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# Virtual Laboratories: Comparability of Real and Virtual Environments for Environmental Psychology

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## Abstract

Virtual environments have the potential to become important new research tools in environment behavior research. They could even become the future (virtual) laboratories, if reactions of people to virtual environments are similar to those in real environments. The present study is an exploration of the comparability of research findings in real and virtual environments. In the study, 101 participants explored an identical space, either in reality or in a computer-simulated environment. Additionally, the presence of plants in the space was manipulated, resulting in a 2 (environment)  $\times$  2 (plants) between-subjects design. Employing a broad set of measurements, we found mixed results. Performances on size estimations and a cognitive mapping task were significantly better in the real environment. Factor analyses of bipolar adjectives indicated that, although four dimensions were similar for both environments, a fifth dimension of environmental assessment—termed *arousal*—was absent in the virtual environment. In addition, we found significant differences on the scores of four of the scales. However, no significant interactions appeared between environment and plants. Experience of and behavior in virtual environments have similarities to that in real environments, but there are important differences as well. We conclude that this is not only a necessary, but also a very interesting research subject for environmental psychology.

## 1 Introduction

Virtual environments (VEs) are applied in many areas such as entertainment, vehicle simulation, industrial and architectural design, training, and medicine (Brooks, 1999). In this paper, we argue that the use of VEs as environmental simulations may provide a valuable tool for both research and practice in environmental psychology.

A VE is an artificial world, created with computers, that can give the observer a sense of “being there” (presence) in the environment. For this, various input devices are needed to interact with or manipulate the environment (such as cursor keys, joystick, or head tracker). The artificial world can be presented visually on a desktop display, a head-mounted display, or on one or more projection displays, sometimes combined with (spatialized) audio, haptic feedback, and sometimes even scents or thermal cues. (See Ellis, 1991, for an in-depth analysis of VEs.) With the development of these types of media, the potential to provide viewers with an accurate representation of nonmediated

experience has increased significantly. These mediated environments are thus able to provoke responses and behavior similar to those portrayed in real environments (Lombard, 1995). The basis for this reasoning is the concept of behavioral realism, which is based on the premise that, as a display better approximates the environment it represents, an observer's responses to stimuli within the display will tend to approximate those that he or she would exhibit in response to the environment itself (IJsselsteijn, de Ridder, Freeman, & Avons, 2000; Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000). To procure behavioral realism, one would have to present a sensorially rich and perceptually realistic environment that facilitates natural interaction between the user and the environment (as well as objects in it). Loomis, Blascovich, and Beall (1999) argue that "the ultimate representational system would allow the observer to interact 'naturally' with objects and other individuals within a simulated environment or 'world,' an experience indistinguishable from 'normal reality'" (p. 557).

### 1.1 The Use of Simulations in Research on Environmental Psychology

Environmental psychology is the study of the molar relationships between behavior and experience and the built and natural environment (Bell, Greene, Fisher, & Baum, 2001). It deals with the reciprocal relationships between humans and their environments. The perspective many environmental psychologists take is that, because environmental effects on behavior are important, much of the research should involve naturalistic studies of behavior in environments (Bell et al., 2001). That means the settings chosen for study are likely to be outside the laboratory. However, for a variety of reasons, researchers are often not able to do research in the field. The appropriate settings may not be available, the logistics of doing a field study may be too great, or sufficient control may not be attainable (Bell et al., 2001). This is why many researchers employ environmental simulations of various kinds. By simulating the essential elements of a naturalistic setting in a laboratory, one

increases experiential realism and external validity, while experimental rigor is retained.

### 1.2 The Validity of Environmental Simulations

The term *environmental simulation* covers a wide range of different types of representations of our natural and human-made habitat. All these simulations have in common that they attempt to represent some aspects of the environment as accurately as possible to assess human responses to them. The need for more research that explores applications of perceptual simulations in general and related questions of validity and reliability has been stressed ever since the emergence of environmental simulation as a research paradigm. However, the number of validation studies has been scarce, even for the most common and traditional simulation types in the field as drawings, sketches, photographs, and slides (Bosselman & Craik, 1987).

In the history of environment behavior studies, the most extensive effort to validate an environmental simulation (in this case a physical scale model of a site in Marin County, including a broad array of land uses) was the Berkeley Environmental Simulation Project (Appleyard & Craik, 1978; Bosselman & Craik, 1987). Few other studies offer comparisons between physical models and the real setting (Hunt, 1984; Kaplan, Kaplan, & Deardorff, 1974; Seaton & Collins, 1972). In reviewing the material, Kaplan (1993) concludes that there is insufficient empirical evidence to conclude that simulations elicit identical reactions to those in real-world settings. In the past, the greatest emphasis has been on static modes of simulation (such as photographs, sketches, slides, and mock-ups). In their review, Craik and Feimer (1987) conclude that the small number of systematic studies with dynamic simulations suggest that descriptive and evaluative responses are comparable to those obtained for direct, on-site presentations. However, evidence concerning cognitive and behavioral responses is less clear.

Knowledge does exist regarding the validity of more conventional types of simulation and presentation in this field: photographs and slides. For instance, based

on a meta-analysis of eleven papers, Stamps (1990) concludes that there are strong relationships between preferences obtained in the environment and preferences obtained through photographs. Others have shown that viewing (nature) pictures has physiological effects that are similar to the experience of natural environments (Ulrich et al., 1991), and that (for a simple service setting, more specifically a railway ticket office) slides evoked the same psychological and behavioral phenomena (related to consumer density) as did the actual setting (Bateson & Hui, 1992). Some, however, have reported contradictory findings (Brown, Richards, Daniel, & King, 1989; Gale, Golledge, Pellegrino, & Doherty, 1990; Hull & Stewart, 1992). One must conclude that, in view of the frequent use of simulations in environmental psychology, too little research efforts have been invested in studying their validity and generalizability to real environments.

Simulations of urban or natural environments created by graphics computer software are increasingly being used, not only in applied contexts, but for research purposes as well (Custers, Aarts, & Timmermans, 2001; Ishikawa, Okabe, Sadahiro, & Kakumoto, 1998; Lombard & Ditton, 1997). However, the quality and utility of such presentation means still need careful validation. For an environmental simulation to be considered valid, it should evoke a similar set of responses as would a direct experience of the same environment (Rohrmann & Bishop, 2002). Although some studies have focused on people's assessments of computer-simulated environments and related visualization techniques (Bergen, Ulbricht, Fridley & Garter, 1995; Daniel & Meitner, 2001; Decker, 1994; Oh, 1994), we know of no other research examining the validity of evaluative and cognitive assessments of interactive virtual environments for research purposes by comparing these assessments to those in real environments.

One of the major problems in the validation of simulations is the fact that progress in environmental psychology has not yielded a comprehensive array of standard response measures (Bosselman & Craik, 1987). The Berkeley Project used numerous response formats (among others, mood checklists, map sketches, environmental adjective checklists, information and recognition

tasks, and environmental evaluations) (Appleyard & Craik, 1978; Bosselman & Craik, 1987). Other studies comparing physical models with real settings (Hunt, 1984; Kaplan et al., 1974; Seaton & Collins, 1972) use a quite different choice of dependent variables. At present, there is no standard set of response measures, although some measurement instruments are used more often than others. For instance, the use of semantic differentials and sketch maps is quite common (Canter, 1991). Interestingly, Billinghamurst and Weghorst (1995) have shown that sketch maps provide a valid measure of internal cognitive maps of virtual environments.

### **1.3 The Utility of Virtual Environments as Simulations**

The utility of any simulation type or technique depends on the context in which it is used, but VEs hold important qualities for use as simulations of the physical environment in diverse areas: they are dynamic and perceptually rich, sometimes even multimodal, three-dimensional, and interactive.

Catalano and Arenstein (1993) point out the danger of the use of purely visual, high-quality images as simulations, for instance in community development processes. They argue that an important problem is that new simulation technologies, giving more weight to the "profound sensation of aesthetic effects" may involuntarily increase the weight that people place on these effects in comparison to other outcomes. This would plead for simulations that perhaps are somewhat less vivid and rich than reality with regard to visual sensations, but that afford different types of experience with the future environment. By virtue of its characteristics, a VE affords more possibilities for meaningful interaction and walkthrough experiences than many other types of simulations. This would offer greater attention to, for instance, contextual qualities, social amenities, accessibility, and functionality.

The use of VEs can increase the power of experimental research by providing both high ecological validity and experimental control (Loomis et al., 1999; Rose & Foreman, 1999). Frank Biocca phrases this elegantly:

If virtual environments are technologies of the mind, then advanced media environments may be to the mind, like cyclotrons are to physics. In cyclotrons, engineers whirl atoms through space to see something essential about their structure. Advanced virtual environment engineers may whirl minds through cyberspace to understand something fundamental about the structure of experience—in a word consciousness (Biocca, 2002 p. vi).

If this is true, this should certainly hold for the sub-domain in which the interaction between individuals and their physical environment is the central object of study: environmental psychology.

Even though simulation and interaction technology have been developing at a steady pace towards a more realistic experience, a few major shortcomings still lead to differences in perception between real and virtual environments. For instance, although in some domains multimodal VEs are quite common, when used for architectural and related environment-behavior purposes, perception in many VEs is unimodal: only the visual sense is stimulated. Because the physical body is absent, there is no correspondence between what the user sees and the movement and position of the body (although sometimes a virtual body is generated to overcome this limitation). Aspects of the VE itself, like the resolution of the projection and the level of detail, also differ from the real environment. Another important difference is that technical devices are necessary to navigate through a VE, which can make the experience even more unnatural. (For example, Usoh et al., 1999 found that reported presence was higher for real walking than for virtual walking and flying in a VE, and Hendrix and Barfield, 1996, showed that head tracking can lead to an increased sense of presence in a virtual environment.) All of these aspects contribute to the fact that the experience of a virtual environment differs from the real environment.

Whether research in VEs will—to a smaller or larger degree—substitute for research in the real world remains to be seen and will definitely require significant progress in technology and a more thorough understanding of the human factors issues involved. (With

complex VEs, end-to-end system latency—the latency between user motion and its representation to the visual system—is still the major technical limitation [Brooks, 1999].) However, the fact that VR technology has already been embraced by large numbers of professionals in design urgently calls for research to increase our understanding of person-environment transactions in virtual worlds.

#### 1.4 Rationale of Study

The present study is the first general exploration of the comparability of research findings in real and virtual environments within the domain of environmental psychology. Some related research was found in other scientific domains. For instance, in discussing the literature on filmed and televised presentations, Lombard (1995) states that there is some compelling empirical evidence that media users react to televised presentations in some of the same ways that they react to non-mediated events, objects, and people despite the fact that mediated presentations provide a limited reproduction of the nonmediated experience. One qualitative study by Murray, Bowers, West, Pettifer, and Gibson (2000) suggested a continuous relationship between real and virtual worlds based on an analysis of the interaction of people with a virtual city: participants were seen to attribute real-world properties and expectations to the contents of the virtual world. However, besides reported similarities between reactions to nonmediated and mediated events, and between real and virtual environments, important differences are also reported; for example, navigation within VEs is not as simple as in the real world and can lead to a higher tendency of a user becoming lost (Witmer, Bailey, Knerr, & Parsons, 1996). There is considerable knowledge on basic task performance in virtual environments and differences with that in real environments (such as discrimination and recognition, tracking, and distance judging). For a review, see Nash, Edwards, Thompson, and Barfield (2000). For instance, egocentric distance estimations in virtual environments are quite poor (Ellis & Menges, 1997; Hu et al., 2000; Willemsen & Gooch, 2002; Witmer & Kline, 1998) although haptic size identification

and discrimination performance is quite comparable in real and simulated environments (O'Malley, Kilchenman, & Goldfarb, 2002)—most of these studies employed head-mounted displays. Moreover, experience and performance on tasks is likely influenced by various characteristics of the simulation, cues, and interaction devices (Cutting & Vishton, 1995; IJsselsteijn et al., 2000; IJsselsteijn, de Ridder, Freeman, Avons, & Bouwhuis, 2001; Janzen, Schade, Katz, & Herrmann, 2001; Riecke, Van Veen, & Bülthof, 2002; Wanger, Ferwerda, & Greenberg, 1992; Witmer & Kline, 1998; Nash et al., 2000).

The sense of presence is the defining experience for virtual reality (Steuer, 1992). Lombard & Ditton (1997) define presence as the “perceptual illusion of non-mediation,” that is, the extent to which the person fails to perceive or acknowledge the existence of a medium during a technologically mediated experience. IJsselsteijn et al. (2000) suggest that four types of factors are thought to underlie presence: the extent and fidelity of sensory information, the match between sensors and the display, content factors, and user characteristics.

The basis for the evaluation of realism in a simulation is a comparison of responses to real places and simulated places (Bosselman, 1993). The aim of the present study therefore is to compare environmental evaluation and cognitive mapping performance in a real-world environment with those in an accurate computer simulation of that environment. Because this was an exploratory study and for want of a standard set of measurements, we employed a broad and fairly general set of measurements including estimations of sizes and heights (tapping metric knowledge), a cognitive mapping task (tapping topological knowledge of the environment), subjective evaluations of the environment using bipolar adjectives, and qualitative analyses of perceived (behavioral) functions afforded by the environment.

In addition to comparing the two environments directly, we set out to compare the influence of a subtle change in these environments, that is, the presence or absence of plants. Plants were chosen to serve as manipulation, because these were both available in the real environment and technically manageable in the VE. Research has shown that adding plants enhances evaluative

assessments of interiors (Larsen, Adams, Deal, Kweon, & Tyler, 1998; Ornstein, 1992). The expectation was that participants would evaluate both types of environment more positively for the situation with plants than without plants. We expected to find some differences in scores between the real world and the virtual world because the real world is always richer with stimulation and because interaction with it is more natural than interaction with a virtual environment. However, we did not expect that this would cause differences in the effects of the additional presence-of-plants manipulation for the two worlds. Our research questions therefore are as follows. In what ways do size and height estimations, cognitive mapping, environmental evaluations, and perceived affordances differ in a real environment (RE) and a VE? And in what ways does the effect of a subtle change in this environment—the addition of plants—on these responses differ between a real environment and its accurate computer simulation?

## 2 Method

### 2.1 Participants and Design

A total of 101 participants (students and recent graduates of various disciplines) were recruited for the experiment via email and poster announcements at the Technische Universiteit Eindhoven. Respondents' ages ranged between 18 and 35 years ( $M = 23.1$ ). Every participant received 7.5 Dutch guilders for their cooperation (equivalent to \$4). The participants were randomly distributed over the four experimental conditions following a 2 (environment: real (RE) vs. virtual (VE))  $\times$  2 (Plants: yes vs. no) between-subjects design, as shown in Table 1.

### 2.2 Materials and Apparatus

The environment in the study was the main hall of the Multimedia Pavilion, a building on the premises of the university that was recently renovated (1999). Only few students ever go there. The fairly new building houses several small companies and has an interesting and colorful design and interior. The L-shaped hall

**Table 1.** *Experimental Design*

Environment	Plants			
	Yes		No	
	N	male/female	N	male/female
real	26	16/10	23	12/11
virtual	26	17/9	26	17/9

measures approximately 400 sq. m. In the “with plants” condition, ten tall rubber plants were placed in the hall (similar places in VE and RE). Figure 1 shows similar views into the building taken in the RE and the VE, respectively.

Calibre BV supplied the equipment and the simulation of the environment. The hardware consisted of a Silicon Graphics Onyx2 Infinite Reality Station, with 2×MIPS R10000 processors, 1 GB internal memory, two Geometry Engines, and one raster manager, a back projection screen (2.40×1.70 m) with Barco 1208 data projector, and a BG-systems Flybox, twelve-button professional serial joystick with 3 degrees of freedom. We used dvMockup simulation software from PTC-Division with plug-ins and adjustments by Calibre.

### 2.3 Procedure

Participants were received in a building adjacent to the Multimedia Pavilion and were taken to the pavilion by a research assistant. There, they were guided either to the main hall or the demonstration room, depending on the experimental condition (RE vs. VE, respectively). Participants in the VE condition did not see the main hall in reality. The experiment was conducted in the evening, so there would be no people working in the offices in the same building, and lighting conditions could be controlled.

Participants explored the main hall of the Multimedia Pavilion, either in the RE or the VE, and either with or without plants. All participants were told the experiment involved multifunctional environments, and they were asked to explore the space very carefully and to imagine

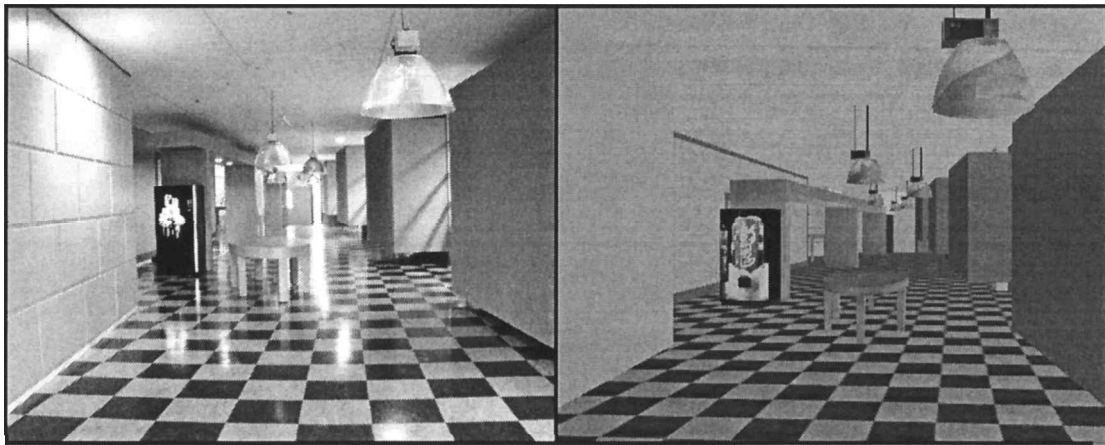
what functions the space could have. The starting point was the same for both RE and VE. After 3.5 min., participants were given a signal whereupon they returned to the starting point. Subsequently they completed a questionnaire.

Prior to their exploration, participants in the VE received short instruction to help them navigate in a (different) VE using the joystick. They were located at a distance of 1.5 m from the screen, and the eye-to-floor distance was set at 1.65 m for every participant (the average human eye-to-floor distance). The horizontal visual angle was 77°. Participants in the VE were specifically asked not to judge the simulation, but the environment.

The questionnaire consisted of five parts (in the order as they appeared in the study):

- (1) basic descriptive data;
- (2) a semantic differential scale, which consisted of 29 bipolar adjective six-point items (listed in Table 2);
- (3) height and color estimations, where participants were asked to estimate the heights of the room and the doors, both with a margin of 10 cm, and to choose the colors of the checked floor from a sample of thirteen colors;
- (4) perceived affordances of the space (they listed the functions they thought the space could provide (“afford”); and
- (5) sketch maps (a cognitive mapping task).

In this phase, participants were asked to draw a map of the environment they had explored as precisely and correctly as possible. The sketches were evaluated independently afterwards by three raters (blind to experimental conditions) on five different five-point scales: completeness of sectioning of the space, correctness of relative proportions, number of omissions and augmentations, correctness of curved and sloping parts, and a general score for the sketch as a whole. The inter-rater reliability for these five items was analyzed using Cronbach’s alpha, which showed that all values were satisfactory (.90, .85, .89, .85, and .93, respectively). Averaged scores of the three observers’ ratings are used in subsequent analyses. We checked whether participants had



**Figure 1.** Real and virtual environment. Left picture was taken at daytime, but the study was performed in the evening, with similar types and levels of lighting for RE and VE.

seen the building before, but no one had. The visit lasted 30 min.

### 3 Results

The primary statistical procedures used to analyze the data were analyses of variance (ANOVAs) and principal components factor analysis. In this section, we will first report the results relating to the performance measures (that is, estimations and cognitive mapping), then those related to the evaluative measures (evaluations and perceived affordances).

#### 3.1 Estimations

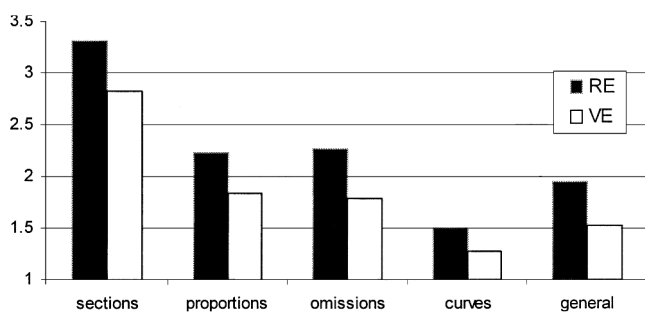
Participants made estimations of the height of the room and the doors. These are shown in Figure 2. Differences were tested with two full-model ANOVAs with door height and room height as dependent variables. Both scores were significantly different for the two levels of Environment ( $F(1,97) = 4.26; p = .042$ ; partial eta sq = .042 and  $F(1,96) = 35.18; p < .001$ ; partial eta sq = .268, respectively). Participants in the RE made estimations that were more accurate than those in the VE. Participants in the VE tended to underestimate the heights of the doors and the room, which are unusually



**Figure 2.** Scores on the height estimations of doors and room for both levels of environment and plants.

high in this building. There was no significant main effect of plants. However, for the scores of door height, a significant interaction appeared,  $F(1,97) = 3.98; p = .049$ ; partial eta sq = .039. This interaction reflected no effect of environment in the “with plants” condition but a strong effect of environment in the “without plants” condition.

Participants also had to judge the colors of the checkered floor: they chose two colors from thirteen samples. They received two points for choosing one of the exact colors, one point for a color that came close to the exact color, and zero points for the other colors. Participants’ scores (ranging between 0 and 4) were analyzed with a Mann-Whitney U-test, which indicated that there



**Figure 3.** Scores on the scales judging participants' sketch maps for both environments.

was no significant difference regarding this measure for the different media ( $U = 1137.5$ ,  $N = 100$ , and  $p = .420$ ). In other words, participants in the RE did not perform better than participants in the VE.<sup>1</sup>

### 3.2 Cognitive Mapping: Sketch Maps

Participants' sketch maps of the environment were assessed on five scales: completeness of sectioning of the space, correctness of relative proportions, number of omissions and augmentations, correctness of curved and sloping parts, and a general score for the sketch as a whole. A factor analysis was performed that indicated that these five variables could be reduced to one variable. The reliability of this scale was high, with Cronbach's alpha = 0.89. The means are shown in Figure 3.

An ANOVA using environment and plants as independent variables and the average score for the cognitive mapping task as the dependent variable revealed a significant difference between the RE and the VE— $F(1,97) = 7.696$ ,  $p = .007$ , partial eta sq = .074—indicating that the sketch maps of participants in the RE were more complete and correct than those of participants in the VE. The remaining effects were not significant.

<sup>1</sup>A similar ANOVA also did not show significant differences ( $F(1,98) = 0.88$ , n.s.).

### 3.3 Environmental Evaluation: Bipolar Adjectives

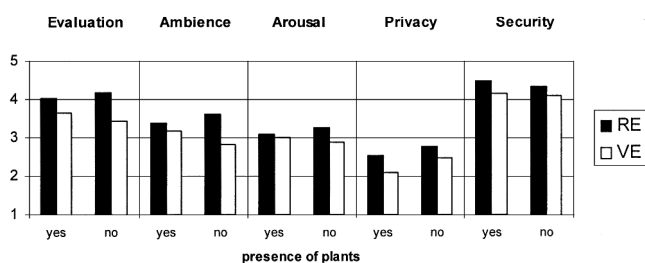
To study environmental evaluation, we performed factor analyses with varimax rotation of the 29 bipolar adjective items and developed indices for the complete sample and for the VE and RE conditions separately. A five-factor solution was chosen in the RE. We termed these factors *evaluation*, *ambience*, *arousal*, *privacy*, and *security*. In the VE, a four-factor solution was chosen. Component loadings for the two types of environment separately are reported in Table 2. Three factors were almost identical for RE and VE: evaluation, privacy, and security. The fourth factor in the VE was similar to the ambience factor in the RE, but consisted of two additional items (calm-busy and monotone-varied). In the RE, these items were clustered with items related to symmetry and legibility of the space and with the item chaotic-ordered. This did not occur in the VE. Forcing a five-factor solution for the VE (or a four-factor solution for the RE) did not result in better interpretable data.

It was decided to compute the scales for all the data based on the five-factor solution in the RE. This solution was clear and based on assessment in an actual environment. Reliability analyses were performed for the complete sample. This resulted in satisfactory to high reliabilities for the complete sample (Cronbach's alpha = .64 – .91). The alpha values for the five scales for both environments separately are reported in Table 2. Next, the scores on these five scales were analyzed with separate ANOVAs using environment and plants as independent variables. This resulted in modest but significant effects of environment on evaluation— $F(1,95) = 9.51$ ,  $p = .003$ , partial eta sq = .09; ambience— $F(1,96) = 8.05$ ,  $p = .006$ , partial eta sq = .08; privacy— $F(1,96) = 5.08$ ,  $p = .026$ , partial eta sq = .05; and security— $F(1,97) = 4.07$ ,  $p = .046$ , partial eta sq = .04. All scores were higher in the RE condition. (See Figure 4.) The effect of plants yielded only a marginally significant effect for privacy— $F(1,97) = 3.61$ ,  $p = .06$ , partial eta sq = .04—resulting in higher scores (more privacy) in the no-plants condition. No

**Table 2.** *Bipolar Adjective Items. Component Loadings after Varimax Rotation and Scale Reliabilities*

	Real environment					Virtual environment				Total
	1	2	3	4	5	1	2	3	4	
Evaluation	<b>.92</b>					<b>.89</b>				<b>.91</b>
ugly–beautiful	<b>.88</b>					<b>.85</b>				
tasteless–tasteful	<b>.79</b>					<b>.69</b>				
unpleasant–pleasant	<b>.77</b>					<b>.79</b>				
boring–interesting	<b>.72</b>	.45				<b>.75</b>				
unattractive–attractive	<b>.65</b>	.44				<b>.64</b>			.40	
meaningless–impressive	<b>.63</b>	.43				<b>.75</b>				
uninviting–inviting	<b>.49</b>	.43			.47	<b>.58</b>				
artificial–natural	<b>.47</b>	.37				<b>.58</b>			.36	
gloomy–cheerful	<b>.61</b>	.43				.39	<b>.54</b>			
Ambience		<b>.84</b>					<b>.82</b>			<b>.84</b>
impersonal–personal		.74				.39	.73			
cold–warm	.16	<b>.74</b>				.65	<b>.54</b>			
gray–colorful		.72				.41	<b>.51</b>			
business-like–playful		.71					<b>.68</b>			
not cozy–cozy	.39	<b>.68</b>				.46	<b>.54</b>			
bare–decorated	.36	<b>.55</b>				.36	<b>.50</b>			
Arousal			.77				<b>.56</b>			<b>.68</b>
chaotic–ordered			<b>.87</b>				.44		–.59	
asymmetrical–symmetrical			.72					–.49		
illegible–legible			.71					–.74	–.39	
calm–busy			<b>.55</b>		–.48		.77			
monotone–varied	.37	.40	<b>.49</b>			.46	<b>.54</b>			
Privacy				.73				.53		<b>.64</b>
public–private				<b>.82</b>				<b>.59</b>	–.40	
common–individual				.74			–.40	<b>.58</b>		
open–enclosed	–.39			<b>.65</b>				<b>.36</b>		
light–dark	–.48			<b>.57</b>				<b>.46</b>		
Security					.72				.66	<b>.70</b>
scary–relaxing	.47				<b>.70</b>				<b>.68</b>	
unsafe–safe		.37			<b>.65</b>				<b>.66</b>	
inaccessible–accessible				–.44	<b>.59</b>				<b>.59</b>	
threatening–protecting		<b>.53</b>			.26		.40		<b>.66</b>	
Not included										
quiet–lively		.45	<b>.50</b>		–.43		.61			

Results are reported for RE and VE groups separately. All component loadings  $> .35$  are reported. Highest loadings for every analysis are printed in bold. Scale reliability: Cronbach's alpha is reported for every scale. The item "quiet–lively" was not included in any of the scales because it decreased scale reliability.



**Figure 4.** Scores on the five evaluative scales for both levels of environment and plants.

significant interactions between environment and plants appeared.

### 3.4 Perceived Affordances

Participants listed the functions they thought the space could afford. These functions were categorized and counted by an independent rater who was blind to the experimental conditions. The categories and their frequencies are reported in Table 3. Participants in the RE condition listed significantly more functions ( $M = 3.2$ ) than did participants in the VE condition ( $M = 2.7$ ):  $F(1,99) = 5.15$ ,  $p = .025$ , partial eta sq = .XX. Chi-square values were calculated and resulted in significant differences between the real and VE for functions related to offices and education (participants reported these functions more often in the VE) and for functions related to social gatherings (these were reported more frequently in the RE). No significant differences were found between the with- and without-plants conditions.

## 4 Discussion

The goal of the present study was to explore the comparability of research findings in real and virtual environments (RE vs. VE). Employing a broad set of measurements, we found mixed results. Performance measures (height estimations and a cognitive-mapping task) were significantly better in the RE than in the VE. Differences also appeared for environmental evaluations and perceived affordances.

**Table 3.** Frequency of Perceived Affordances of the Space as Perceived and Listed by Participants

	Environment		Chi	Sig
	Real	Virtual		
Coffee or lunch breaks	27	20	2.81	n.s.
Passage/corridor	22	22	.21	n.s.
Reception/meeting place	20	19	.06	n.s.
Socials gatherings	27	9	22.99	< .001
Offices	8	26	12.81	< .001
Waiting	15	8	3.33	n.s.
Education	2	16	12.27	< .001
Expositions	7	2	—	
Public/municipal space	1	7	—	
Foyer theatre	4	1	—	
Library	1	2	—	
Hospital	2	1	—	
Apartments	2	1	—	

Chi-square was not computed for functions with total  $N < 10$ .

### 4.1 Performance Measures: Estimations and Sketch Maps

Participants in the RE made height estimations that were more accurate than those in the VE. Participants in the VE tended to underestimate the heights of both the doors and the room. These findings correspond to findings on egocentric distance estimations in VE that are also systematically underestimated. It seems likely that these processes are similar, although these studies generally employed head-mounted displays and involved horizontal distance estimates (Ellis & Menges, 1997; Hu et al., 2000; Willemsen & Gooch, 2002; Witmer & Kline, 1998).

The interaction between environment and plants on the estimation of door height indicated that perhaps the plants served as a familiar-size cue in height perception for participants in the VE. This effect did not appear in the RE. People in the RE probably used their own

height as a cue, whereas participants in the simulation did not. The findings are somewhat ambiguous, especially because the plants did not serve as a cue in the estimation of the height of the room, but perhaps the plants were too small (relative to the height of the space) for that purpose.

For the cognitive mapping task, participants in the RE performed significantly better than those in the VE: their sketch maps were more complete and correct. Several reasons can be given to explain these findings. One explanation could be that the cognitive load posed by the medium of virtual reality itself and operating the joystick for navigation. However, we feel that this load was only minimal. A second possibility is that these differences are attributable to the relatively small field of view in the VE. Venturino and Wells (1990) argue that this allows the user to integrate smaller amounts of spatial information at a time. Thirdly, the unnaturalness of navigating through a VE—using a joystick—may make it more difficult to infer spatial information and create an accurate overall image of the environment. We conclude that these findings call for additional research in which the role of these possible determinants can be investigated.

#### **4.2 Evaluation: Bipolar Adjectives and Perceived Affordances**

Evaluation of the environment as measured with 29 bipolar adjective items resulted in five connotative dimensions in the RE. We termed these factors *evaluation*, *ambience*, *arousal*, *privacy*, and *security*. In spite of the differences in factor structures (which are discussed in subsection 4.3), five identical scales were computed for both environments. For these dimensions, significant differences were found between the two environments on all scales except the arousal scale. Participants evaluated the RE more positively on evaluation, ambience, privacy, and security. Differences could be due to the lower level of experiential realism in the VE and the quality and vividness of the simulation, which, in spite of its sophistication, is lower than that of real environments. The differences in the scores for these dimensions were also reflected in the perceived affordances:

social gatherings were mentioned more frequently in the RE, and more-formal activities were mentioned less frequently there.

#### **4.3 Utility of VEs as Virtual Laboratories**

The second main research question of the present study was “In what ways does the effect of a subtle change in this environment—that is, the addition of plants—on these responses differ between a real environment and its accurate computer simulation?” Two aspects are relevant in this respect. First, it is imperative that effects of manipulations in real and simulated environments are equal, as was generally the case in the present study. Only one significant difference arose between the two media with regard to the presence or absence of plants. However, the plant manipulation may have been too subtle because it showed only one marginally significant main effect (for the privacy scale).

Second, it is relevant to determine the similarity of the nature of environmental perception and experience as for instance reflected in the factor structure of the bipolar adjective items. Whereas five factors appeared in the RE, only four dimensions appeared in the VE; the arousal dimension was absent there. Some of the items clustered with ambience, and the others with privacy and security. The differing factor structures between real and virtual environments seem to support the idea of different ways of looking at and making sense of environments. On the other hand, one could also argue that the fact that four out of five dimensions were very similar looks promising.

We must note here that a similarity—or dissimilarity—in factor structure across media conditions itself grants no assurance that specific research sites will be described or evaluated comparably (Craik & Feimer, 1987). Furthermore, it should be noted that conclusions based on factor analyses with only one type of environment are somewhat premature. Strong conclusions should be drawn only after analyzing a broader set of environments, both in reality and virtual reality. It will be interesting to pursue these issues in future investigations.

#### 4.4 Presence

It would be both interesting and wise to study the mediating role of presence in this line of research. Presence is probably related to lower levels of cognitive load for navigation purposes and the medium itself. Secondly, it is a strong indicator of “experiential realism” (IJsselsteijn et al., 2000), which could be an important determinant of the comparability of the subjective evaluations and perceived affordances between real and virtual environments and thus a key factor in the validity and generalizability of research findings from virtual to real environments.

In the present study, we have used a rather sophisticated simulation of the physical environment. However, the simulation was unimodal and presented on one screen. The importance of sound and haptics and more-intuitive interaction and navigation devices (HMD, actual locomotion, and so on) for the sense of presence has been speculated on and documented (IJsselsteijn et al., 2000, Lombard & Ditton, 1997; Nash et al., 2000). It is very likely that this would also greatly improve the comparability of experience and interpretation of virtual environments.

The relevance of presence in the context of environmental psychology research with VEs calls for a measuring instrument that could be used in both real and virtual environments. The authors are currently in the process of developing such an instrument.

#### 5 Conclusion

The experience in a VE is different from that in a RE in several ways. The main differences reported in the present study are those related to the problems in integrating spatial information to configurational knowledge of the space. The present study also showed modest but significant differences in evaluations between a virtual and the real environment.

In spite of the reported differences, there probably are numerous situations in which VEs better approximate perception of and interaction with spatial and architectural features of naturally occurring settings than other

simulation types (such as drawings, scale models, or slides) and offer ample means to carefully register and study behavior in environments. We conclude that it is highly interesting to pursue this type of research, not only because of the possible benefits of the future use of VEs as research instruments, but also because VEs and people’s experience of and interaction with them are interesting research objects in themselves. We argue that VEs could prove a valuable simulation technique for a broad range of scientific and applied projects once we have discovered its basic requirements for valid research findings.

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#### References

- Appleyard, D., & Craik, K. H. (1978). The Berkeley Environmental Simulation Laboratory and its research programme. *International Review of Applied Psychology*, 27, 53–55.
- Bateson, J. E., & Hui, M. K. (1992). The ecological validity of photographic slides and videotapes in simulating the service setting. *Journal of Consumer Research*, 19(2), 271–281.
- Bell, P. A., Greene, T. C., Fisher, J. D., & Baum, A. (2001). *Environmental Psychology*, (5th ed.). Fort Worth: Harcourt College Publishing.
- Bergen, S. D., Ulbricht, C. A., Fridley, J. L., & Ganter, M. A. (1995). The validity of computer-generated graphic images of forest landscape. *Journal of Environmental Psychology*, 15(2), 135–146.
- Billinghurst, M., & Weghorst, S. J. (1995). The use of sketch maps to measure cognitive maps of virtual environments. Proceedings of the IEEE 1995 Virtual Reality International Symposium, 40–47.
- Biocca, F. (2002). Preface. In G. Riva, F. Davide, & W. A. IJsselsteijn (Eds.), *Being there: Concepts, effects and measurements of user presence in synthetic environments* (vol. 5.). Amsterdam: IOS Press.

- Bosselman, P. (1993). Dynamic simulations of urban environments. In R. W. Marans & D. Stokols (Eds.), *Environmental simulation: Research and policy issues* (pp. 279–302). New York: Plenum Press.
- Bosselman, P., & Craik, K. H. (1987). Perceptual simulations of environments. In R. B. Bechtel, R. W. Marans, & W. Michelson (Eds.), *Methods in environmental and behavioral research* (pp. 162–190). New York: Van Nostrand Reinhold Company.
- Brooks, F. P. (1999). What's real about virtual reality. *IEEE Computer Graphics and Applications*, 19(6), 16–27.
- Brown, T. C., Richards, M. T., Daniel, T. C., & King, D. A. (1989). Recreation participation and the validity of photo-based preference judgments. *Journal of Leisure Research*, 21(1), 40–60.
- Canter, D. (1991). Understanding, assessing, and acting in places: Is an integrative framework possible? In T. Gärling & G. W. Evans (Eds.), *Environmental cognition and action: An integrated approach* (pp. 191–209). Oxford: Oxford University Press.
- Catalano, R., & Arenstein, W. (1993). Strategies of environmental simulation: Theoretical, methodological, and policy issues. In R. W. Marans & D. Stokols (Eds.), *Environmental Simulation: Research and Policy Issues* (pp. 303–313). New York: Plenum Press.
- Craik, K. H., & Feimer, N. R. (1987). Environmental assessment. In D. Stokols & I. Altman (Eds.), *Handbook of Environmental Psychology* (pp. 891–918). Chichester: Wiley-Interscience.
- Custers, R., Aarts, H., & Timmermans, H. (2001). Evaluaties van de gebouwde omgeving: Het effect van impressieformatiedoelen op de relatie tussen geheugen en oordeel [Evaluations of built environments: The effect of impression formation goals on the relationship between memory and assessment]. *Sociale Psychologie & haar toepassingen*, XV, 9–21.
- Cutting, J. E., & Vishton, P. M. (1995). Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth. In W. Epstein & S. Rogers (Eds.), *Perception of Space and Motion* (pp. 69–117). *Handbook of perception and cognition* (2nd ed.). San Diego: Academic Press.
- Daniel, T. C., & Meitner, M. M. (2001). Representational validity of landscape visualizations: The effects of graphical realism on perceived beauty of forest vistas. *Journal of Environmental Psychology*, 21(1), 61–72.
- Decker, J. (1994). The validation of computer simulations for design guideline dispute resolution. *Environment and Behavior*, 26, 421–443.
- Ellis, S. R. (1991). Nature and origin of virtual environments: A bibliographical essay. *Computer Systems in Engineering*, 2, 321–346.
- Ellis, S. R., & Menges, B. M. (1997). Judgments of the distance to nearby virtual objects: interaction of viewing conditions and accommodative demand. *Presence: Teleoperators and Virtual Environments*, 6(4), 452–460.
- Freeman, J., Avons, S. E., Meddis, R., Pearson, D. E., & IJsselsteijn, W. A. (2000). Using behavioral realism to estimate presence: A study of the utility of postural responses to motion stimuli. *Presence: Teleoperators and Virtual Environments*, 9, 149–164.
- Gale, N., Gollidge, R. G., Pellegrino, J. W., & Doherty, S. (1990). The acquisition and integration of root knowledge in an unfamiliar neighborhood. *Journal of Environmental Psychology*, 10(1), 3–25.
- Hendrix, C., & Barfield, W. (1996). Presence within virtual environments as a function of visual display parameters. *Presence: Teleoperators and Virtual Environments*, 5(3), 290–301.
- Hu, H. H., Gooch, A. A., Thompson, W. B., Smits, B. E., Rieser, J. J., & Shirley, P. (2000). Visual cues for imminent object contact in realistic virtual environments. *IEEE Visualization Proceedings of the Conference on Visualization '00*, 179–185.
- Hull, R. B., & Stewart, W. P. (1992). Validity of photo-based scenic beauty judgments. *Journal of Environmental Psychology*, 12(2), 101–114.
- Hunt, M. E. (1984). Environmental knowing without being there. *Environment and Behavior*, 16, 307–334.
- IJsselsteijn, W. A., de Ridder, H., Freeman, J., & Avons, S. E. (2000). Presence: Concept, determinants and measurement. *Proceedings of the SPIE*, 3959, 520–529.
- IJsselsteijn, W. A., de Ridder, H., Freeman, J., Avons, S. E., & Bouwhuis, D. (2001). Effects of stereoscopic presentation, image motion, and screen size on subjective and objective corroborative measures of presence. *Presence: Teleoperators and Virtual Environments*, 10(3), 298–311.
- Ishikawa, T., Okabe, A., Sadahiro, Y., & Kakumoto, S. (1998). An experimental analysis of the perception of the area of an open space using 3-D stereo dynamic graphics. *Environment and Behavior*, 30(2), 216–234.
- Janzen, G., Schade, M., Katz, S., & Herrmann, T. (2001). Strategies for detour finding in a virtual maze: The role of

- the visual perspective. *Journal of Environmental Psychology*, 21, 149–163.
- Kaplan, R. (1993). Physical models in decision making for design: Theoretical and methodological issues. In R. W. Marans & D. Stokols (Eds.), *Environmental Simulation: Research and Policy Issues* (pp. 61–86). New York: Plenum Press.
- Kaplan, R., Kaplan, S., & Deardorff, H. L. (1974). The perception and evaluation of a simulated environment. *Man-Environment Systems*, 4, 191–192.
- Larsen, L., Adams, J., Deal, B., Kweon, B.-S., & Tyler, E. (1998). Plants in the workplace: The effects of plant density on productivity, attitudes and perceptions. *Environment and Behavior*, 30, 261–281.
- Lombard, M. (1995). Direct responses to people on the screen: Television and personal space. *Communication Research*, 22(3), 288–324.
- Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of Computer Mediated Communication*, 3(2), [on-line]. Available: <http://www.ascusc.org/jcmc/vol3/issue2/Lombard.html>.
- Loomis, J. M., Blascovich, J. J., & Beall, A. C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behaviour Research Methods, Instruments, & Computers* 1999, 31(4), 557–564.
- Murray, C. D., Bowers, J. M., West, A., Pettifer, S., & Gibson, S. (2000). Navigation, wayfinding, and place experience within a virtual city. *Presence: Teleoperators and Virtual Environments*, 9(5), 435–447.
- Nash, E. B., Edwards, G. W., Thompson, J. A., & Barfield, W. (2000). A review of presence and performance in virtual environments. *International Journal of Human-Computer Interaction*, 12, 1–41.
- Oh, K. (1994). A perceptual evaluation of computer-based landscape simulations. *Landscape and Urban Planning*, 28, 201–216.
- O'Malley, M., & Goldfarb, M. (2002). Comparison of human size identification and discrimination performance in real and simulated environments. Proceedings of the IEEE 10<sup>th</sup> International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, *Haptics 2002*, pp. 10–17.
- Ornstein, S. (1992). First impressions of the symbolic meanings connoted by reception area design. *Environment and Behavior*, 24(1), 85–110.
- Rohrmann, B., & Bishop, I. (2002). Subjective responses to computer simulations of urban environments. *Journal of Environmental Psychology*, 22, 319–331.
- Riecke, B. E., Van Veen, H. A. H. C., & Bülthof, H. H. (2002). Visual homing is possible without landmarks: A path integration study in virtual environments. *Presence: Teleoperators and Virtual Environments*, 11(5), 443–473.
- Rose, D., & Foreman, N. (1999). Virtual reality. *The Psychologist*, 12(11), 550–554.
- Seaton, R. W., & Collins, J. B. (1972). Validity and reliability of ratings of simulated buildings. In W. J. Mitchell (Ed.), *Environmental Design: Research and Practice* (pp. 6-10-1–6-10-12). Washington, D.C.: EDRA.
- Stamps, A. E. (1990). Use of photographs to simulate environments: A meta-analysis. *Perceptual and Motor Skills*, 71, 907–913.
- Steuer, J. S. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication*, 42(4), 73–93.
- Ulrich, R., Simons, R., Losito, B., Fiorito, E., Miles, M., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, 11, 201–230.
- Usoh, M., Arthur, K., Whitton, M. C., Bastos, R., Steed, A., Slater, M., & Brooks, F. P. Jr. (1999). Walking > walking-in-place > flying, in virtual environments. *SIGGRAPH 99*, Los Angeles, (pp. 359–364).
- Venturino, M., & Wells, M. J. (1990). Head movement as a function of field of view size on a helmet-mounted display. *Proceedings of the Human-Factors and Ergonomics Society, 34<sup>th</sup> Annual Meeting*, 2, 1572–1576.
- Wanger, L. R., Ferwerda, J. A., & Greenberg, D. P. (1992). Perceiving spatial relationships in computer-generated images. *IEEE Computer Graphics & Applications*, 12(3) 44–58.
- Willemsen, P., & Gooch, A. A. (2002). Perceived egocentric distances in real, image-based, and traditional virtual environments. *IEEE Virtual Reality 2002 (VR'02)*, 275–276.
- Witmer, B. G., Bailey, J. H., Knerr, B. W., & Parsons, K. C. (1996). Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies*, 45, 413–428.
- Witmer, B. G., & Kline, P. B. (1998). Judging perceived and traversed distance in virtual environments. *Presence: Teleoperators and Virtual Environments*, 7(2), 144–167.