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Subjective responses to simulated and real environments: a comparison

I.D. Bishop[a,*], B. Rohrmann[b]

[a] *Centre for Geographic Information Systems and Modelling, University of Melbourne, Victoria 3052, Melbourne 3010, Australia*
[b] *Department of Psychology, University of Melbourne, Melbourne 3010, Australia*

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Abstract

In order to assess the validity of computer-generated environment simulations, an empirical field study was conducted. First a computer model of a real urban park environment was developed and used to produce both daylight and night-time animations of a 3 min walk into and through the park. The level of visual detail is high with all trees, buildings and hard surfaces correctly textured. Moving vehicles are also included. Sounds recorded on-site along the selected path were dubbed onto the animations and recorded on videotape. Then an elaborated questionnaire was constructed which measures respondents' cognitive and affective reactions to the presented environment, including impressions of the area, content retention and comprehension, and their evaluation of the simulations' realism. Four groups of participants saw the animations and were also taken for a walk in the real environment, either by day or night; for half of them the order of simulation and reality was reversed. The results show that even detailed and time-consuming computer simulations do not necessarily generate the same responses as the corresponding real environment. However, differences between day and night conditions are mostly the same in the simulated as in the real environment, and the realism ratings of the viewers were generally encouraging. The findings elucidate where further development and evaluation are warranted.

Keywords: Environmental simulation; Subjective evaluation; Validity; Day–night

1. Introduction

1.1. Quality appraisal of environmental simulations

The critical assessment of environmental simulations in relation to the depicted reality is important because the simulation of physical environments using computer graphics is becoming a commonplace occurrence. Meanwhile, the psychological validity of such presentations has received far less attention. The capacity to generate highly realistic environmental simulations has developed with increasing computer power and sophistication in rendering algorithms. Landscape, environmental and urban researchers have begun to adopt the new technology for the purpose of design communication (e.g. Clipson, 1993; Decker, 1994; Levy, 1999), resource management (e.g. Daniel, 1992) and research into human responses to environments (e.g. Bishop and Rohrmann, 1995; Rohrmann et al., 2000). Recently, Pietsch (2000) has reviewed the several roles of computer visualisation in urban design.

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[*] Corresponding author. Tel.: +61-3-344-7500;
fax: +61-3-347-2916.
E-mail addresses: idbishop@unimelb.edu.au (I.D. Bishop), rohrmann@unimelb.edu.au (B. Rohrmann).

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Environmental simulation is particularly important for two purposes: the communication of the impacts of planning and design in environments which do not yet exist, and controlled experiments into perceptions and evaluations of environmental change. Many different surrogates for direct experience of landscapes and built environments have been used in the past (Zube et al., 1987; Sheppard, 1989) and for many purposes these simulations may appropriately be highly abstracted (Pietsch, 2000). The use of simulated environments in the study of human perception, on the other hand, requires high levels of sensory realism (Daniel and Meitner, 2000). As our longer term objective is to use virtual environments to understand human perception and behavior better—not just to support planning decisions—sensory realism is the focus of this paper.

The literature clearly indicates that the greater the degree of realism in the simulation the more effective, in this context, it becomes.

> For centuries it appears to have been assumed that a drawing—is a drawing—is a drawing, and that it probably means the same thing to all who view it. The evidence ... suggests that the most realistic simulations, those that have the greatest similitude with the landscapes they represent, provide the most valid and reliable responses. (Zube et al., 1987, p. 76)

Since Zube et al. reviewed the range of options in environmental simulation, and drew this conclusion, computer graphics have provided increasingly accessible platforms for the achievement of similitude in simulation. Stamps (1990) used meta-analysis to show that photographs are a good surrogate for direct experience in the evaluation of scenic preference. A number of studies have addressed the issue of the validity of computer simulations in comparison to photographs (e.g. Bishop and Leahy, 1989; Daniel and Meitner, 1997; Oh, 1994; Bergen et al., 1995). While these studies have generally supported the conclusion of Zube et al. (1987) that a good simulation can be used as a surrogate for a direct view of the environment, they are not necessarily sufficient since:

- these studies have primarily been based on static imagery (cf. Hetherington et al., 1993);
- none has undertaken a direct comparison between computer simulations and first-hand environmental experience;
- the majority of comparative studies have restricted themselves to comparisons of preference ratings and have not addressed other important aspects of environmental response (Bishop and Hull, 1991; Bishop and Rohrmann, 1995). Yet a comprehensive understanding of the multiple aspects of subjective appraisal of environmental quality is important for understanding of human–environment interactions and, we believe, effective environmental planning (Rohrmann, 1988).

Consequently, research should address these deficiencies

- by working with animations rather than static images;
- by taking subjects to the actual site rather than relying on photographs as ‘reality’;
- by comparing a range of perceptual responses in the real and simulated environments.

We also note that an interactive experience (Bishop and Dave, 2001) is superior to viewing an animation. However, at this stage of computer development the realism of a real-time simulation of an exterior environment is inferior to that created by frame-by-frame rendering and playback as an animation.

1.2. Framework for this study

Perceived environmental quality (Craik and Zube, 1982) is a subjective transformation of ‘objective’ features of the environment according to individual experiences and preferences. Environmental psychologists have identified several types of cognitive, affective and conative responses (e.g. Gaerling and Golledge, 1993; Gifford, 1997; Kaplan and Kaplan, 1982; Nasar, 1988; Stokols, 1988; Ulrich, 1986):

- identification (for objects and structures, according to existing knowledge);
- orientation (depending on the “legibility” and the novelty of the environment);
- encoding (storage of the perceived environment in memory);
- aesthetic evaluation (perceived beauty and congruity according to individual standards);

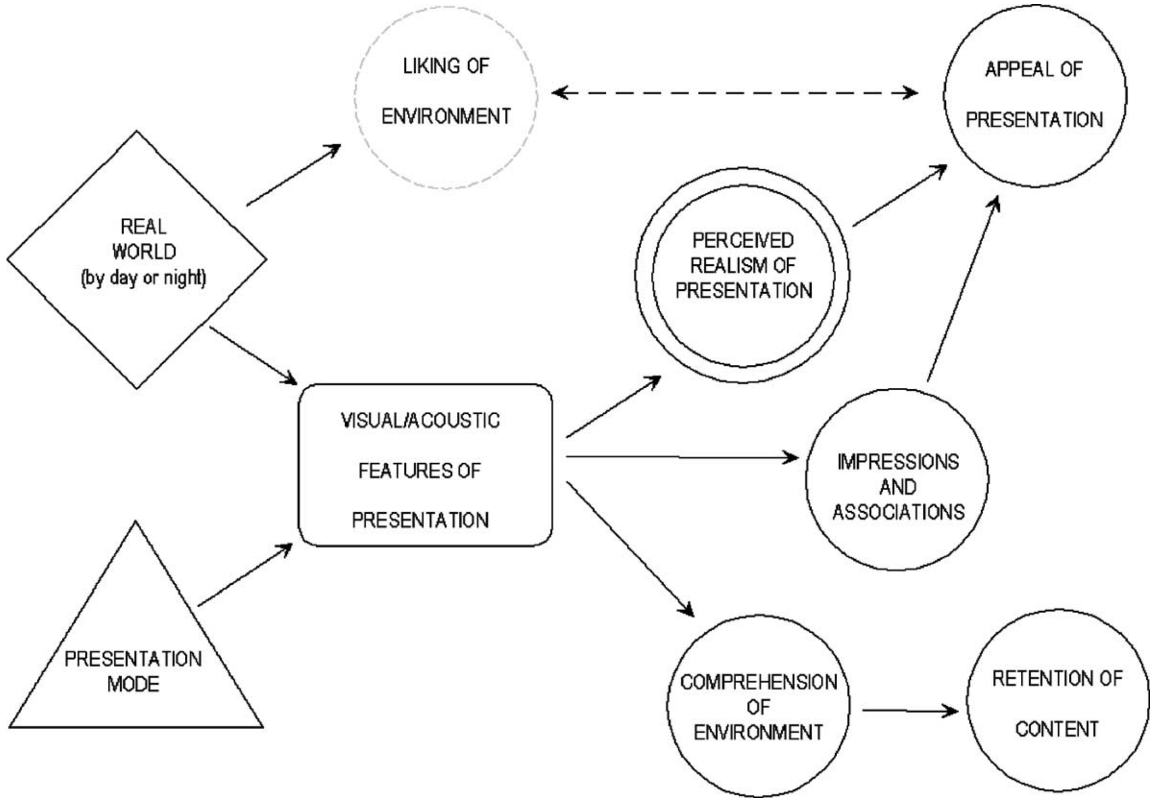

Fig. 1. Conceptual framework of the study. Participant responses to the presentations are shown in circles. The presentations are a combination of the actual features of the environment and the chosen means of presentation (i.e. site visit or computer simulation).

- personal liking (subjective pleasantness, familiarity, historical and symbolic value);
- adaptation and safety (behavioural intentions to conform with physical reality);
- manipulation (modifying an environment for personal utilisation).

For an environmental simulation to be considered valid it should evoke an equivalent set of responses, in each such category, as would direct experience of the same environment. The two sets cannot be expected to be identical because it is impossible to match the richness and complexity of reality. However, the more similar they are the greater the faith we can place in environment simulation as a tool for, e.g. evaluating alternatives in environmental design, for providing stimuli for perception research, or for using simulations in environmental hazard education. The search for generality can be extended to the presentation of different weather and light conditions, i.e. the validity of a sunny versus 'grey' situation or day versus night simulations. Ideally, all should be tested specifically, but according to the same set of responses.

Fig. 1 shows the conceptual framework developed for a series of studies on environment simulations (cf. Rohrmann et al., 2000). It integrates the major factors to be considered in an evaluation of computer simulations and identifies the main influences on response variables. What respondents see in a presentation results from a combination of the characteristics of the objective environment (the box labelled "real world") and the chosen presentation means (the triangle labelled "mode"), i.e. various forms of experience of the environment, including computer simulations, video recordings and site visits. These in combination determine the "features of the presentation". In Fig. 1, all variables to be measured as viewer's responses are shown as circles (dotted: appraisal of the represented environment; solid: reactions to the presentation). The core variable, perceived realism (double-circled) refers to an evaluating judgement in which the simulation, in relation to the viewer's beliefs about the reality, is assessed. The figure also makes clear that judgements about the environment itself and about its depiction—which is dependent on the available representation means—are likely to interact (double-headed arrow, indicating mutual causality). Real environments as well as simulated ones are always experienced within a subjective context of cognitive and evaluative factors.

1.3. *Objectives of the study*

The principal aim of this study is to clarify the validity of carefully prepared computer simulations for representing urban environments under day-time and night conditions. In particular, the following research questions were posed:

- Are evoked cognitive and affective responses to the simulations similar to those when exposed to reality?
- Is the level of information recalled similar for real and for simulated environments?
- What level of realism rating will people attribute to computer simulations and what features contribute to the realism rating?
- Are night-time simulations more or less valid in their induced perceptions than the daylight equivalents?

These questions cover a range of response types (above). However, as the project focuses on the perception and evaluation of environments, the cognitive impacts (e.g. comprehension and retention) and affective responses (e.g. impression and likeability) are of prevalent interest. Both aspects are crucial for the perceived realism of simulations. Given the computer resources available at the time of the experiments, adaptation or manipulation responses could not be studied. These require an interactive environment as discussed in Bishop et al. (2001).

Landscape and urban designers are among the major potential users of computer simulation as a communication tool. Their operational environment commonly includes public places near major buildings. Landscape perception research is often focused on the natural environment but also includes many urban studies (Kaplan and Kaplan, 1982; Smardon, 1988; Herzog and Chernick, 2000). For generality, we therefore chose our study area in the environs of a suburban civic centre. It includes a major transport route, shops, civic buildings and parkland. Such an environment is heavily used in both the day-time and after night-fall. A representative simulation must therefore include presentations of both daylight and artificial lighting conditions. This is also relevant for impressions such as safety versus threat (cf. Nasar et al., 1993; Painter, 1996), as fear associations are considered more likely for the night situation.

The current study is the third component of a larger project on the validity of environment simulations. In study (1), several variations in a simulation of the environment mentioned above were investigated (Rohrmann and Bishop, 2002). In study (2), a computer simulation and a video recording of that environment were compared (Palmer, 1998; Rohrmann et al., 2000). All three studies used simulations of the same area.

2. Research plan

2.1. *Design of the experiment*

In order to address these questions, a combined field/laboratory experiment was designed. It was based on a 3 min walk through the chosen environmental setting. Participants were exposed to both the actual and the simulated environment (half of them in reverse order). Thus, "presentation mode" (cf. Fig. 1) means either a site visit or a computer simulation. Different groups were employed for the "day" and the "night" condition. The resulting mixture of between and within groups design is summarised in Table 1.

Altogether 84 people participated, 43 in the "day" and 41 in the "night" experiment. All respondents were University of Melbourne psychology students. In general, they had had little prior exposure to computer graphics or simulated environments.

2.2. *Development of the model and animations*

The area used in the experiment was a subset of a larger suburban model of the area around Camberwell

Table 1
Simulation and reality as conditions for four groups of respondents

	Presentation mode			
	Site visit		Computer simulation	
	Day	Night	Day	Night
Groups and session order				
$N = 21$	First		Second	
$N = 22$	Second		First	
$N = 21$		First		Second
$N = 20$		Second		First

Junction in Melbourne, Australia. Development of the initial model using photogrammetric techniques is described in Bishop et al. (1995). Further detail is given in Rohrmann and Bishop (2002). Fig. 2 gives an oblique aerial view of the simulated environment and shows the path of the walk used in the experiment. The covered area is about 1 km^2. The full model includes approximately 150,000 polygons and 52 different surface textures (approx. 18 Mbytes). Separate day and night versions were developed. In the day-time simulation there was a single light source positioned to correspond to mid-morning on a sunny day. Fig. 3 shows an on-site daylight photograph from one point along the walk and a corresponding simulated view. In the night-time simulation there were 38 independent light sources—both street lights and lights within the park area. Model development, animation and rendering were all done using the Alias/Wavefront Advanced Visualizer software. Rendering into PAL resolution images (780 by 576) with full shadow-casting and anti-aliasing took 2 min on an average for the daylight and 40 min on an average for the night scenes. In each case, 1500 frames were rendered for the animation. The field of view was approximately 50° and the camera was pointed in the direction of movement with occasional slow rotations of up to 15° on either side. The nature of the path was such that all major features of the simulated environment were visible (although the tops of trees and flagpoles were never seen). The frames were recorded to video at 8.33 frames/s giving an overall playback time of 180 s. This was the same time as it took to complete a brisk walk of the route. The simulation includes moving objects (e.g. passing trams) but no humans except for the shadow of a person walking through the area.

Fig. 2. An oblique aerial view of the simulation model and the path taken in both the animation and the on-site walk.

Fig. 3. Partial view of the environment under study. Taken with digital camera (above). Computer simulation (below). The bus shelter was constructed after the experiment was completed.

Sounds were recorded on-site in both day and night conditions. The animation route was walked with a sound recorder and the resulting sound recording was dubbed onto the video tape of the respective animation.

2.3. The questionnaire

To measure responses to environmental features as well as to the perceived simulation quality, a standardised questionnaire booklet was developed. This was based on the conceptual framework presented in Fig. 1. It consists of four parts. Two of these relate specifically to the study environment: one for after walking through the real environment, the other for after viewing the animated walk though the simulated environment. These two parts were designed to be as comparable as possible but also contained questions specific to the real walk or the virtual walk. A third section asked participants explicitly to compare the computer simulation with the real experience. Finally, basic demographic items are administered. A full list of variables (such as perceived legibility/comprehensibility; and general appreciation/liking) and the respective response formats are given in Table 2. For comparison, the variable names and labels are the same as used in Rohrmann and Bishop (2002).

Table 2
Overview: concepts, variables, scales

Stimulus features (S)	
S1	Presentation mode: reality and computer simulation
S2	Time of day: day and night
Appraisal of the content (A)	
A1–A3	Liking and appreciation of the presented area, aspects: likeable, nice to walk through, good to live in (ratings; scale: 1–7)
A4–A11	Impressions and associations: aspects arousal/disliking/inertia/order/pleasure/threat/similar/natural (see Table 3)
A12	Appreciation of the area (index, 1–7, based on A1–A3)
Retention (R)	
R1–R7	Recall of specific items (weather, time of day, sound, shadows, pace, buildings and vegetation)
R8; R9	Number of correctly cited features; number of incorrect replies
R10	Recollection correctness (index: (R8 − R9)/10; range: 0–2)
Comprehension (C) (for simulation only)	
C1	Understanding of the setting (legibility) (rating; scale: 1–7)
C2	Correctness of area map drawn by respondents (assessment; scale: 1–5)
Evaluation of realism (E) (for simulation only)	
E1	Perceived realism of simulation, holistic overall rating; E1d = direct rating (scale: 1–7); E1c = comparative rating (scale: 0–10)
E2	Presentation validity (its capacity to induce a “correct” impression of the area) (scale: 0–10)
E3–E17	Realism of 15 specifics (e.g. weather, buildings, vegetation, lighting, pace and sound) (rated twice, directly (scale: 1–7) and comparatively after site visit; scale: 0–10)
E18	Index of realism quality (using eight visual aspects out of E3 to E17: buildings, benches, vegetation, light, colors, shadows, traffic, pace; index E18d based on direct, E18c on comparative item ratings)
E19	Appeal of presentation and reasons for simulation evaluation (coded responses to open question; (A): general appraisals, (B): specific shortcomings)
Demographics (D)	
D1–D5	Age, sex, ethnicity, education and place of residence
Moderator variables (M)	
M1	Order of presentations: simulation–reality or reality–simulation
M2	Computer usage and familiarity with graphics-based simulations (index, 1–5)

A key aspect of response measurement in either the real or simulated environment was the use of impressions such as pleasant, exciting, natural, familiar and threatening. In total 24 adjectives, extending an approach by Russell and Lanius (1988) were used. As Table 3 shows these were then grouped into eight composite indices of attribute perception.

The questions which are common to both the real and simulated environments cover perception and evaluation aspects of responses, as discussed in the environmental psychology literature (e.g. Lynch, 1960; Bonaiuto et al., 1999; Gaerling and Golledge, 1993; Nasar, 1988, 1997; Kaplan and Kaplan, 1989; Russell and Lanius, 1988; Sundstrom et al., 1996; Scott and Canter, 1997). In order to measure the respondents' cognitions and assessments, a variety of scale-based and open-ended qualitative questions were employed. For comparability, many questions/scales were the same as in our preceding studies (Rohrmann et al., 2000; Rohrmann and Bishop, 2002) that dealt only with computer-simulated environments.

Table 3
Perceived attributes (impressions and associations) and composite indices

	Attribute adjectives[a]	Index
A4	Beautiful, pleasant, pretty	Pleasure
A5	*Artificial*, natural, *unnatural*	Naturalness
A6	Familiar, *unfamiliar*, well-known	Familiarity
A7	Orderly, *spacious*, understandable	Order
A8	Drowsy, lazy, slow	Inertia
A9	Active, arousing, intense	Arousal
A10	Forceful, threatening, unpleasant	Threat
A11	Displeasing, dissatisfying, uncomfortable	Disliking

[a] Rated on scale 1–7, negative contributors in italics.

2.4. Experimental procedure

The data collection was conducted in six steps:

(1) gathering in a seminar room, for general instructions;
(2) presentation #1, reality or simulation;
(3) questionnaire about presentation #1;
(4) presentation #2, simulation or reality;
(5) questionnaire about presentation #2;
(6) questionnaire section #3, asking for comparative judgements about presentations #1 and #2.

2.4.1. Simulation presentation

The simulation was presented as video via a television screen (size: diagonal = 58 cm) which was about 2 m from the audience.

2.4.2. Reality presentation

Groups of 10 were taken to the real environment. At the study site the participants were walked as a group along the same path as was followed in the animation. Before beginning the walk they were instructed to follow the experimenter's pace and direction. At the conclusion they were taken to a foyer where they completed the appropriate part of the questionnaire. They were then returned to the University in order to complete the remaining tasks.

3. Results

3.1. Overview

Responses to the real and simulated environments were compared in terms of the variables listed in Table 2. Subjective assessments of simulation realism and ability to match specific features were analysed based on both direct and comparative ratings. It was considered important to determine not only the degree to which mean responses compared but also how scores were distributed between respondents. That is, an effective simulation should generate a similar profile of response as will the depicted reality—not merely a similar mean.

In general, we kept the day-time and night-time analyses separate because it is important to know whether a presentation via simulation maintains the relationships between day and night responses found in the real environment. Responses to a presentation, whether experienced first or second, were usually merged to enhance statistical reliability. However, order effects were also investigated and will be discussed below. All main differences between mode of presentation and time of day conditions were tested for statistical significance; however, the respective results are not added to each table but listed, in conjunction with order effect, in one integrated list. Table 4

Table 4
Influence of presentation mode (S1), time of day (S2) and order (M1) on selected appraisals—ANOVA results

	Factor	S1	S2	M1	S1 × S2	S1 × M1	S1 × S2 × M1
A4	Impression "pleasure"	22^{**}	7^{*}				
A5	Impression "naturalness"	55^{**}		5^{*}	4^{+}		
A6	Impression "familiarity"	21^{**}					
A10	Impression "threat"	20^{**}	12^{**}	8^{*}	4^{+}		
A12	Appreciation of area	11^{**}					
R10	Recollection index	34^{**}				40^{**}	8^{**}
C1[a]	Legibility of setting			5^{*}			
E1c[a]	Perceived realism (compar.)		9^{**}				
E1d[a]	Perceived realism (direct)						
E2[a]	Presentation validity			23^{**}			
E18d[a]	Index of realism (direct)		5^{+}	9^{**}			
E18c[a]	Index of realism (compar.)		4^{+}				

Values are percentages = η^2 for explained variance in dependent variable. Blank cells indicate that the influence was insignificant. See Table 2 for explanations of variables.

[a] Presentation mode not applicable.

$^{+}$ 0.10 significance level.

* 0.05 significance level.

** 0.01 significance level.

Table 5
Impressions of the area: responses to reality and simulation

	Factor	Reality (S1)		Simulation (S1)	
		Day (S2)	Night (S2)	Day (S2)	Night (S2)
Indices of perceived attributes of the environment (scale: 1–7)					
A4	Pleasure	5.1	4.5	4.1	3.6
A5	Naturalness	5.0	4.6	2.7	3.1
A6	Familiarity	3.5	3.5	4.4	4.6
A7	Order	4.5	4.4	4.8	4.9
A8	Inertia	3.1	2.5	3.7	3.7
A9	Arousal	2.5	2.6	2.4	2.8
A10	Threat	1.8	2.2	2.3	3.2
A11	Disliking	1.9	2.2	2.6	3.1
A3	Liking of the environment	4.8	4.4	3.8	3.7
A12	Nice area to walk thru	4.3	4.1	3.9	3.6
A13	Good area to live in	4.3	4.4	3.9	3.9
A12	Appreciation of the area	4.5	4.3	3.9	3.7
C1	Legibility	–	–	5.3	5.6

S1: presentation mode (reality and simulation); S2: time of day (day and night).

shows significance levels and explained variances for the core variables of this study (items merged into indices were not tested separately).

3.2. Perception of environmental qualities

Are evoked cognitive and affective responses to the simulations similar to those when exposed to reality?

Table 5 reports the comparison between responses to real and simulated environments, based on impressions of the area, comprehension and ratings of likeability. Fig. 4 shows how the impressions differ between the real and simulated environments. Ideally these values would be zero. The factor showing greatest difference is clearly naturalness. The generally parallel nature of the two lines shows that the successes or failing of the simulations are similar in both the day and night conditions.

There are both some good signs and some bad signs here for the computer simulations. In broad terms the negative effects seem to be overrated (e.g. disliking and threat) in the simulations while the positive effects are underrated (e.g. pleasure, naturalness and overall liking). However, as Fig. 4 illustrates, there is consistency in the response pattern. For example, the “pleasure” scores at night are lower than the daylight scores in both real and simulated exposures; the opposite is true for “disliking”. Only the “naturalness” index shows significant inconsistency in this regard.

“Familiarity” is greater for the simulation than for the site visit. It may be that the ‘generic’ quality of the trees and other textures reduces the individuality of the place and it becomes more ‘familiar’ in a general sense. Thus, there seems to be a difference in the interpretation of the term ‘familiar’ in the two conditions: in the real environment people say ‘not familiar’ if they have not been there before. Whereas, in the simulation, people may say ‘familiar’ if they have seen this type of place before. The two impression profiles (based on the ranks of the scores in Table 5) correlate 0.70/0.60 for day/night, respectively. This suggests the simulations are being fairly effective at picking up changes in perceptions of one situation relative to another (relative response)—but are not so good at generating valid impressions of an isolated situation (absolute response).

Table 5 is based on group means for exposure conditions. When individual responses are considered, the correlations between simulation scores and reality scores across the 82 valid respondents for each of the 24 attributes (i.e. those in Table 3) are all positive but with values ranging from 0.11 to 0.54. This suggests that consistency is greater for group means than for individual responses. This is a common finding in the limited number of perceptions studies that calculate individual consistency (e.g. Patsfall et al.,

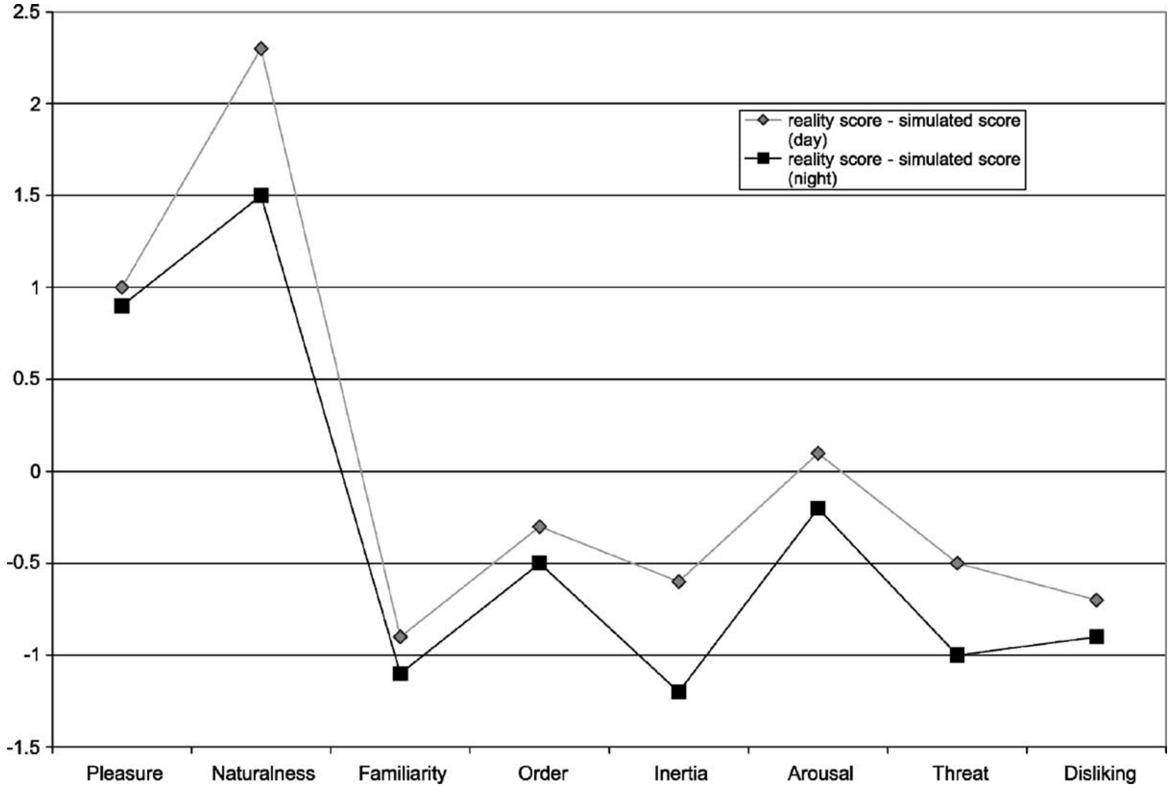

Fig. 4. Impression profiles: differences between reality and simulation assessments (A4–A11).

1984; Hull and Stewart, 1992) and has provoked some debate about the appropriateness of using group averages. However, Daniel (2001) has argued in favor of the use of group means in comparing different landscapes or landscape outcomes. We share this view and consider group means appropriate in assessing computer-simulated environments.

3.3. Differences in retention

Is the level of information recalled similar for real and for simulated environments?

The main results on retention for the real and simulated environments are shown in Table 6, separately for day and night.

The respondents recall more accurately in the real environment. As the significance tests show (Table 4), this is strongly influenced by presentation mode ($\eta^2 =$ 34%). Again, however, the relative day/night values are sensible (e.g. the recall rates are slightly higher at night in both reality and simulation). The difference in the indices arises wholly from the number of items which people did recall, i.e. very few people saw things which were not there. Some items on each list—such as flag poles—were only partly visible in the simulation and could not easily have been identified. Others such as moving cars were simply not present in the simulation. The results are therefore rather closer than the figures suggest. There is also a small but consistent day/night difference, in that main features such as the type of buildings, vegetation and existence of shadows are more correctly remembered in the night condition.

Interestingly, many respondents perceived the pace of their real walk as faster than the pace perceived in the simulation, even though the time (180 s) and traversed distance were almost identical. Apparently the perceived walking speed in the simulation was slower than the actual camera movement speed. This may reflect the difference in effort involved in taking a fairly

Table 6
Differences in retention

		Reality (S1)		Simulation (S1)	
		Day (S2)	Night (S2)	Day (S2)	Night (S2)
R1	Recall: weather correct			70%	–
R2	Recall: time of day correct			95%	88%
R3	Recall: sound “yes”			100%	100%
R4	Recall: shadows “yes”			63%	88%
R5	Recall: pace “quick”	51%	66%	7%	7%
R6	Recall: buildings correct	67%	78%	37%	49%
R7	Recall: vegetation correct	61%	76%	55%	60%
R8	Correct recall of specific items (list of 20)	14.2	14.5	10.9	11.4
R9	Incorrectly cited features	0.2	0.3	0.1	0.2
R10	Recollection correctness (index)	1.4	1.4	1.1	1.1

Note: Values in percent are percentages of all respondents in the respective experimental condition. S1: presentation mode (reality and simulation); S2: time of day (day and night).

lively walk through an environment compared with sitting comfortably to view an animation. If the pace of both were slower there may have been less difference in the perceived pace. However, there is a clear question about psychologically correct movement speed in animated or virtual environments that requires further investigation.

In the responses to the simulation, recollection correctness index (R10) also correlated with the two comprehension variables. The correlation was 0.25 with C1 (understanding of the setting) and 0.46 with C2 (correctness of the area map drawn by respondents). Comprehension of the computer simulation thus seems to be aiding recollection.

3.4. Appraisal of realism

What level of realism rating will people attribute to computer simulations and what features contribute to the realism rating?

Overall ratings for realism (holistic judgements and indices based on ratings for eight main environmental features) are given in Table 7. In general, the

Table 7
Evaluation of the realism of the simulation

		Simulation assessment			
		Direct (1–7)		Comparative (0–10)	
		Day (S2)	Night (S2)	Day (S2)	Night (S2)
E1	Perceived simulation realism—overall rating	4.1	4.4	5.4	5.5
E2	Presentation validity (inducing valid area impression)	n/a	n/a	5.8	6.0
E3	Realism of shadows	4.4	4.4	5.2	5.8
E4	Realism of lighting	4.0	4.6	4.4	5.8
E5	Realism of buildings	4.4	4.6	5.9	5.5
E6	Realism of vegetation/trees/shrubs	3.6	3.9	5.0	5.5
E11	Realism of colors	3.6	4.0	3.8	4.7
E13	Realism of traffic (cars/trams)	4.8	5.1	6.2	6.0
E14	Realism of benches/bins/signs	4.2	4.8	4.2	4.8
E17	Realism of pace	3.6	4.0	4.1	3.8
E18	Index of realism quality	4.2	4.6	5.1	5.3

Note: ANOVA results for E1, E2 and E18 are in Table 4. Response scales (cf. Table 2): 1–7 for direct ratings and 0–10 for comparative ratings. S2: time of day (day and night).

simulations were rated moderately realistic (on an average as 4.3 on a 1–7 scale, anchored “not at all” and “very much so”). The comparative rating (after seeing both reality and simulation) yields a similar outcome (5.4 on a 0–10 scale anchored “not at all” and “completely matching”).

We also asked—again after exposure to both the real and the simulated environments—how well the computer simulation provided a valid impression of the presented urban area. On a scale ranging from “very incorrect” to “very correct” (scored 0–10) the resulting ratings were mildly positive as well (average for day and night conditions: 5.9). Contrary to our expectation, the respondents were not more critical of the simulation once they could compare with reality. There are necessarily some order effects in the comparative case and these are discussed below.

The contribution of specific features to overall realism was explored in a number of ways:

(a) assessments of specific facets;
(b) open-ended questions about the qualities of the simulation;
(c) correlations and regression of the overall ratings against ratings of individual features of the simulation.

Table 7 shows the ratings of a selection of these specific features (i.e. those features which were included in both the direct and comparative evaluations). Realism of traffic is highest (this was clearly based on the moving tram since all cars were parked), realism of color is lowest; however, these differences are small. Table 8 contains a summary of the main reported shortcomings of the simulations. These relate most frequently to insufficient animation and unsatisfactory realization of light and color. After experiencing the real walk, the pace of the simulation was commented upon critically by more than a third of the participants. While many respondents picked up these limitations, several deficits, such as the lack of people and animals, were not much mentioned.

Correlations between specific realism components and overall ratings are shown in Table 9 under “rPC”. Furthermore, several multiple regression models were computed. The dependent variables were overall rating for perceived realism (E1) in both day and night conditions and the comparative overall presentation validity (E2). Each shows that building, vegetation, color and sound realism have most influence on realism evaluations. Only few day/night differences are salient (e.g. realism of details such as benches; legibility). Neither recollection nor the legibility of the area’s features explain much additional variance. Finally, computer familiarity is not predictive here, and there are no male/female differences.

The results also indicate that while accuracy in vegetation representation is very important to people’s ratings of the realism of a simulation (criterion E1), it seems to be less crucial when judging how well a place is represented by the simulation (criterion E2). This makes intuitive sense since a good representation of a place’s character can be achieved by presenting a tree in recognizable form whereas a high level of realism demands that the tree be not only

Table 8
Reasons for simulation quality evaluations

		Simulation assessment			
		Direct		Comparative	
		Day (S2)	Night (S2)	Day (S2)	Night (S2)
E19A	General/overall comments about the simulation				
	Positive or neutral statements	37	57	n/a	n/a
	Critical or negative statements	33	15	n/a	n/a
E19B	Shortcomings or improvement desirable				
	Animation, motion, pace	28	6	37	36
	Light, color, shadows	23	17	15	28
	Objects (buildings, trees, etc.)	17	29	15	13
	Sound	14	14	10	10
	People, animals (missing)	6	3	12	5

Note: All values are in percentages of 84 respondents. S2: time of day (day and night). n/a: not applicable.

Table 9
Single and multiple correlations for perceived simulation quality

		Perceived realism (E1)				Presentation validity (E2)	
		Day		Night		All	
		rPC	Beta	rPC	Beta	rPC	Beta
E5	Building realism	64	37	52	20	47	28
E6	Vegetation realism	66	51	66	33	38	11
E11	Color realism	45	−05	54	16	50	29
E3	Shadow realism	42	−10	42	13	29	−00
E13	Traffic realism	52		35		25	
E14	Benches/bins/signs	45		10		29	
E7	Sound realism	38	22	51	23		
R8	Recollection index	26	15	11	−11	22	09
C1	Legibility	16	02	34	08	25	12
M2	Computer familiarity	04	−03	−04	04	−10	05
D2	Sex	−02	04	−06	−04	−10	−10
Multiple *R*			79		77		61
R^2			63		60		37
Significance			**		**		**

Note: All correlations and coefficients multiplied by 100. Single predictor-criterion correlations shown as rPC. In the multiple correlations, not all predictors were used (in order to avoid multi-collinearity). See Table 2 for explanations of variables. E1 and E2: dependent variables.
** 0.01 significance level.

recognizable but also visually realistic. Given the difficulty of realistic representation of vegetation, especially for real-time simulation, this is an encouraging finding for simulators. That is, effective representation of a place and valid responses to it may be possible without the highest possible ratings for realism.

A further variable of interest is the appreciation of the area (A12). Usually it is assumed that the quality of a representation will influence how favourably a building or environment is judged (designers may try to utilize this mechanism). However, it may be that the influence is the other way round, i.e. people who like an environment might evaluate the simulation quality more leniently. In the current study mutual causality is assumed (cf. the model in Fig. 1), thus this variable was not used as a predictor in the multiple regressions. The empirical data show a significant correlation ($r = 0.42$) between perceived simulation realism (E1) and (A12). For the "disliking" attribute of the impression profile (A11) the correlation with perceived realism (E1) is $r = -0.26$. The set-up of the study did not allow us to analyze this causality issue unequivocally; respondents also often find it difficult to separate the two aspects conceptually.

3.5. Day/night differences

- Are night-time simulations more or less valid in their induced perceptions than the daylight equivalents?

This is a relevant issue because night-time simulations require more preparation time and computational resources. Fig. 5 (based on Table 5) suggests that the pattern of impressions induced by the night-time simulations is very similar to those in the day-time. Positive values mean that the aspect was scored more highly in the day-time, negatives mean higher scores at night. Clearly the patterns are similar (the two mean profiles correlate 0.92) meaning that a tendency towards higher day (e.g. pleasure) or night (e.g. threat) scores occurs in both reality and the simulations. The greatest deviation from this pattern was again naturalness which in reality was higher in the day-time but in the simulation was higher at night. This seems to relate to the perceived realism of the vegetation which was generally rated more highly at night—when it was also less visible.

An examination of the subjective realism evaluations in Table 7 reveals that people consistently found

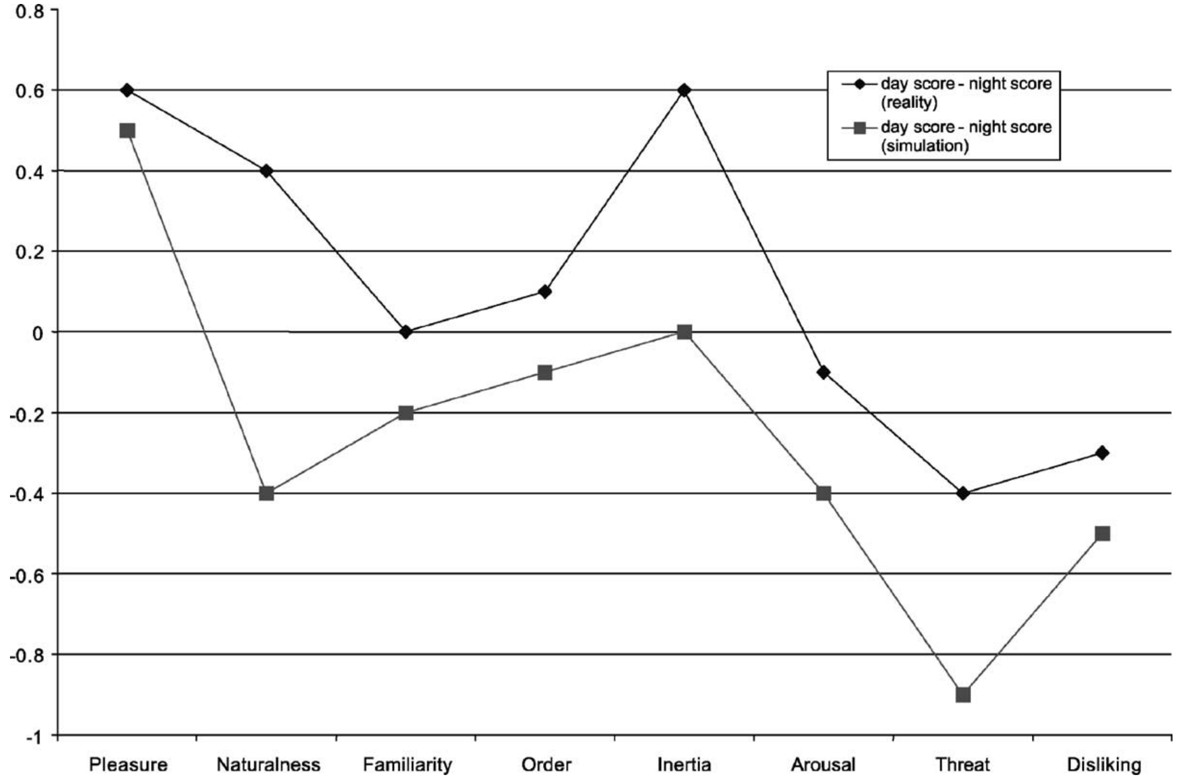

Fig. 5. Impression profiles: differences between day and night assessments (A4–A11).

the night-time simulations more realistic than the day-time ones (small but significant effect; $\eta^2 = 5\%$). The stronger assessment of the night simulation may be the result of the softer colours and restricted depth of vision. Accuracy of detail seems to matter less in the night situation.

In the context of environments at night, the perception of safety is of special interest (Loewen et al., 1993; Painter, 1996). Are associations more negative for night-time than day-time conditions? This appears to be the case in both real and simulated environments. Table 5 shows that the “threat” index is higher at night in both cases. However, there is also a presentation mode effect: threat perceptions are stronger for the simulation. As can be seen in Table 4, both main effects are significant, with $\eta^2 = 12$ and 20%. We also checked the distribution of responses in this case to see whether many people felt a low level of increased threat or whether the effect was greater but restricted to fewer people. Examination of the spread of individual responses to threat showed that the increased threat perception at night is roughly normally distributed for the real environment but for the simulation showed a bi-modal tendency. Potentially this could reflect a difference between those who are responding to the environment itself and those who are responding to the representation (however, only a study with additional measures could clarify this issue).

3.6. Experimental order effects

While the question of order effects was not on the study’s agenda in its own right, it was nevertheless likely that the presentation sequence would impact on responses in an experiment such as this. With one half of the participants presented with the simulation before, the other half after the site visit this influence was effectively balanced. However, order effects were still analysed for several variables (Table 10).

Table 10
Order effects in simulation evaluation

		Order of exposure (M1)			
		Simulation then reality		Reality then simulation	
		Day (S2)	Night (S2)	Day (S2)	Night (S2)
E1d	Perceived simulation realism (*direct overall rating*)	3.7	4.5	4.5	4.2
E1c	Perceived simulation realism (*comparative rating*)	4.9	5.9	5.0	6.0
E2	Presentation validity (*inducing valid area impression*)	5.2	5.2	6.6	6.8
E18d	Realism quality index (*direct ratings*)	3.9	4.4	4.5	4.7
E18c	Realism quality index (*comparative ratings*)	4.6	4.9	5.5	5.7

Note: Response scales (cf. Table 2): 1–7 for direct ratings and 0–10 for comparative ratings. For significance tests see Table 4. S2: time of day (day and night).

For these, and seven further main variables, ANOVAs were run to test the significance of order effects in interaction with the two major experimental factors of this study, presentation mode and time of day. The results were already summarised in Table 4.

These analyses reveal that those who saw the simulations after being to the real environment were more impressed by the realism and presentation quality of computer simulations (significant for variables E2 and E18d but not E1d). The effect is slightly stronger for the night condition. The legibility ratings are also higher under this condition. A further order effect occurs for one of the impression indices, threat (decreasing); an expected increase in familiarity on second presentation is not significant. Apparently it matters whether respondents have already some knowledge of the environment; it helps to interpret a simulation and induces higher acceptance of its quality.

The appropriate order (simulation first or reality first) for a validity study depends upon its objective. In many planning contexts, people would see a simulated setting first and only later the realised design. If, on the other hand, we wish to test the effect of minor environmental changes on people's responses, then we merely need to know if the existing local model is good and will be accepted by people already familiar with the area. In these circumstances, respondents should inspect the reality first. This study was not committed to either of these purposes. Therefore, the respective subgroups were merged, equally weighted. This also gave the advantage of better sample sizes.

Although a number of response variables showed little order effect, it remains true that the sequence of presentation modes must be carefully considered in decisions about pertinent research designs.

4. Conclusions

4.1. The validity of responses to simulated environments

The results suggest that detailed and often laborious computer simulations can provide valid outcomes for the main aspects of environmental perception but, from several points of view, do not generate the same responses as the corresponding real environment. Using a simulated environment, the appreciation of the study area is less positive, and retention is less detailed. However, differences between day and night conditions are mostly the same in the simulated as in the real environment.

Of course we did not expect to obtain identical responses. While we wished to determine how close we could get to identical responses, we recognize that in practical applications this may not be necessary. The question then emerges: how much realism is needed? Depending on the decision context, different levels of realism will be appropriate. In fact, while specific features such as vegetation, colors and animation were rated as not fully convincing, on the whole most viewers accepted the presentation as reasonably valid. They got a good idea of the principal character of this urban area. Somewhat unexpectedly, this was true for the night simulation as well, even though this was technically more difficult.

This study indicates that particular environmental features—especially vegetation but also the colors of objects—may require more realistic presentation. As suggested above, this may be less critical when people already know the location, including the trees, and perhaps require reminders of vegetation type more than highly realistic vegetation. Furthermore, in the case of moving through an environment, the pace has to be carefully set.

The simulations are producing affective response measures that do not always match the absolute affective pattern induced by reality. However, relative responses seem to be generally reliable and the value of presenting environments via computer graphics, at least in this urban/park environment, is supported. The potential becomes particularly relevant in situations when a building, urban area or landscape cannot be visited or is to have its features changed, or when hypothetical situations are to be demonstrated. This applies to many tasks within environmental planning, environmental choice and environmental education.

4.2. Considerations for further research

Two substantive issues which deserve closer attention are the interaction between appraisals of the environment itself and its depiction; and the psychological reasons for day/night differences. This would require additional response measures.

Furthermore, future studies should include simulations of several *different* environments (both 'pure' natural and built ones), in order to test the stability of preference orders against presentation modes. Using a wider range of visual/graphic means (regarding color, texture, animation and so on) is necessary in order to assess which findings can be *generalised*. The more interactive the presentation techniques become, the better the chances will be to fully exploit the potential of this technology, including advanced experiential approaches to landscape assessment (Zube et al., 1982; van Veen et al., 1998; Bishop et al., 2001). Applications to 'real-life' problems—such as an information program for residents, urban design review (Levy, 1999) or an environmental planning decision of a council (Lawrence, 1993; Decker, 1994)—should be designed and investigated, in each case in contrast to conventional presentation techniques (such as drawings, models, verbal descriptions). Such research would help to decide where further sophistication of the simulation technology is most crucial.

Given the relevance of validity issues for the effective implementation and use of such technologies, it should become 'standard procedure' to include validity assessments with pertinent samples of users whenever new means of computer-simulation and virtual reality modalities are invented and applied (Bishop and Rohrmann, 1995; Globus and Azelton, 1995; Haase and Dohrmann, 1996). *Empirical* validation, while demanding, is the most effective way to learn *why* a technology has particular impacts and *which* improvements are essential.

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