EVALUATING COGNITION IN A WORKSPACE VIRTUALLY

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Abstract. In any built environment, there exist certain subtle stimuli that affect the occupants' cognitive processes and performance. This research intends to identify: (1) what environmental stimuli an office building would generate that could affect the habitants' cognitive ability, and (2) how the habitants react to these stimuli. The goals of the study are to develop a new method for using immersive virtual reality to represent a built environment for simulating environmental impact, and to discover factors that could influence habitants' cognitive performance in a space. It is expected that the discoveries could advance the application of virtual reality to study human cognition in architecture.

1. Introduction

Research in the field of "design studies" has examined how designers mentally process design tasks. Such studies apply theories from cognitive psychology to explore the cognitive processes involved in design thinking. Underlying this approach is the recognition of the human mind as an information processor. This idea can be further extended to study the relationships between human cognition and a built environment.

It is suggested in this research that a building is a living environment that interacts with occupants to generate sensory stimuli. Inside a building, given environmental stimuli would yield certain cognitive reactions. A healthy environment, then, should provide positive stimuli to promote productive cognitive responses. In office environments, for example, an open workspace is considered healthier than a confined space, as confined spaces tend to make most occupants feel claustrophobic. Occupants are thus affected by their environment because the human mind experiences architecture through visual perception (Eberhard, 2003). The way a person first responds to a particular space is likely to influence his/her perception of similar spaces encountered in the future, and may affect his/her cognitive performance in such spaces. The mechanisms and principles by which the human brain processes information is the focus of cognitive science (Anderson, 1995). Some of these mental activities, such as attention span and perception, are the essential cognitions for problem solving—a critical activity for many office occupants.

The environment surrounding the problem solver, then, can influence problem-solving ability. For example, the environment may be a source of distraction or stress, causing occupants to have difficulty concentrating and triggering changes in cognition. The goal is to discover and identify specific environmental factors that: (1) affect cognitive processes and (2) cause changes in problem-solving skills. For the purposes of this research, the effectiveness of cognitive performance defines the habitants' well-being in a given workspace, as well as the level of comfort that a working environment can potentially provide.

The conceptual framework developed in this study includes theories from the fields of cognitive science, human-computer interaction, and building performance. The methodology used should be able to visualize environmental factors and to record cognitive changes. One possible method is to virtually simulate the environmental factors and to observe their effects on subjects. In this study, the first of its kind, virtual reality is the means applied to measure the habitants' well-being and cognitive performance in a simulated workspace. The experiments and findings described in this paper are initial steps to test and validate the methodology and determine how to proceed with further studies.

2. Significance of virtual reality

Virtual reality (VR) is a technology that simulates objects and environments via three-dimensional computer models. In a VR model, the feeling of realism is derived from a sequence of high-resolution, stereoscopic images. If the display allows viewers to project themselves into the scene, then a virtual environment (VE) is created. If the scene is shown in full scale and viewers are surrounded by 3D images, an immersive environment is generated. The CAVE (Cave Automatic Virtual Environment), a room-sized, projection-based, high-resolution, 3D video and audio environment, has this capacity. In the immersive environments of the C4 (a three-sided) and C6 (a six-sided) CAVE facilities at Iowa State University, users have the sense of "being there," or the sense of presence experienced in the environment resulting from cognitive processes (Chan & Wang, 2005).

3. Sense of presence

The sense of presence (see Web page at http://www.presence-research.org/) is obtained through the human senses of sight, sound, taste, smell, and touch. Virtual displays must satisfy three conditions to generate the sense of presence through visual perception (Lombard and Ditton, 1997): image quality, image dimension, and view distance.

1. **Image quality:** The quality of a perceived image is determined by resolution, brightness, sharpness, contrast, color accuracy, and the absence of noise. High-quality images are acknowledged as more realistic (Reeves, Detenber, and Steuer, 1993).
2. **Image dimension:** Larger images evoke a variety of more intense presence-related responses. Experiments have shown that subjects who watched larger images experienced a greater "sensation of reality" and reported a greater "sense of participation" and "involvement" (Yuyama, 1982; Reeves, Detenber, and Steuer, 1993).

3. **View distance:** When viewers are physically closer to an image, they feel a greater sense of being a part of the image and therefore a greater sense of presence exists (Yuyama, 1982).

The immersive projection system (CAVE) fulfills these requirements, for it closely approximates actual size and distance with full-scale, high-resolution 3D objects generated in real time. Therefore, both three-sided and six-sided CAVEs (C4/C6) may create a very vivid sense of presence, compared to other VR facilities, e.g., head-mount display or bench, that do not provide full scale immersion. In this regard, experiments conducted in full-scale virtual environments (C4/C6) are valid replications of the experiences derived from real-world interactions. Figure 1 shows a virtual model of a Chinese temple displayed in the C4 facility at Iowa State University.

Figure 1. Photo of the C4 displaying a temple.

4. Sensory input and the sense of presence

What constitutes realism in virtual reality, and how do we measure it? One metric is the quantity and quality of sensory information perceived by the user. For instance, the more sensory input generated by a VR model, the greater the viewer’s response to stimuli and the stronger his/her sense of presence in the environment. One experiment interestingly indicated that adding motion and audio components to a VR model increased cognitive reactions to the environment. Even if the model consisted only of primitive forms with very simple color and low-resolution images, subjects were still able to immediately comprehend and react to the model. This might suggest that the quantity (the number of different types or categories) of sensory input is more significant than the quality (Chan, and Weng, 2005).

On the other hand, more realistic sensory input (high-resolution image, 3D stereo sound, or realistic smell) results in a better sense of presence. For instance, if a VR environment has only visual input, a very detailed, high-resolution model will provide a better sense of presence than a simple low-resolution model. This relates to the notions of between-group (across sensory) versus within-group (the same sensory). It is suggested that the between-group (more sensory) inputs would suppress within-group (single) sensory input.

5. Cognitive processes

A sense of presence is the result of a cognitive process. Attention is a key measure of this cognitive process. By definition, attention is the taking possession by the mind, in clear and vivid form, of one out of what seem to be several simultaneously possible objects or trains of thought (James, 1890). The concept of “attention” can be thought of as a filter for cognitive signals to avoid being overwhelmed with information. The amount of attention paid by a human to VR stimuli, then, reflects the amount of identification on the part of the person; the more he/she recognizes the environment as real, the greater the sense of presence in that environment.

Human intelligence can be defined as a neural mechanism or computational system, genetically programmed to be activated or “triggered” by certain kinds of internally or externally presented information. Changing the externally presented information will change the information input to our senses. This will cause different neural mechanisms to create different cognitive functions. Environmental factors in a space could potentially trigger some internally presented information, which in turn would cause different cognitive operations and performance. These factors, for example, could be space proportion, materials, lighting, temperature, ambient sound, or movement in a space (see Table 1). Different factors may also be weighted differently; certain humans may consider some factors more important than others. This article concentrates specifically on the impact of building materials on human perception.

TABLE 1. Environmental factors that would affect habitants’ cognition.

Environmental Factors	Senses
Materials used in the space (**texture** and **color**)	Sight
Space proportion and shape (orthogonal, curved)	Sight / body
Motion and movement (dynamic space / quiet space)	Body interaction
Lighting (direct light, indirect light, ambient light)	Sight
Temperature (hot, comfortable, cold)	Body
Ambient sound (**noise**)	Sound

6. Hypothesis

In design, building materials are used not only for structural and functional purposes, but also aesthetic purposes. Some materials, while potentially pleasing, cannot be used together due to technological and physical limitations; for instance, one cannot integrate bamboo and glass. Other materials can be physically assembled, but will produce incongruent visual combinations. Plywood and marble, for example, would generate such an awkward combination. In short, certain materials and combinations of materials, with varying colors and textures, provide a strong visual impact on human perception and have the potential to influence habitants’ comfort levels in a space. These materials, then, are critical to design.

The hypothesis is that certain materials are strongly associated with certain building typologies. Due to these associations, then, the use of certain specific materials implies that a building has a certain specific purpose.

Different materials used in a building would change the perception of the built environment. For instance, wood is a very common building material used mostly in unremarkable contexts. Marble, however, is used mostly for public and civic buildings to convey a sense of grandeur. If a traditionally wooden texture were changed to marble, it may be difficult for occupants to psychologically accept the new environment. In other words, if a material is used in an unconventional design context, then it will be visually attended and may evoke a negative reaction. A study was arranged to explore the relationship between the materials used in a room and the resulting visual perceptions of that room.

7. Methods and experimental sequences

An existing office building was selected for modeling in virtual reality (see floor plan shown in Figure 2). This space consists of twelve single-occupancy cubicles used by the General Services Administration in Washington, DC. The cubicle spaces are divided by partition walls, which have metal frames and panels covered in gray fabric (Figure 3). In this study, a digital master model, which closely represents the existing space, was created (Figure 4). Six variations based on the master model also were generated; in each instance some textures were changed, such that it appeared to be constructed from a different material.

Figure 2. Floor plan.

Figure 3. Actual cubicle partitions.

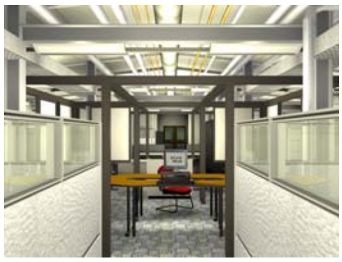

Figure 4. Master model.

These six models were converted to virtual reality format and displayed in the C4, where the experiments were held. The models were divided into two groups. The three models in the first group (see Figure 5) applied the same material to all components (boards, signs, partition walls, and frames): a light brown oak texture, (model 2), a dark brown cherry wood texture, (model 3), and marble texture (model 4). The models in the second group (see Figure 6) only used the same material for partition walls: oak (model 5), plywood (model 6), and marble (model 7).

Figure 5. Oak, cherry, and marble used for all components.

Figure 6. Oak, plywood, and marble used for partitions only.

The subjects, including faculty members and college students, were first exposed to the master model to familiarize themselves with the experiment and the interface, and to give them an idea of the office floor plan. Subjects would then navigate the remaining models in the given sequence. There was no time limit for navigation of the models; however, the time required to load new models into the system was approximately one minute, which provided subjects with a break between models.

In the process, subjects would visually perceive the model. They were then asked to score each model based on the level of comfort derived from the visual experience on a scale from one to nine, where a one represents a very uncomfortable experience, and a nine represents a very comfortable experience. The entire experimental process took about one hour. Figure 7 is the office as seen in the C4.

Figure 7. The office model displayed in the C4.

8. Experimental results and data analyses

Ten subjects participated in the experiments. Five subjects were undergraduate architecture majors ranging from freshman to senior level, whereas the other five subjects of faculty and students were not architecture majors. Theoretically, subjects trained in architecture should have the design knowledge and background to perceive a space in more detail than non-architecture majors. However, the data obtained from this experiment series (see Table 2) showed similar patterns between the two groups. For instance, if the same material was applied to all structural components and partition walls—as in the first model group displaying oak, cherry, and marble textures—the level of comfort (4.42) was less than that derived when the same material was used only for partition walls (5.48 for the second model group of oak, plywood, and marble), regardless of whether the subject was an architecture or non-architecture major.

Non-conventional materials tended to yield low perceived levels of comfort in the office setting. Dark cherry and light marble used for all structural elements and partition walls were not welcomed visually. The oak partition, on the other hand, resulted in a consistently high score across the two subject groups (higher even than oak used for all components). This is likely due to two reasons: (1) it has a very light color which is perceived more comfortable, and (2) oak has been used in most furniture design and conventionally used in partition walls in the US. It might be a culturally/geographically based result.

TABLE 2. Scores of cognitive reaction to visual perception.

	Models	**Arch**	**NonArch**	**Material**	**Group means**
Group 1	Oak	5.3	6.2	5.75	
	Cherry	3.6	3.8	3.7	4.42
	Marble	3.4	4.2	3.8	
Group 2	Oak	7	7	7	
	Plywood	5.4	4.9	5.15	5.48
	Marble	3.7	4.9	4.3	

9. Discussion

In this experiment, subjects were required to first familiarize themselves with the master model, then use it as a standard pattern representing an office and commit it to memory. When subjects navigated later models, they would theoretically be able to recall the stored master image to compare with the new images perceived. In this experiment, subjects only memorized a part of the image in detail if they had paid attention to particular details and could recall them after the model changed. Unlike still images or photographs, VR models are complicated, rich, and dynamic. Much like walking in a real physical environment, viewers can obtain/perceive information in the VR environment only by paying careful attention to their 3D surroundings. As such, while viewers were in the VR environment, all perceived detail would generate tremendous visual cues to stimulate various responses. Since visual cues obtained in a full scale immersive VR environment are vivid and continuous, subjects could recall the attended parts, identify and explain the changes in certain details across models. Therefore, visual attention paid in the 3D VR settings required higher level of cognitive efforts, whereas browsing through 2D images mostly used the pattern recognition sections of the brain. In short, visual attention plays an important role in navigating the VR models and in cognitive response to stimuli in the virtual environment.

10. Conclusions

Attention allows the mind to perceive and recognize changes in a built environment. After the images are perceived, related knowledge stored in memory theoretically is recalled and applied for making judgments, which should influence how habitants react to the environment. But, in this experiment, domain-specific knowledge was not really significant to how subjects felt about the environment. Instead, the materials used were the critical factor affecting subjects' perceptions, as they generated strong impressions about the character of the space. Any unconventional uses of materials would affect visual perception, which would yield certain cognitive responses.

In sum, the application of virtual reality proved an efficient method for this preliminary study, which demonstrated to some degree that materials used in a building are a major factor affecting visual perception. Further studies could involve more subjects from different backgrounds to verify that differences in prior architecture and design knowledge do not really affect the impact of materials used in design. Future studies also should explore more environmental variables—such as proportion, lighting, motion—that would affect human visual perception.

Acknowledgements

This project was funded by the American Institute of Architects and the General Services Administration from 2002 to 2005. Results and observations generated in this article are the author's interpretations. Thanks go to YuNgok Lo and Qian Chen for their skill and devotion in creating the digital models. Credit also goes to members of the Architecture Cognition Group at Iowa State University for managing the VR facilities and operating the cognitive experiments.

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