The influence of Lighting on the Affective Qualities of a Virtual Theater

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In the development of 3D models of buildings, much time and effort is spent on enhancing lighting effects, to improve the perceived realism and quality of the models, and to create ambience. In an experimental setup, two versions of a 3D model of the Royal Carré Theater with different lighting conditions were presented to viewers, to assess the influence of lighting effects on their affective appraisals. A small group visited the real theater. The differences between the affective qualities of the models are smaller than expected, and participants seem to infer affective qualities and dimensions of an environment without paying attention to the specific lighting information. The affective qualities of the real theater show a correspondence to both versions.

Keywords: 3D models; virtual environments; affective appraisal; lighting.

Introduction

It is generally assumed that the validity of a computer simulation increases with the fidelity of its representation. However, the affective appraisal of a 3D model may differ considerably from its real counterpart, as a result of choices made in the modeling process, the restrictions of hardware, software and display, and the perception of the user (Bishop and Rohrmann, 2003; Houtkamp, 2004, Houtkamp and van Oostendorp, 2007). Lighting is recognized as a fundamental issue in 3D graphics (Slater et al., 2002). Challenges are to maintain a sufficient level of perceptual fidelity, while reducing the computational burden of models used for real time navigation.

We determined the affective qualities of a 3D model of the Royal Carré Theater for two different lighting conditions: a shadowless one with only ambient lighting, and a shaded representation with enhanced lighting. We also obtained appraisals from participants who visited the real theater. The effects of illumination and shadows on the affective appraisal of desktop virtual environments are relevant for architects and visualization developers, since they determine both the validity of the models, and the development costs of 3D models. They may also affect the validity of virtual environments for training purposes, where the environment provides the stage setting for actions and events, and must be convincing and convey the desired ambience.
**Background**

The interaction of light and shade provides a wide range of informational cues to the human visual system, and can also elicit a range of human responses such as the affective appraisal of an environment. (Zimmons, 2004; Slater et al., 2002) In environmental psychology and architectural design, the effects of light and shadows on a varied range of human responses have been investigated. It was found that people use brightness and variability of luminance distributions for their affective appraisal of the illumination of environments (Flynn et al., 1973; Flynn, 1977; Flynn, 1988; Flynn, 1992; Hendrick et al., 1977; Slater et al., 2001; Veitch, 2001; Zimmons, 2004). A uniformly lit environment appears more spacious (Flynn et al., 1973), whereas a non-uniformly lit environment appears more complex, thereby making it more interesting or pleasant (Hanyu, 2000; Loe et al., 2007; Newsham et al., 2005; Protzman and Houser, 2005; Veitch, 2001). These principles are for instance deployed in the design of ambient lighting schemes to create a mood, impression or visual interest in a given real-world environment (Flynn, 1977; Ginthner, 2003; Miwa and Hanyu, 2006). In video games light and shadows are used to evoke suspense, dread, and comfort (Niedenthal, 2005). Lighting also affects the color distribution in a scene, which in turn determines the perception and appraisal of architectural space. Although studies on the effect of color are incomplete, warm and saturated colors are generally considered as more arousing. Brightness and saturation contribute to higher valence (Mehrabian and Russell, 1974), while luminance variations determine the dominance dimension. Generally, cool, desaturated, and light colors are considered to enhance the experienced spaciousness (Franz, 2006).

**Research Methodology**

**3D Models**

We used two manipulated versions of a 3D interior model of the lobby, corridor and main theater hall of the late nineteenth century Royal Carré Theater in Amsterdam, the Netherlands. The interior decoration of Carré shows many characteristics of the baroque style, such as the extensive use of the color red, typical decorations, and chandeliers. The model was created by VSTEP B.V. for a media presentation by Koppla Media B.V., to showcase the renovation plans for fundraising purposes, before the actual renovation work began in 2004. It was made in Quest3D and 3D Studio Max, on 2D CAD-drawings of the building. The model did not include sounds.

We created two versions of the theater model (figs. 3-6). In one version all textures were given the same emissive value and all the shading was removed, resulting in a bland environment. The
second version featured pre-computed light-maps for the shadows and additional real-time light sources for extra saturation and diffuse glow. The lighting was kept subtle since the goal was to mimic the real environment, and not to surpass it in experienced intensity. However, the shadows were purposely made noticeable. The lightmaps were created with 3D Studio Max v7’s native engine, analogous to what VSTEP used at that time. Although this is not the cutting-edge of contemporary lighting technology, for our research a technique which is in use in the architecture visualization industry is more relevant. The architect who supervised the renovations of the theater, from Greiner, van Goor, Huijten architects, confirmed that the enhanced model more closely simulated the festive effect brought about by the theater’s illumination, and created an impression of excitement and expectancy.

Two of our manipulations may have influenced the outcome. First, since the seats comprise a large number of polygons they could not be lightmapped. Therefore we added real-time omni lights at the location of the chandeliers, resulting in sufficiently realistic illumination on the seats. Second, the model uses a semi-transparent bitmap to create a hazy halo effect on and around the chandeliers. While this is arguably lighting information, removing the bitmap altered the appearance of the chandeliers, i.e. they appeared less rounded and showed more detail. Therefore we
chose to retain the haloes in both versions, but kept them subdued in the degraded version.

**Participants**

A group of participants, N= 33, 20 to 62 years old (mean 30.3), was randomly split into three. 12 participants traversed the degraded version of the model, and 12 participants the version with lighting. 9 participants visited the real theater.

**Equipment**

The experiment was conducted on a desktop Pentium 4 computer, running at 2.4 GHz, 512 MB RAM, supporting a GeForce 6600GT, and equipped with a 17" CRT screen. The computer was located in a room with artificial lighting.

**Procedure**

**Assessment of the models**

After a short exercise to practice navigating the 3D-model, participants were positioned in the lobby of the theater, with instructions to enter the corridor, and pass through the door into the theater hall. From there they were transported to a seat on one of the higher rows of chairs. Participants assessed the affective quality of the environment twice: in the corridor and in the theater hall. For this, we used the SMB-scale (Semantic Environmental Scale). It comprises 36 adjectives in eight dimensions that describe the experience of persons in a man-made environment (Küller, 1977; Küller 1991). The dimensions are: Pleasantness, Complexity, Unity, Enclosedness, Potency, Social Status, Affection, and Originality. In addition, questions were presented to elicit verbal reactions to the subjective impression of the spaces, the quality of the representation, and the perceived dimensions of the spaces traversed.

Besides determining the effect of the lighting condition on the affective appraisal and on distance perception, we wanted to assess participants' awareness of the differences in lighting between the two versions of the model. Therefore, after completing their assessment of one of the models, we asked the participants to briefly navigate the same path in the other version of the model, and to answer questions on the perceived difference between the two conditions.

**Assessment of the real theater**

A similar procedure was used to assess the real theater. Participants were led to the lobby of the theater and received instructions on how to proceed. Questions about the representation had been removed from the questionnaire. In this condition several additional factors may have influenced the assessment of the theater, such as the presence of the experimenter and maintenance personnel, and the lighting conditions in the theater that were not controlled by the experimenter. We can therefore only draw rather crude conclusions on the correspondence between the experience of the real theater and the modeled theater.

**Hypothesis**

We expected the lighting effects to enhance the depth perception, the perceived quality of textures, the information richness, and therefore the overall perceived quality of the represented theater. We expected to find differences in several dimensions of the SMB-scale, especially Pleasantness, Complexity, Enclosedness, and Social Status. We hypothesized that the affective appraisal of the enhanced model would be more similar to that of the real theater, than the appraisal of the degraded model.

**Results**

**Affective appraisal of the models measured by the SMB-scale**

The dramatic lighting effects inserted into the model show a significant effect only on the SMB-dimensions of Enclosedness and Originality in the corridor, and on none of the dimensions in the theater hall. In
the theater hall, the enhanced model scores higher on Complexity. In the corridor, the enhanced model does not score higher on Complexity, and even lower on Social Status, which is contrary to our hypothesis. A problem, that we also noted in earlier experiments (Houtkamp and Van Oostendorp, 2007), is that the reliability of some of the SMB-dimensions is low (Cronbach’s alpha < .6). In several dimensions we removed one item to improve the reliability. The results, including the adjusted dimensions, are shown in table 1, and figures 7 and 8.

**Comparison with the real theater**

The results of the experiment in the real theater must be used with care, because of the small number of participants (n=9), and factors mentioned above. An ANOVA-analysis and post-hoc analysis showed a significant difference (p<.05) in the appraisal of the corridor, between the degraded model and reality on the dimension Pleasantness; and between the degraded model and the enhanced model, and the degraded model and reality, on the dimension Originality. A weak effect was noted in the appraisal of the hall, between the enhanced model and reality on the dimensions Pleasantness (p=.055) and Originality (p=.084). In every case, the real theater scored higher, so participants in general found the real theater more pleasant and more original than the model. The information richness of the real theater may have contributed to this effect.

**Materials, decorations, lighting and atmosphere**

Questions were presented to participants to elicit verbal reactions to the subjective impression of the corridor and hall, and the quality of the representation. The answers only show a few marked differences between the versions, mainly in the identification of materials, and appreciation of their representation. Appreciation of the quality of the models in general was high: for the degraded version mean 7.71, for the enhanced version 7.88, on a scale from 1 -10.

For both model versions, and the real theater, the chandeliers, the illumination, the predominance of the color red, and the decorations were reported as especially characteristic. In all three conditions, participants described their affective response as festive, anticipative, impressed, and excited. About half of the participants referred to a feeling of recognition, to this or a similar theater, induced by the model.

After assessment of one version of the model, participants were presented with the other version. Many noticed differences in the representation as well as atmosphere (varying from 71 – 79%) but were not able to indicate in which respect both versions differed, until this was pointed out to them after the experiment. In the verbal comments, the enhanced version is appreciated slightly more than the degraded model, and elicited statements such as ‘more realistic’, ‘felt warmer’, and was ‘nicer to visit’.

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**Figure 7**
Mean scores on the SMB-dimensions, corridor

**Figure 8**
Mean scores on the SMB-dimensions, hall
### Table 1
Mean scores on the SMB-scale, corridor, and theater hall; version 0: degraded, unlighted model; version 1: enhanced, lighted model

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On the other hand, some of the participants appreciated the colors, and spaciousness, of the degraded version more.

Spatial Dimensions
Estimations of the dimensions of both corridor (except the height) and theater hall were higher in the enhanced version. The judgments of the view from the upper balcony in the enhanced model were more negative, stating it was rather high and far from the stage. This indicates that the perception of depth and distances is influenced by the manipulations in the models. However, the estimated distances in the enhanced version were not closer to the actual dimensions.

Conclusions and Discussion
The lighting conditions in our experiment only weakly determined the affective qualities of the 3D model. However, low Cronbach's alpha's for some of the dimensions indicate that the SMB-scale is perhaps not the optimal instrument for this research. The enhanced version appeared to give a more vivid sense of depth, but shadows and illumination did not improve dimension estimates.

The results of this study suggest that although viewers are susceptible to differences in lighting conditions when comparing scenes, they do not need specific lighting information when inferring affective qualities and dimensions of an environment. The models used in this study contain so many typical elements of a baroque style theater that they may invoke impressions of earlier visits to, or descriptions and images of, a similar theater, and induce subjective responses that are based on these mental representations and not only on the actual represented environment (Danford and Willems, 1975).

Further research is required to fully establish the effects of illumination and pre-existing mental representations on the affective appraisal of 3D environments, and to develop appropriate instruments to measure these effects.

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