC:** Spatial Presence: Possible actions (SPPA)

**Q1** I thought most about things having to do with the [medium].
**Q2** I thoroughly considered what the things in the presentation had to do with one another.
**Q3** The [medium] presentation activated my thinking.
**Q4** I thought about whether the [medium] presentation could be of use to me.

**Table M5 MEC:** Higher Cognitive Involvement

**Q1** I concentrated on whether there were any inconsistencies in the [medium].
**Q2** I didn’t really pay attention to the existence of errors or inconsistencies in the [medium].
**Q3** I took a critical viewpoint of the [medium] presentation.
**Q4** It was not important for me whether the [medium] contained errors or contradictions.

**Table M6 MEC:** Suspension of Disbelief (SoD)

**Q1** I am generally interested in the topic of the [medium].
**Q2** I have felt a strong affinity to the theme of the [medium] for a long time.
**Q3** There was already a fondness in me for the topic of the [medium] before I was exposed to it.
**Q4** I just love to think about the topic of the[medium].

**Table M7 MEC:** Domain Specific Interest (DSI)

| |
|---|
| **Q1** When someone shows me a blueprint, I am able to imagine the space easily. |
| **Q2** It's easy for me to negotiate a space in my mind without actually being there. |
| **Q3** When I read a text, I can usually easily imagine the arrangement of the objects described. |
| **Q4** When someone describes a space to me, it's usually very easy for me to imagine it clearly. |

**Table M8 MEC:** Visual Spatial Imagery (VSI)

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