CHAPTER IV.
RESULTS

This chapter reports the data analyses. First, the description of the sample is presented. Second, the results of analyzing the data from the experimental test and testing hypotheses are reported. Third, the results of the data analyses from the interview are reported.

Description of the Sample

Age

A total of sixty subjects participated with most participants in the 21–50 age group. Eighteen (30 %) were 21-30 years old. Fifteen (25 %) were 31-40 years old. Seventeen (28.3 %) were 41-50 years old. Seven (11.7 %) were 51-60 years old. Three (5 %) were 61-70 years old.

Thirty of the sixty were assigned to each of the two groups (the PC group and the CAVE^{TM} group) by matching subjects according to the screening test scores. Figure 24 illustrates the frequency of age range of the two groups.

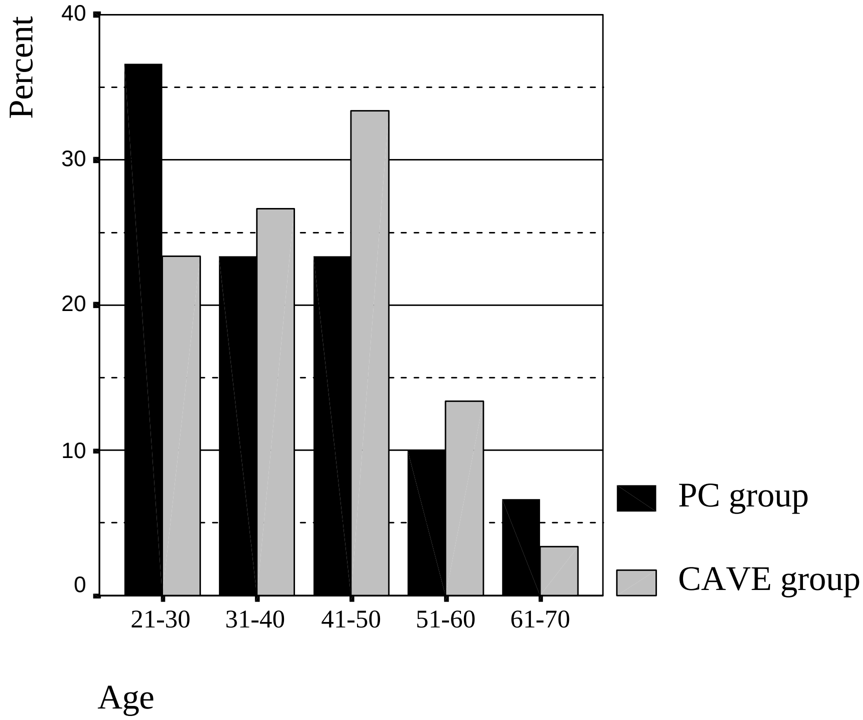

Figure 24. Frequency of the Age Range of the Two Groups.

In the PC group, eleven of the thirty subjects (36.7 %) were 21-30. Seven (23.3 %) were 31-40 years old. Seven (23.3 %) were 41-50 years old. Three (10 %) were 51-60 years old. Two (6.7 %) were 61-70 years old. In the CAVE™ group, seven (23.3 %) were 21-30 years old. Eight (26.7 %) were 31-40 years old. Ten (33.3 %) were 41-50 years old. Four (13.3 %) were 51-60 years old. One (3.3 %) was 61-70 years old.

Gender

There were more females than males in the study. Thirty-four of the total sixty subjects (56.7 %) were female. Twenty-six (43.3 %) were male. In the PC group, eighteen of thirty subjects (60 %) were female while twelve (40%) were male. In the CAVE™ group, sixteen of thirty subjects (53.3 %) were female while fourteen (46.7 %) were male. Figure 25 presents the frequency of the gender of the two groups.

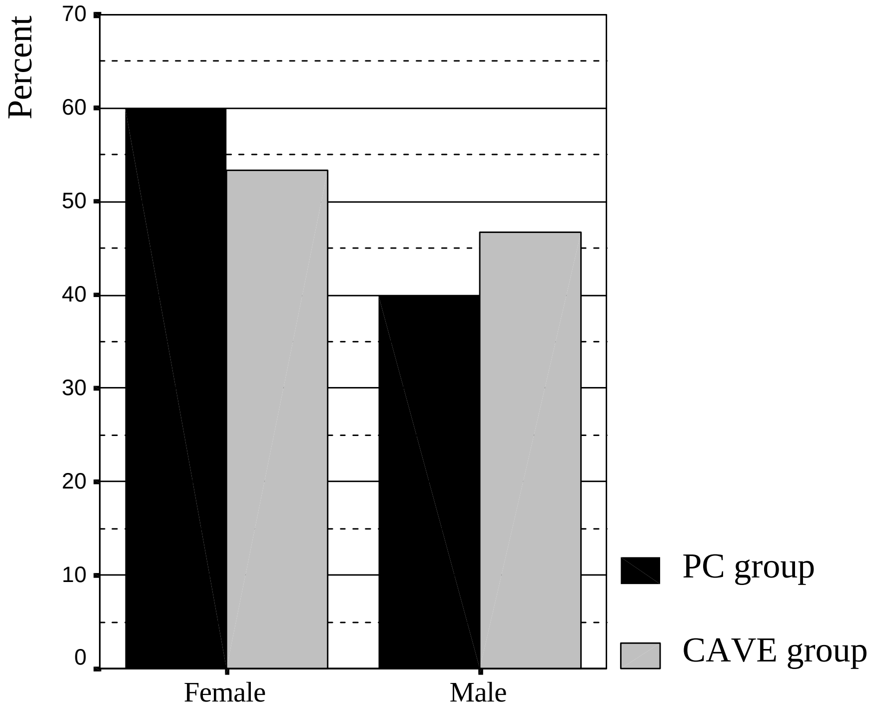

Figure 25. Frequency of the Gender of the Two Groups.

Occupation

The subjects' occupations were divided among faculty (38%), staff (33%), and graduate students (28%). Twenty-three of the total sixty subjects were faculty. Twenty were staff. Seventeen were graduate students. In the PC group, twelve (40%) of the thirty subjects were faculty, eight (26.7 %) were staff, while ten (33.3 %) were graduate students. In the CAVE™ group, eleven of the thirty subjects (36.7 %) were faculty, twelve (40 %) were staff, while seven (23.3 %) were graduate students. Figure 26 illustrates the frequency of the occupations of the two groups.

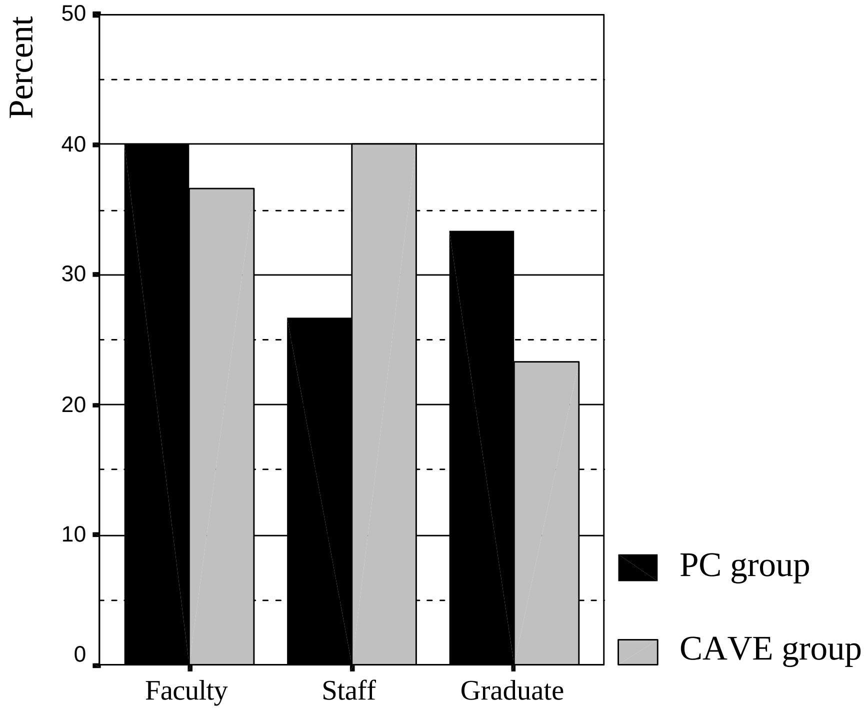

Figure 26. Frequency of the Occupation of the Two Groups.

Subjects, matched according to the screening test score and random assignment to two groups, equated individual differences on the dependent variables. Therefore, differences of age, gender, and occupation in the two groups would not affect the results in this study.

Results of the Experimental Test

The data from the experimental test were analyzed statistically to test the four research hypotheses.

Research Hypothesis One: the Accuracy of Participants' Perceptions of Visual Forms

Research Hypothesis One: Participants' perceptions of visual forms shown the simulation in the CAVE™ will be more accurate than those of participants shown the simulation on the PC monitor.

This hypothesis was tested with three measures of the variables of shape, proportion, and size.

1) Shape

Question two asked participants to choose a drawing out of four drawings that represented the shape of the reception room floor (See Appendix C). The correct answer was drawing b. The majority, 19 (63.3 %), in the CAVE™ group were correct, while only one (3.3 %) in the PC group had the correct answer. The significant result of the Chi-square indicated that more participants in the CAVE™ group chose correct answers to the question about shape (X^2=24.3, p=0.000).

Table 9. Frequency of the Question about Shape.

	CAVE™	PC	Total
Correct	19 (63.3%)	1 (3.3%)	20
Incorrect	11 (36.7 %)	29 (96.7%)	40
total	30	30	60

X^2 (1, N = 30) = 24.3, $p < .05$, s.

2) Proportion

Question four asked participants to choose a ratio out of four ratios that was the ratio of the width to the length of the conference room floor. The right answer was 1:1.5. The majority, 23 (76.7 %), in the CAVE™ group were correct, while 14 (46.7 %) in the PC group had the correct answer. The significant result of Chi-square indicated that more participants in the CAVE™ group chose correct answers to the question about proportion (X^2 = 5.711, p=0.017).

Table 10. Frequency of the Question about Proportion.

	CAVE™	PC	Total
Correct	23 (76.7%)	14 (46.7%)	37
Incorrect	7 (23.3 %)	16 (53.3%)	23
	30	30	60

X^2 (1, N = 30) = 5.711, $p < .05$, s.

3) Size

Question ten asked participants to choose the largest of four desktops in the presentation room. The right answer was the middle right one. The majority, 27 (90 %) in the CAVE™ group chose the correct answer, while no one (0 %) in the PC group chose it. The significant result of Chi-square indicated that more participants in the CAVE™ group chose correct answers to the question about size ($X^2 = 49.091$, p=0.000).

Table 11. Frequency of the Question about Size.

	CAVE™	PC	Total
Correct	27 (90 %)	0 (0 %)	27
Incorrect	3 (10 %)	30 (100 %)	33
	30	30	60

X^2 (1, N = 30) = 49.091, p< .05, s.

According to the results of Chi-square, more participants in the CAVE™ group gave correct answers to the questions about shape, proportion, and size, which were measurements of accuracy of the perception of visual forms. The results were statistically significant. Therefore, research hypothesis one was supported. Participants' perceptions of visual forms shown simulation in the CAVE™ were more accurate than those of participants shown simulation on the PC monitor.

Research Hypothesis Two: the Accuracy of Participants' Perception of Spatial Relationships

Research Hypothesis Two: Participants' perceptions of spatial relationships shown the simulation in the CAVE™ will be more accurate than those of participants shown the simulation on the PC monitor.

This hypothesis was tested with three measures of the variables of distance, depth, and proximity

1) Distance

Question one asked participants to estimate the width of the entrance door of the reception room and to choose one of the four multiple choices. The correct answer was 4 ½ feet.

The majority, 18 (60%), in the CAVE™ group had the correct answer, while only seven (23.3%) in the PC group had it. The significant result of the Chi-square indicated that more participants in the CAVE™ group chose correct answers to the question about distance ($X^2 = 8.297$, p=0.004).

Table 12. Frequency of the Question about Distance.

	CAVE™	PC	Total
Correct	18 (60 %)	7 (23.3 %)	25
Incorrect	12 (40 %)	23 (76.7 %)	35
total	30	30	60

X^2 (1, N = 30) = 8.297, $p < .05$, s.

2) Depth

Question three asked participants to estimate the length of the area with red chairs in the reception room and to choose one of the four multiple choices. The correct answer was 16 feet. Ten (33.3 %) in the CAVE™ group chose the correct answer, while fifteen (50 %) in the PC group chose it. However, the result of Chi-square showed that there was no statistical difference between the two groups ($X^2 = 1.714$, p=0.190).

Table 13. Frequency of the Question about Depth.

	CAVE™	PC	Total
Correct	10 (33.3%)	15 (50 %)	25
Incorrect	20 (66.7%)	15 (50 %)	35
total	30	30	60

X^2 (1, N = 30) = 1.714, $p > .05$, s.

3) Proximity

Question nine asked participants to choose the closest chair to them of four chairs in the presentation room. The correct answer was the beige chair. The majority, 27 (90 %), in the CAVE™ group were correct, while eight (26.6 %) in the PC group had the correct answer. The significant result of Chi-square indicated that more participants in the CAVE™ group chose correct answers to the question about proximity ($X^2 = 24.754$, p=0.000).

Table 14. Frequency of the Question about Proximity.

	CAVE™	PC	Total
Correct	27 (90 %)	8 (26.6 %)	35
Incorrect	3 (10 %)	22 (73.3 %)	25
total	30	30	60

X^2 (1, N = 30) = 24.754, $p < .05$, s.

In the case of the questions about distance and proximity, more participants in the CAVE™ group gave correct answers to the questions. The results were statistically significant. In the case of the question about depth, more participants in the PC group chose correct answers, but there was no statistically significant difference between the two groups. Because two measures of three measures were significant, research hypothesis two was supported. Participants' perceptions of spatial relationships shown simulation in the CAVE™ were more accurate than those of participants shown simulation on the PC monitor.

Research Hypothesis Three: the Accuracy of Participants' Perception of Colors

Research Hypothesis Three: Participants' perceptions of colors shown the simulation in the CAVE™ will be more accurate than those of participants shown the simulation on the PC monitor.

This hypothesis was tested with three measures. The variables of value, chroma, and hue were analyzed statistically by using T-test.

1) Value

Question five asked participants to mark all squares that were same as the test square above the set of sixteen squares on poster one in the conference room. When a participant marked all of the five squares that were the same as the test square, he/she received 10 points. In any other case, he/she received two points per right square, but two points were deducted per wrong square. The t-test results showed that the mean of the score of the question about value in the PC group was significantly higher than that of the CAVE™ group ($p=0.003$, $alpha=0.05$).

Table 15. Means and Standard Deviations of the Scores of the Question about Value.

	N	M	SD
CAVE™	30	7.5333	4.5994
PC	30	9.9333	0.3651

Table 16. T-test of the Question about Value.

F	Sig.	t	df	Sig.(one-tailed)
28.213	0.000	2.849	58	0.003

2) Chroma

Question six asked participants to mark all squares that were same as the test square above the set of sixteen squares on poster two in the conference room. When a participant marked all of the five squares that were the same as the test square, he/she received 10 points. In any other case, he/she received two points per right square, but two points were deducted per wrong square. The t-test results showed that the mean of the score of the question about chroma in the PC group was significantly higher than that of the CAVE™ group ($p=0.000$, $alpha=0.05$).

Table 17. Means and Standard Deviations of the Scores of the Question about Chroma.

	N	M	SD
CAVE™	30	-3.4333	4.7828
PC	30	4.6667	4.7075

Table 18. T-test of the Question about Chroma.

F	Sig.	t	df	Sig.(one-tailed)
0.000	0.988	6.611	58	0.000

3) Hue

Question seven asked participants to mark all the squares that were same as the test square above the set of sixteen squares on poster three in the conference room. When a participant marked all of the five squares that were the same as the square, he/she received 10 points. In any other case, he/she received two points per right square, but two points were deducted per wrong square. The T-test results showed that the mean of the score of the question about chroma in the PC group was significantly higher than that of the CAVE™ group (p=0.000, alpha=0.05).

Table 19. Means and Standard Deviations of the Scores of the Question about Hue.

	N	M	SD
CAVE™	30	5.8000	5.6654
PC	30	9.8000	0.8052

Table 20. T-test of the Question about Hue.

F	Sig.	t	df	Sig.(one-tailed)
38.688	0.000	3.829	58	0.000

According to the results of T-test, more participants in the PC group than the CAVE™ group gave correct answers to the questions about value, chroma, and hue that were measurements on accuracy of the perception of colors. The results were statistically significant. Research hypothesis three was not supported. Participants' perceptions of colors shown simulation on the PC monitor were more accurate than those of participants shown simulation in the CAVE™.

Research Hypothesis Four: the Accuracy of Participants' Perception of Textures

Research Hypothesis Four: Participants' perceptions of textures shown the simulation in the CAVE™ will be more accurate than those of participants shown the simulation on the PC monitor.

This hypothesis was tested with two measures of the variables of roughness of texture and size of texture.

1) Roughness of texture

Question eight asked participants to mark all tiles that have the roughest texture. When a participant marked all of the five tiles that have the roughest texture, he/she received 10 points. In any other case, he/she received two points per right square, but two points were deducted per wrong square. The mean of the PC group was higher than that of the CAVE™ group, but T-test results showed that there was no significant difference between two groups (p= 0.1985, alpha=0.05).

Table 21. Means and Standard Deviations of the Scores of the Question about Roughness.

	N	M	SD
CAVE™	30	7.0000	4.2264
PC	30	7.9333	4.2502

Table 22. T-test of the Question about Roughness.

F	Sig.	t	df	Sig.(one-tailed)
0.314	0.577	0.853	58	0.1985

2) Size of texture

Question eleven asked participants to mark all tiles that have the smallest size of texture. When a participant marked all of the five tiles that have the smallest size of texture, he/she received 10 points. In any other case, he/she received two points per right square, but two points were deducted per wrong square. The mean of the CAVE™ group was higher than that of the PC group, but t-test result showed that there was no significant difference between the two groups (p= 0.3785, alpha=0.05).

Table 23. Mean of Scores of the Question about Size of Texture.

	N	M	SD
CAVE™	30	0.4000	6.0207
PC	30	-0.1333	7.2194

Table 24. T-test of the Question about Size of Texture.

F	Sig.	t	df	Sig.(two-tailed)
2.869	0.096	-0.311	58	0.3785

The results of questions about roughness of texture and size of texture, which were measurements of accuracy of the perception of textures, did not show statistical differences between the two groups. Research hypothesis four was not supported. There were not statistical differences between participants' perceptions shown the simulation in the CAVE™ and those of participants shown the simulation on the PC monitor.

Results of the Interview

Description of the Simulation

Question 12 asked participants to describe, in as much detail as possible, what they saw in the simulation, starting at the beginning. As discussed in Chapter III, the data from question 12 were analyzed by two categorical methods. The first category was whether their descriptions seemed to indicate that the participants were oriented to the spaces. The second category refers to how much detail the participant related about the VALAB.

1) Orientation to spaces in the spaces of the VALAB

Participants' whole descriptions were investigated whether they described the correct sequence or directions of rooms that they saw in the simulation. Oriented participants generally understood how the spaces in the lab were arranged. The correct description of the sequence was that they entered the reception area, went to the presentation room, went back to the reception area, went to the conference room, went back to the reception area, went to the observation room, and went back to the reception area. The correct description of the direction was that there are the reception area in the center, the conference room to the front, the presentation room to the right, and the observation room to the left.

Majority of participants in both groups was oriented without showing much difference. Eighteen (60 %) in the CAVE™ group were oriented, and 17 (57 %) in the PC group were oriented. However, slightly more participants tended to experience the simulation actively in the simulation in the CAVE ™. Twenty nine (97 %) in the CAVE™ group and 24 (80 %) in the PC group described as if they were actively walking through the spaces during the simulation as the following: "I walked into…," "I entered…," or "I passed…," Six (20 %) in the PC group and one (3 %) in the CAVE™ group described passively as if they observed the simulation as follows: "I saw…," "I noticed…," or "The simulation started.…"

2) Detail related to the VALAB

More participants in the CAVE™ group gave detailed descriptions of the interior than the PC group. For example, when participants described the reception counter, participants in the PC group typically said "reception desk" or "reception counter". In contrast, participants in the CAVE™ group said more detail as follows:

- "semi-circular reception desk"
- "curved reception table with a notepad and a pen"
- "green glass jar with red flowers on the table"

A frequency count of these detailed descriptions was made. The results indicated that 25 (83 %) in the CAVE™ group gave the more detailed descriptions about the reception counter while only 14 (47 %) in the PC group did.

Another example was their descriptions about what they saw through the large glass window in the observation room. Participants in the PC group said, "the human figure through the window" while participants in the CAVE™ group described more details as follows:

- "human figure with some sort of facility through the window"
- "human figure with some sort of facility and some red lines behind the human figure through the window."

Nine (30 %) in the CAVE™ group gave the more detailed description while 3 (10 %) in the PC group did.

Some participants in the CAVE^{TM} group gave very detailed descriptions, which were not given in the PC group, as follows:

- " The wording, CAVE^{TM}, looked three-dimensional and looked like it was carved into the wall."
- "The windows looked like bay windows in a house. They were recessed to the wall windows on three edges of the walls looking out of the hallway."
- "Dark brown file box with black knobs."

The findings on detail indicated that participants in the CAVE^{TM} group noticed more details.

General Perception of the Simulation

Question 13 asked the participants how they felt while they watched the simulation. This question was asked in order to obtain their general perceptions. The responses were categorized into the following: fascination with the technology, physical sensation, sense of presence, and a three-dimensional perception.

1) Fascination with the Technology

The participants' general perceptions during the simulation were classified by whether they were intrigued by the simulation. The intrigued participants described their perceptions by using the words, 'interesting,' 'amazing,' 'exciting,' or 'fascinating.' Slightly more participants tended to be intrigued by the simulation in the CAVE^{TM}. Fourteen (47 %) in the CAVE^{TM} group indicated that they were intrigued while nine (30 %) in the PC group were.

In the PC group, the participants' interests focused on the movement of walking through the room as follows: "It was kind of exciting. I tried to picture myself, walking through, observing details. It was a new experience. It was kind of anticipation of what is there, what is next, what to expect, what I am looking at." In the CAVE^{TM} group, their interests focused on walking through, as well as the three-dimensional feeling as follows: "It was cool. It was really neat. I really enjoyed it. It looked like real three-dimensional. I felt like I was moving through."

2) Three-dimensional perception

Three-dimensional perceptions were described by the words, 'three-dimensional', 'depth', and 'feeling of space'. Slightly more participants tended to have three-dimensional perceptions in the simulation in the CAVE^{TM}. Eleven (37 %) in the CAVE^{TM} group had feelings related to three-dimensional effects while three (10 %) in the PC group had.

Participants in the CAVE^{TM} group described the definite three-dimensional perceptions as follows:

- "It was three-dimensional."
- "There was depth from how far away."

Participants in the PC group described their perceptions related to three-dimensionality as the following: "It gave the feeling of space." On the PC, the movement of walking through helped the participants feel three-dimensional spaces. A participant in the PC group said, "It was a lot better than looking at pictures. When I followed the walk-through the rooms, I felt like I was moving through something instead of looking at pictures." However, other participants pointed out the lack of three-dimensionality in the simulation on the PC:

- "It was hard to picture the third-dimension. We can imagine it, but we can't really see it."
- "It was like looking at a set of elevations except for the effect that we moved in."
- "It was obviously two-dimensional on the screen, but it tried to convey three dimension to it. But it wasn't."

3) Sense of Presence

Participants described sense of being present in the simulated spaces as follows: 'I felt like I was walking through..' and ' I felt like I was in.." Slightly more participants tended to have the sense of presence in the simulation in the CAVE^{TM}. Eleven (37 %) in the CAVE^{TM} group mentioned the sense while three (10 %) in the PC group did.

Most of participants' descriptions about the sense of presence in the CAVE^{TM} group were direct: "I felt like I was actually exactly standing in the room." Also, participants in the CAVE^{TM} group described the feeling present in the full-scale and surrounded spaces as follows:

- "It was really amazing; we could look and actually turn our heads and see things."
- "I was a real person in there."

In the PC group, most of participants described the sense of presence with movement of walking through the spaces: "I felt I was walking through the space." The movement of walking through helped the participants have a feeling of being in the spaces on the PC. However, eight participants mentioned that absence of peripheral vision and small scale on the PC screen hindered the feeling of being present in the following statements:

- "I felt I was an outside observer looking at a doll house. I never felt I was in it."
- "Here it was looking at a certain size of screen. It tried to show the ceiling, but you don't get the feeling you are really in there."
- "I felt out of the room somewhat. I didn't know if I would put my feet on the floor. I didn't feel I was in the same perspective with things around me."
- "We had no perception of peripheral vision or anything about what we were doing in reality. We see everything to 270 degrees almost. Here was just looking at one plane. We are taking in the complete environment from top to bottom, from left to right in addition to looking at it. Here just looking at a certain size of screen. It tried to show the ceiling, but you don't get the feeling you are really in there."

4) Physical Sensation

Some participants mentioned their physical discomfort during the simulation. The reason for physical discomfort was because of limitations of movement and lighting. The majority in both groups felt physical discomfort during the simulation. Slightly more participants tended to have physically uncomfortable feeling in the simulation in the CAVE™. Twenty (67 %) in the CAVE™ group felt physical discomforts while 16 (53 %) in the PC group did.

The major reason of the physical discomfort in both groups was the movement of the walking through, which was the walk-through animation on the PC and the point to point navigation in the CAVE™. Participants described the physical discomfort feelings by using the words, 'dizzy,' 'disoriented,' 'anxious,' 'queasy,' 'headache,' or 'motion sickness.' The participants said that they felt uncomfortable because the movement was jerky, and they could not control the movement. They said that the movement was like riding a car rather than walking. Examples of the descriptions of the physical discomfort in both groups are as follows:

- "I felt unsteady. It was not a normal pace of walking, a little bit jerky."
- "I felt disoriented, some kind of dizzy. I felt like I was controlled over what I was looking at"
- " The speed of movement hindered the reality of it because it was not the speed I would go."

In addition to the jerky motion, the participants in the CAVE™ group mentioned unusual feelings caused because their surroundings were moving, but their body did not move:

- "I felt queasy at one point. The movement, but I was not actually moving. I didn't have a lot of balance."
- "First, I felt unusual because there was motion but my body wasn't moving. Things were moving about me, but I wasn't the cause of it, so I felt a little bit out of control."

Lighting caused another reason for physical discomfort. The participant in the PC group said that lighting that was flashing on the wall irritated their eyes. The participants in the CAVE™ group said they felt discomforts to their eyes because the lighting was dim and the images were not clear.

Realism of the Simulation.

Question 14 asked how close the simulation was to reality. Slightly more participants tended to feel reality in the simulation in the CAVE™. Twelve (40 %) in the CAVE™ group said the simulation was close to reality while eight (27 %) in the PC group did. Eleven in the PC group and eleven in the CAVE™ group said that the simulation was not close to reality. Other participants did not say exactly whether it was close to reality or not. The participants described what aspects made the simulation close to reality or what limitation of the simulation hindered reality.

In the PC group, the participants described the aspects that made the simulation real as follows:

- "Colors were vivid. Furnishings looked real."
- "It was close to reality. It gave the feeling of space when I was walking through and looking around"
- " It was pretty real. I could visualize what was supposed to be there and how it was supposed to look."

In the CAVE™ group, the participants described the aspects as follows:

- "It was close to reality. I enjoyed it. It would be a great way to show like a design that you are doing or something and what it would look like when it's built and you can go in look at something in it. I think that will be great."

- “It was definitely 3D in that aspect it’s kind of neat because actually we can see overall shape, placement of things.”
- “Mostly, rooms seemed to be very right on perspectives and dimension.”
- “The perspective idea, you going from left to right and getting close to an object, was close to reality.”
- “ I felt I was moving. We were getting too close. Chairs looked like chairs. Everything looked realistic.”
- “It was a realistic sense of moving through rooms.”
- “It gave a feeling of being actually in that particular room or area.”

However, many participants in the PC group pointed out the limitations that hindered reality as graphic quality, lighting, movement, three-dimensional effects, perspective effects, scale, and lack of information. In the CAVE™ group, somewhat similar and somewhat different limitations were underlined in terms of graphic quality, lighting, movement, and lack of information. Participants mentioned the limitations with suggestions when they answered about improvement of the simulation in the question 15.

<u>Improvement of the Simulation</u>

Question 15 asked what should be made different to improve the simulation. Table 25 presents the limitations mentioned by participants and their suggestions for improvement of the simulation as well as showing the categories of participants’ responses.

Table 25. Limitations Mentioned and Suggestions by the Participants.

Limitation		Description by participants	Suggestion by participants
Graphic quality	PC & CAVE™	• Image looked like cartoon or drawing. • Color is too bold and solid. • Texture looked flat • Objects were less detailed	• Make less cartoonish • More color graduation • More texture & 3D texture • More details of objects
	CAVE™	• Images were not clear and looked fuzzy.	• Brighter lighting • More pixels
Lighting	PC	• Round light was flashing on the walls.	• Removal of the cause of flashing.
	CAVE™	• It was dim and dark. • Bright spot in the center. • Not uniform lighting.	• Brighter lighting. • Uniform lighting.
Movement	PC & CAVE™	• Jerky • Slow • Lack of control • Different from walking pace	• Smoothness of walking through • Speed up • Interactive self navigation mouse control in real time
	CAVE™	• Noticeable frame separation while moving. • No body movement coupling movement of visual field.	• Speed up in order not to aware the frame separation or using more powerful computer. • Synchronization of screen movement and body movement.
3D effect	PC	• Limited vision without peripheral vision on the small computer screen • Two-dimensional images and no depth	• Showing side views • Three-dimensional images • Putting moving objects to show depth
	PC & CAVE™	• Not showing where is lighting source and no shadows.	• Showing lighting source and shadowing
	CAVE™	• More three-dimensional effects • No shadowing • Noticeable lines in the corner of the CAVE™ • Bent lines distorted in the corner of the CAVE™	• More objects • Clear lighting and shadowing • Curved or continuous screen to make the corner of the CAVE™ less noticeable • Removal of distortion or wearing the tracking glasses.
Perspective	PC	• While moving, exaggerated perspective changes happened as followings: angles were changing, sizes were changing, lines were shrinking and expanding.	
Scale	PC	• Small scale	• Actual size
Necessary information	PC	• Difficulty to know the locations	• Showing overhead views
	PC & CAVE™	• No standard references for measuring • Less things	• Putting standard references like human figure. • Putting more objects
	CAVE™	• Less sensory • Not solid	• Putting sound or smell • Solid touching

1) The limitation of graphic quality

In terms of graphic quality, the participants in the PC group and the CAVE™ group showed the same opinions. Many participants mentioned a graphic quality that was not detailed enough, color that was too bold, and texture that looked flat. In addition, the participants in the CAVE™ group mentioned the lack of clarity of the images.

2) The limitation of lighting

Although lighting of the simulation on the PC and the simulation in the CAVE™ were different because the lighting made by 3D Studio software was not be able to import into the CAVE™, participants in both groups mentioned the limitation s of lighting. Some participants in the PC group said that the flashing light caused by omni light from 3D Studio software on the wall distracted from reality. Participants in the CAVE™ group mentioned strange and dark shading and brighter light in the center, which was caused by light from the Saranav program. Also, participants in the both groups mentioned that the simulation needed more appropriate lighting and shadowing to show depth. It is said that they did not know where the lighting sources were, and they did not see enough shadowing.

3) The limitation of movement

In terms of movement, the participants in both groups pointed out that the movement was jerky, slow, out of control, and different from a normal walking pace. Previously mentioned in the physical feeling, these limitations of movement caused physical discomforts. In addition to these limitations, the participants in the CAVE™ group pointed out the noticeable frame separations when it was moving as follows:

- "There were frame separations. I didn't feel like it was reality in that sense. If you think about the real old cartoons there are different frames of separations."

4) Lack of three-dimensional effects

As previously mentioned, the participants in the PC group described the lack of three-dimensionality. It was said that the simulation was two-dimensional, and they had no depth perception and peripheral vision.

The participants in the CAVE™ group had three-dimensional perceptions with peripheral vision, but they mentioned the noticeable corner of the CAVE™ facility and distortion in the corner hindered their three-dimensional feeling and reality:

- "I think that the corners of the viewing area conflicting with the simulated room corners really detracted from my ability to see the simulated room. I was trying to match up the areas somehow. When we were standing in one spot, this became more obvious."
- "Some with the glasses, not a special one, some lines as the walls of the CAVE™ facility, I noticed bend a little bit. When I wear the special glasses (tracking glasses) it goes away. I noticed it changed a little bit."

5) Perspective problems

In the PC group, the participants mentioned strange perspective effects. They pointed out the perspectives, which changed when movement happened on a two-dimensional computer screen, were different from reality. These perspective problems were not mentioned in the CAVE™ group. Participants in the PC group said that the perspective problems hindered reality as followings:

- "Perspective changes that happen don't really follow reality. That's notable effect of movement, but in reality, it was distortion."
- "I had a really hard time to figure out what the shape of the room was. I noticed the way that objects were taking on different shapes when we were simulating movement. It was not something that I notice in reality. Like chairs getting bigger or a side of a wall changed angle. It still looked very flat, not three-dimensional."
- "Something else weird when I was watching it was, when I am in real space when I look around, I realize perspective changes, but I don't have the sense of things shrinking and expanding. In the simulation, it was very weird that when I looked around the room, angles were changing and things were expanding. I felt like I was Alice in Wonderland. It was very exaggerated for me."

6) The limitation of scale

The small scale of the simulation on the PC screen was pointed out as a limitation in the

PC group. They pointed that the small screen of the PC limited the simulation. They said that scale is different from real environment and everything looked little.

7) Lack of information

The participants in both groups said that they needed more information to understand the spaces and feel reality. Participants in the PC group said they needed to see overhead views as follows:

- " I wished that I had seen a floor plan of the places before I had walked through. I would like to know which room I was going into and where were the relations to get the places."

Some participants mentioned that they had just visual senses, so they could not have other sensory feelings as follows:

- "It was good simulation, but not close to reality. I didn't feel I had full sensory, all the information I need to interpret the environment."
- "I didn't feel like I was in a real room. I knew that I reached out but my hand went through it. I didn't feel very solid."

<u>Difficulties Related to the Experimental Test</u>

Difficulties in answering questions of the experimental test, which were mentioned in the interview by participants, were supportive of the results of the experimental test. As a result of the experimental test score, difficulties in answering questions on visual forms and spatial relationships were mentioned in PC group, and difficulties in perceiving colors were mentioned in the CAVE™ group.

One (3 %) in the CAVE™ group mentioned difficulty in figuring out the shape of the reception room floor (question #2) while 8 (27 %) in the PC group mentioned it. The perspective problems caused difficulty according to the descriptions of the participants in the PC group:

- "Because the camera caused angles to change, what appeared to be diagonal, but when the camera moved, it seemed to be straight. I couldn't figure out whether it's diagonal or whether it was more than 90 degree angle."

A participant in the CAVE™ group pointed out the distortion in the corners of the CAVE™. He said, "There was distortion of the wall when you asked about the shape of the room."

No one in the CAVE™ group mentioned difficulty in figuring out the proportion of the conference room floor (question # 4) while two (6.7 %) in the PC group did. The perspective problems and the limited vision on the PC caused the difficulties according to the descriptions of the participants:

- "I never could see one full length of the room in comparison with the other. I felt I had no way to make that distinction."
- "The wall was growing as you panned"

No one in the CAVE™ mentioned difficulty when they chose the biggest size of the four desktops in the presentation room (question #10), while three (10 %) in the PC group did. The difficulty was because of lack of the standard references according to the participants' descriptions: "Because there is no clear size of references."

No one in the CAVE™ group mentioned difficulty in distance (question #1) while four (13 %) in the PC group did. They said they had difficulty in figuring out the width of the entrance doorframe. The difficulty was because of the small scale of the simulation on the PC monitor according to the participants' descriptions:

- "The door was so small. I couldn't figure out how the door was double door."
- "I found myself trying to go back to real life things analyzing it. Two doors opened but it looked like a small opening. I kept going back and forth with reality."

Different from the result of the experiment test on depth, two (6 %) in the CAVE™ group mentioned the difficulty in the depth (question # 3) while five (16 %) in the PC group did. They had difficulty figuring out the length of the area with red chairs. Participants in both groups mentioned the difficulty was because they did not have standard references.

No one in the CAVE™ group mentioned the difficulty in proximity (question #9) while one (3 %) participant in the PC group did. He said that he had difficulty when he figured out the closest chair of the four chairs in the presentation room. The difficulty was because of the perspective problems on the PC monitor according to his description: "The height of the eyes of the camera was somewhat deceiving."

Seven (23 %) in the CAVE™ group mentioned difficulty in answering questions on colors (question #5, #6, and #7) while four (13 %) in the PC group did. They said that they had difficulty in distinguishing the color squares on the posters in the conference room. The participants in the PC group mentioned that the difficulty was because of the repeating animation. Participants in the CAVE™ group gave a different reason for the difficulty from the PC group. The reason was the limitation of the lighting that was not uniform according to the descriptions of participants as follows: "The center was bright, but the top and bottom were dim."

Five (17 %) in the CAVE™ group mentioned difficulty in answering questions on textures (question # 8 and #11) while eight (27 %) in the PC group did. They said they had difficulty distinguishing the texture tiles on the wall in the conference room. The reason for this difficulty in the PC group was because of repeating animation. Another reason mentioned by the participants in the PC group was that the size of texture was too small to see.

Different from the reason in the PC group, participants in the CAVE™ group mentioned that the reason was the limitation of lighting, which was not uniform. Table 26 presents the causes of the difficulties in the experimental test mentioned by participants and their suggestions.

Table 26. Causes of the Difficulties in the Experimental Questions and Suggestions by Participants.

	Causes		Suggestions
Shape(#2)	PC	• Perspective problem	• Showing over head view
	CAVE™	• Distortion in the corner of the CAVE	• Removal of the distortion or wearing the tracking glasses.
Proportion (#4)	PC	• Perspective problem and limited vision	
Size(#10)	PC	• No standard reference	• Putting standard reference like human figure
Distance(#1)	PC	• Small scale	
Depth(#3)	PC & CAVE™	• No standard reference	• Putting standard reference
Proximity(#9)	PC	• Perspective problem	• Showing overhead view
Colors (#5, 6, 7)	PC	• Repeating animation	• Staying on the frame for enough period time
	CAVE™	• Dark and not unified lighting	• Brighter and unified lighting
Textures (#8, 11)	PC	• Small scale • Repeating animation	• Larger view • Staying on the frame for enough period time
	CAVE™	• Dark and not unified lighting	• Brighter and unified lighting

CHAPTER V.
SUMMARY, FINDINGS, CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

This chapter summarizes the study, states the major findings, presents the conclusions, discusses the findings, and makes recommendations for future work.

Summary of the Study

The role of the computer in the interior design field has increased as an integral part of design work during the design process. The images or animation generated on the PC have been found to be a good simulation for visual communication. However, the simulation on the PC is limited to a lack of three-dimensionality and a small scale. Virtual Reality (VR) techniques have been developed to overcome the limitations of the simulation on the PC.

This study was designed to compare the communication effectiveness of two types of computer simulation: passive walk-through animation of an interior design on the PC monitor, and the immersive walk-through of the same design in the CAVE™, a recently developed VR technique. Comparison of communication effectiveness was investigated by measuring how accurately participants perceived the basic visual information, such as visual forms, spatial relationships, colors, and textures, through the simulations.

Four research hypotheses were developed to compare the accuracy of perceptions of visual forms, spatial relationships, colors, and textures. The experimental test was developed to measure the dependent variables. The interview questions were prepared to compare subjects' opinions.

For this study the interior design of the Visualization and Animation Laboratory (VALAB) in the Advanced Communications and Information Center (ACITC), which is under construction on the Virginia Polytechnic Institute and State University, was modeled by using 3D Studio software on the PC. This computer model was animated on the PC for the passive walk-through animation, and the model was imported into the CAVE™ for the immersive walk-through.

A total of 60 voluntary subjects who were faculty, staff, or graduate students at Virginia Polytechnic Institute and State University participated in this study. The subjects were lay people who did not have professional knowledge and experiences in the environmental design field. A screening test was used to match the individual differences on dependent variables (the accuracy of perceptions of visual form, spatial relationships, colors, and textures). After matching, 60 subjects were randomly assigned to the two groups (the PC group and the CAVE™ group), with 30 in each group.

The subjects in both groups had the experimental test while they were watching the simulation, and they were interviewed after they watched the simulation. The data from the experimental test were analyzed by Chi-square and T-test to investigate the research hypotheses. The interview data were categorized and summarized.

Major Findings

The statistical results found that participants' perceptions of visual forms shown simulation in the CAVE™ were more accurate than those of participants shown simulation on the PC monitor. Each Chi-square result of the questions about shape, proportion, and size was significant.

Also, it was found that participants' perceptions of spatial relationships shown simulation in the CAVE™ were more accurate than those of participants shown simulation on the PC monitor. Each Chi-square result of the questions about distance and proximity was significant. More participants in the PC group chose correct answers to the question about depth, but the Chi-square result of the question was not significant.

It was found that participants' perceptions of colors shown simulation on the PC monitor were more accurate than those of participants shown the simulation in the CAVE™. Each T-test result of the three questions about value, chroma, and hue was significant. The means of the participants' scores of each of the questions in the PC group were higher than in the CAVE™ group.

It was found that there is no difference between accuracy of participants' perceptions of textures shown simulation on the PC monitor and those of participants shown the simulation in the CAVE™. The means of the participants' score of the question about roughness of texture were higher in the PC group than in the CAVE™ group, but the T-test result was not significant.

The means of the participants' score of the question about size of texture were higher in the CAVE™ group than in the PC group, but the T-test result was not significant. Table 27 presents the summary of the statistical results of the experimental test.

Table 27. Summary of the Results of the Experimental Test.

Research hypotheses	Dependent variables	Measurements	Data analyses	Results
1	Visual Forms	Shape	Chi-square	CAVE™ > PC (s. $p<.05$)
		Proportion	Chi-square	CAVE™ > PC (s. $p<.05$)
		Size	Chi-square	CAVE™ > PC (s. $p<.05$)
2	Spatial relationships	Distance	Chi-square	CAVE™ > PC (s. $p<.05$)
		Depth	Chi-square	PC > CAVE™ (ns.$p>.05$)
		Proximity	Chi-square	CAVE™ > PC (s. $p<.05$)
3	Colors	Value	T-test	PC>CAVE™ (s. $p<.05$)
		Chroma	T-test	PC>CAVE™ (s. $p<.05$)
		Hue	T-test	PC>CAVE™ (s. $p<.05$)
4	Textures	Roughness	T-test	PC>CAVE™ (ns.$p>.05$)
		Size of texture	T-test	CAVE™>PC (ns.$p>.05$)

According to the interview, a majority of participants in both groups was oriented to the spaces. Participants did not show much difference in terms of orientation to spaces in the simulation on the PC and in the CAVE™. However, participants obtained more information about details of the interior spaces in the simulation in the CAVE™.

During the simulation, participants had the following perceptions: fascination with technology, three-dimensional perception, sense of presence, and physical sensation. Slightly more participants tended to have those perceptions in the simulation in the CAVE™. Seventeen percent more participants were fascinated with technology, twenty-seven more participants had three-dimensional perceptions, and twenty-seven more participants had the feeling of being present, and fourteen percent more participants had physical discomforts.

In terms of reality, 13% more participants in the CAVE™ group than in the PC group said that the simulation was close to reality. Problems in graphic quality, lighting, movement, lack of information were found in both groups. In the PC group, problems of perspective, scale, and lack of three-dimensional effects were found. In the CAVE™ group, problems of lack of clarity of images and distortion in the corners of the CAVE™ facility were reported.

Conclusions

According to the findings in this study, it was concluded that the simulation in the CAVE™ was more effective than the simulation on the PC in communicating information about visual forms and spatial relationships in interior design.

On the other hand, it was concluded that the simulation on the PC was more effective than the simulation in the CAVE™ in communicating information about colors. In the case of textures, there is no difference in communication effectiveness between the simulation on the PC and in the CAVE™.

According to the findings from the interview, both the PC and the CAVE™ can have a role for general understanding of the interior spaces. However, people can gain more information about details of the interior spaces in the CAVE™ simulation. Likewise, the simulation in the CAVE™ appears to have more of a three-dimensional perception and a sense of actually being present in the space.

Discussion

Based on the findings, the PC and the CAVE™ can be complementary as communication tools in interior design because the two techniques have different strengths and weaknesses. According to the findings from the experimental test, the CAVE™ is a better communicator for information about visual forms and spatial relationships in interior design than the PC, but it has a limitation in communicating information about colors. On the other hand, the PC is a better communicator for information about colors, but it has limitations in communicating the information about visual forms and spatial relationships. In the case of communicating information about textures, both the PC and the CAVE™ have limitations.

From the finding that the CAVE™ is better in communicating information about visual forms and spatial relationships, it was concluded that the CAVE™ technology is a more effective communication tool than the PC for representing three-dimensional interior spaces. Researchers have stated that the CAVE™ is a powerful tool for simulating a complex three-dimensional structure (Bradshaw, Canfield, Kokinis, & Disz, 1995). The simulation in the CAVE™ has a major advantage: it generates three-dimensional immersive images in full scale. This advantage is helpful for people's perceptions of visual forms and spatial relationships.

From the interview in this study, it was found that participants understood more details of the interior design in the simulation in the CAVE™. The high level of understanding details is helpful for user evaluation. The findings of this study indicated that the CAVE™ simulation can be useful for research on interior designs that need detailed feedback from user evaluation. For example, in the case of healthcare units, such as nursing homes for the elderly or the disabled, future users can evaluate whether visual forms and spatial relationships of the interior spaces are designed properly to fit them.

This use of VR technology was also proposed by Helmick (1993). The finding of this study can be compared with the findings from previous VR research conducted to test Head Mounted Display (HMD) technology (Henry, 1992; Lindsey, 1997). The HMD is a VR technology with different characteristics from the CAVE™. However, the research on HMD and this study had a similar purpose of testing the potential of VR for representing interior spaces. Similar to this study, Lindsey (1997) concluded from her study that VR technology is used to aid anthropometric judgments for standardized universal design or special populations, and VR technology can be a valid predictor of spatial relationships and objects' size and shape. However, Henry (1992) found that VR technology had difficulties in perceiving distance and spatial orientation.

Because of HMD's limitations of low resolution and distortion, the findings of those two studies about HMD might not have been reliable. Researchers stated that the CAVE™ has higher resolution and lower distortion than HMD (Cruz-Neira, Sandin, & Defanti, 1993). However, studies on comparison of HMD and the CAVE™ would be useful to support the findings of this study.

Although the CAVE™ was found to be a better tool for representing three-dimensional spaces than the PC, the distortion in the corner of the CAVE™ was found to be a limitation to interfere with a three-dimensional perception according to participants' statements. They said that the distortion changed the shapes of objects since the objects were bent in the corner. The distortion was related to distance between regular shutter glasses and the tracking glasses. The farther the viewers wearing the regular shutter glasses were from the tracking glasses, the more distortion they saw. If the distortion can be removed, the CAVE™ would be a stronger tool to communicate three-dimensional information related to visual forms and spatial relationships.

Compared to the CAVE™, the PC was found not to be as valid a tool in communicating information about visual forms and spatial relationships in this study. In the interview, many participants in the PC group mentioned that the lack of three-dimensionality, the absence of peripheral vision, the small scale, and perspective problems hindered their perceptions of visual forms and spatial relationships. They said that they wished they had had additional presentations, such as overhead views and standard references, when they answered questions on visual forms and spatial relationships in the experimental test. Similar to these limitations, a lack of information about dimensions has been mentioned as a limitation of the simulation on the PC in previous research related to the simulation of interior design on the PC (McLain-Kark, Dhuru, Parrott, & Lovingood, 1998).

The major reasons for difficulties in perceiving visual forms and spatial relationships in the PC group were perspective problems caused by movement and the small, two-dimensional screen. The simulation on the PC showed the walk-through of the interior spaces by animating a series of image frames on the screen. People stared at the screen without turning their heads. As the number of frames changed on the screen, the information about visual forms, such as shape, proportion, and size, and the information about spatial relationships, such as distance, depth, and proximity, are changed inconsistently. Although, more participants in the PC group tended to give correct answers to the question about depth in the experimental test, the statistical result was not significant. Participants in the PC group mentioned difficulty in figuring out depth in the interview while few participants mentioned it in the CAVE™ group. Participants described the strange perspective effect as the following: angles became wider or narrower, lengths became longer or shorter, and sizes became bigger or smaller. Because of those limitations, the simulation on the PC cannot be as helpful for future users' accurate evaluation in terms of visual forms and spatial relationships in interior design as much as the simulation in the CAVE™.

The PC was found to have the strength of generating clear colors. Participants' perceptions of colors were more accurate in the PC group than in the CAVE™ group. More participants in the CAVE™ group mentioned difficulties in answering the questions about colors, and their perceptions of colors were not accurate. Proper lighting that is generated on the PC enhanced the color effects. Limitations related to colors, which were mentioned by the CAVE™ group, were lack of clarity of the images and lack of uniform lighting.

Currently, lighting that is created by 3D Studio can not be imported into the CAVE™. In the VALAB computer model, all objects and materials were imported in the CAVE™, but the lighting of the model could not be imported. Rather, simple lighting generated by the Saranav program was used. Many participants in the CAVE™ group said that the images in the CAVE™ looked blurred. In this sense, the PC is more useful for color analyses of interior designs than the CAVE™. However, for color analyses, lighting should be used properly because lighting factors, such as color of lighting, brightness of lighting, and direction of lighting, have strong influence on the perception of color. Considering this influence, actual color samples should be presented for correct analyses.

Although the PC generates better color than the CAVE™, it is not good enough for color analyses. The limitation of a small-scale screen of the PC does not allow people to see colors of surfaces with full scale. Therefore, the improvement of color rendering in the CAVE™, which can show full-scale images, is important.

The lack of clarity of images and the limitation of lighting in the CAVE™ hindered participants from perceiving texture accurately. Many participants said that the texture images were not clear enough, and the brighter lighting in the center of the front screen in the CAVE™ disturbed them. In the PC group, participants had difficulties in distinguishing the textures, but their difficulties came from the fact that the texture images were too small. On the PC screen, a image can be zoomed in to see the enlarged image, but if it is zoomed in, people can see only an enlarged part of the image. In this study, the images of texture tiles were not zoomed in much because participants needed to see all texture tiles together to distinguish differences of textures. The small screen on the PC has limitations in representing texture in terms of scale. For correct analysis, texture should be represented in full scale. In this sense, the CAVE™ has the potential for texture analysis if the clarity of images and lighting can be improved.

In terms of a realistic representation of interior spaces, the limitations of the graphic quality, lighting, movement, and lack of information were mentioned in both groups. More color gradations and more textures were necessary for better graphic quality. Participants wanted to know where the lighting sources were and wanted shadows proper to the lighting. They wanted a smooth movement that is the same as their natural walking pace. They said that more objects, such as accessories and human figures would be helpful for reality. For complete reality, participants said that they needed to feel senses of touching, smelling, and hearing, not only seeing.

In this study, simple graphics and lighting were used in the VALAB model because it was used to test dependent variables (the accuracy of participants' perceptions of visual forms, spatial relationships, colors, and textures) experimentally in both simulations on the PC and in the CAVE™. Currently, more advanced lighting can be generated on the PC. For example, a variety of directional or overall lighting can be created. Lighting color and brightness can be adjusted while objects can have shadows based on the lighting. Those lighting techniques cannot be imported with the present CAVE™ technology. When the computer model made on the PC is imported in the CAVE™, the CAVE™'s limitation of lighting and lack of the clarity of images decreases the graphic quality. An improvement of lighting and clarity of images in the CAVE™ will be helpful to import graphic quality of the computer model made on the PC as it is.

The limitation of movement was mentioned to be the major cause of physical discomforts in both groups. Many participants wished that they could control the movement, and they said lack of control increased this discomfort. In this study, pre-determined paths according to the walk-through process of the VALAB model were used to equate the movement of the simulation on the PC and that in the CAVE™.

The VALAB model could not be navigated interactively by users on the regular PC. For interactive self-navigation with mouse control, other software programs would need to be used, and these programs would limit the amount of geometry that could be shown in real-time animation. The CAVE™ already has interactive self-navigation system by a wand, but the advantage was not used in this study. The VALAB model was pre-navigated, and the navigation was saved to equate the navigation in the CAVE™ and the animation on the PC. The pre-determined path of the walk-through animation on the PC has been mentioned as a limitation to restrict the control of movement (Henry, 1992). The interactive self-navigation system of the CAVE™ in the simulation would be helpful to reduce the physical discomfort and to orient people.

Many strengths and weaknesses of the two types of simulations were explored in this study. The simulation on the PC had the problems of a lack of three-dimensionality, an absence of peripheral vision, a small scale, and perspective problems. It will be difficult to improve three-dimensionality on the PC screen. If the PC screen was larger, people could see larger images, but it cannot be full scale at this time. To solve the perspective problems on the PC, animation and camera effects could be changed, but the problem cannot be solved completely because the perspective images on the PC screen are not three-dimensional, immersive, and full scale. In this sense, VR technology should be developed to solve these simulation problems on the PC.

The immersive, three-dimensional, full-scale images generated by the CAVE™ can enhance the simulation of interior spaces. For the enhancement, the current limitations of the CAVE™, such as lack of clarity of images, lighting, and distortion in the corners of the CAVE™, should be improved. Clarity of images in the CAVE™ can be improved to develop the resolution of the projected images and shutter glasses. Lighting technology can be improved to import the actual lighting created in the computer model. The distortion in the corner of the CAVE™ can be removed with improvement of the head tracker.

In summary, the simulation by the current CAVE™ technology can be used as a more valid tool for detailed analyses of interior designs in terms of visual forms and spatial relationships than the simulation on the PC. If the current limitations of the CAVE™, such as lack of clarity of images, inappropriate lighting, and distortion in the corner, can be fixed, it can contribute to the analyses of color and texture also because the CAVE™ can simulate full-scale images.

The PC may not be as valid a tool for studying visual forms and spatial relationships as the CAVE™ but it is still a useful tool for design work. Compared to the CAVE™, it has a convenient size and an affordable cost. According to the results of question one in the interview, its capability for giving a general understanding of interior spaces is almost the same as that of the CAVE™. The PC can be used efficiently when designers want to give a general introduction of interior designs to future users. Also, it is a useful tool for presenting alternative design ideas conveniently (McLain-Kark, Dhuru, Parrott & Lovingood, 1998).

Previous VR research mentioned the limitations and discomfort of the VR facility. Although the research indicated the great potential of the VR technology, this study also suggested improvements to the limitations of the CAVE™ facility. The limitations found in VR research will contribute to the improvement of VR simulation, while useful advantages indicated by research gives confidence for the possible usage for VR technology that can is currently available.

Recommendations

Interior Designers

1) The simulation on the PC

The PC is a useful tool for giving general instructions of interior designs and presenting alternative design ideas. However, it should be considered that the simulation on the PC is not an effective tool for representing visual forms and spatial relationships of the interior design as the CAVE™.

The animation is a recommended technique to give more feeling of the spaces. However, the feeling of space is not accurate, but general because there are strange perspective effects of movement on the PC. To help the perceptions of visual forms and spatial relationships, using standard references, such as human figures or objects, would be useful. For better communication effects, when the designer use computer generated images or animation, it is recommended to combine other presentations that do not have the perspective effect, for example, scale models or two-dimensional construction drawings such as floor plans, elevations, and sections.

2) The simulation in the CAVE™

The CAVE™ is a valid tool for accurate user evaluation in terms of visual forms and spatial relationships in interior designs. Designers can get detailed responses from users because the CAVE™ helps users perceive information about visual forms and spatial relationships accurately. Also, discussions about the details of interiors with users are possible. Nevertheless, it should be considered that users can have difficulties in perceiving colors and textures of interior designs because of the current limitations of lighting in the CAVE™.

Designers need to make computer models more detailed for the simulation in the CAVE™ than they would make it for the simulation on the PC. The reason is that people are able to see more detail in the CAVE™. Mistakes and incompleteness are easily found in the CAVE™. During the simulation, people can see the distortion in the corner of the CAVE™.

Tracking glasses are more helpful to reduce the distortion. It should be considered that the simulation in the CAVE™ can cause physical discomforts such as motion sickness.

The CAVE™ Researchers and Developers

The CAVE™ has great potential for many fields, but its use is different for every application such as science or engineering. In the interior design field, the major role of CAVE™ is a visually accurate representation of interior designs. According to this study, the limitations of lighting, and distortion in the corner of the CAVE facility need to be improved.

The improvement of lighting is necessary for better graphic quality of the simulation in the CAVE™. The distortion in the corner of the CAVE facility affects people's perceptions of visual forms and spatial relationships. This is a factor that impedes the major advantage of the CAVE™: the three-dimensional and immersive feeling.

Future Research

1) The CAVE™ and HMD could be compared to explore their strengths and weaknesses in simulating interior designs by testing the accuracy of perception and level of understanding of the interior design.
2) The dependent variables (the accuracy of perceptions of visual forms, spatial relationships, colors, and textures) of this study can be tested in a real environment and in a simulated environment in the CAVE™ to investigate whether there are differences in terms of perceptions.
3) For practical use, the research on analyses of interior designs such as nursing homes, kitchens, and offices could be conducted. Real settings and the simulated settings in the CAVE™ can be compared in terms of user evaluation.
4) As the technology improves, repetition of this study would be helpful. Longitudinal evaluation research about resolution would be useful to see the process of the improvement of the CAVE™.

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APPENDIX A

Letter Asking for Participation

To: Faculty, Staff, and Graduate Students in VT

From: Jongran Lee

Department of Housing, Interior Design, and Resource Management

Subject: Research on Computer Simulation in Interior Design

Would you participate in my dissertation research about computer simulation in interior design? Sixty voluntary subjects are needed for this research. In the test, you experience a dynamic walk-through of an interior in computer simulation.

The test will take about15 minute in a small computer lab (#400, Wallace Hall). One or two weeks after, you will experience the computer simulation and have questions for about 45 minute. Location will be either in #400, Wallace Hall or the Cooperate Research Center in VT).

If you would like to participate, please send email to Jongran Lee, the researcher of this study. (Email: jolee9@vt.edu)

APPENDIX B

Screening Test

Could you please tell a little about yourself (CIRCLE ONE)

1. What is your occupation?

Faculty, Staff, Graduate student

2. How old are you?

Under 20,	21- 25,	26-30	31-35	36-40	41-45
46-50,	51-55,	56-60,	61-65,	65-70	Over 70

3 Gender

Female, Male

Please read the questions and follow the instruction. After that, circle one of three multiple choices.

4. There are three grays on the desk and a gray on the sheet. Which of three grays on the desk is the same as the gray on the sheet.

   a. GRAY 1 b. GRAY 2 c. GRAY 3

5. There are three reds on the desk and a red on the sheet. Which of three reds on the desk is the same as the red on the sheet.

   a. RED 1 b. RED 2 c. RED 3

6. There are three colors on the desk and a color on the sheet. Which of three colors on the desk is the same as the color on the sheet.

   a. COLOR 1 b. COLOR 2 c. COLOR 3

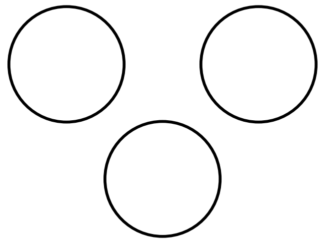
7. There are three rough texture samples on the desk. Which of three samples on the desk is the most rough?

   a. SAMPLE 1 b. SAMPLE 2 c. SAMPLE 3

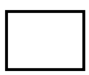
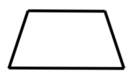
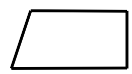
8. There are three patterns of texture on the desk. Which of three patterns of texture on the desk is the smallest.

a. PATTERN 1 b. PATTERN 2 c. PATTERN 3

9. There are three circles made with color dots on the desk. Write down the number or drawing on each circle.



10. There is a box on the desk. Look carefully at the shape of the top of the box. Which of three drawings represent the shape of the top of the box?

a.  b.  c. 

11. There is a box on the desk. Look carefully at the top of the box. Which of the three ratios matches the height and width ratio of the box top?

a. 1:1 b. 1:1.5 c. 1 :2

12. There are three boxes on the desk. Look carefully at the sizes of the boxes. Which of three boxes is the biggest?

a. BOX 1 b. BOX 2 c. BOX 3

13. There are two balls on the desk. Look carefully at the left ball and the right ball. How far are the two balls apart?

a . 1 ft b. 2 ft c. 3 ft

14. There are two balls on the desk. Look carefully at the front ball and the rear ball. How far are the two balls apart?

a. 1 ft b. 2ft c. 3ft

15. There are three balls on the counter. Look carefully at the three balls and your location. Which of three balls is the closest to your location?

a. LEFT BALL b. MIDDLE BALL c. RIGHT BALL

APPENDIX C

Experimental Test

You will watch the simulation of the Visualization and Animation Laboratory. The simulation will take you through the entrance, the reception room, the conference room, and the presentation room. Please, watch these simulations and answer the following questions.

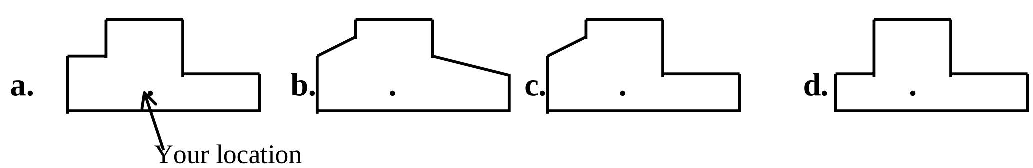
1. *You will proceed through the entrance door and go into the reception room in the simulation. Look at the door frame carefully and answer the following question.*

How wide is the entrance door frame? (CIRCLE ONE)

a. 3 1/2 FT (1.05m)
b. 4 1/2 FT (1.35m)
c. 5 1/2 FT (1.65m)
d. 6 1/2 FT (1.95m)

2. *In the simulation, you will proceed into the reception room. Look around the room. Look at the shape of the floor carefully and answer the following question.*

Which of four drawings represents the shape of the reception room floor? (CIRCLE ONE)



3. *In the simulation, you will look at the right side of the reception room. Look carefully at the area with red chairs and answer the following question.*

How long is the area with the red chairs? (CIRCLE ONE)

a. 10 FT (3m)
b. 13 FT (3.9m)
c. 16 FT (4.8m)
d. 19 FT (5.7m)

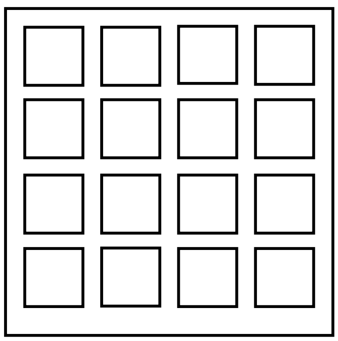
4. *In the simulation, you will go into the conference room from the reception room. Look around the conference room. Look at the floor carefully and answer the following question.*

What is the ratio of the width to the length of the conference room floor? (CIRCLE ONE)

a. 1:1 b. 1: 1.5 c. 1: 2 d. 1:2.5

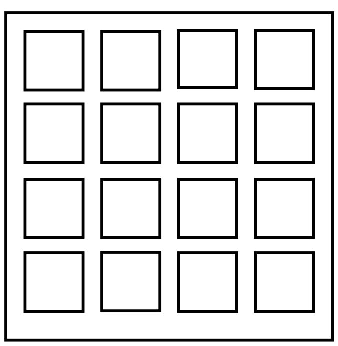
5. *The simulation will take you close to the poster on the wall in the conference room. Look carefully at the squares on the poster and the square above the poster. Answer the following question.*

Mark all squares that are the same as the square above the poster?



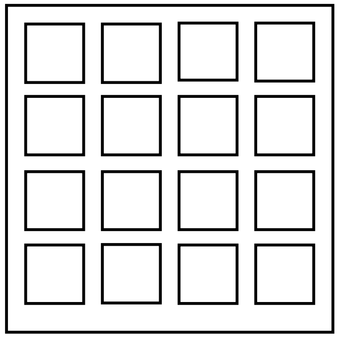
6. *In the simulation, you will go close to the next poster in the conference room. Look carefully at the squares on the poster and the square above the poster. Answer the following question.*

Mark all squares that are the same as the square above the poster?



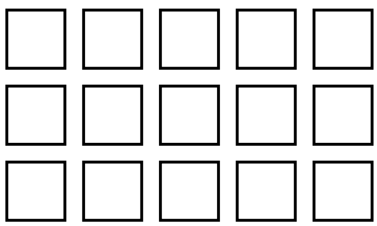
7. *In the simulation, you will go close to the next poster on the conference room. Look carefully at the squares on the poster and the square above the poster. Answer the following question.*

Mark all squares that are the same as the square above the poster?



8. *In the simulation, you will go close the wall with texture tiles in the conference room. Look carefully at the texture tiles on the wall answer the following question.*

The tiles have four kinds of rough textures. Mark all tiles which have the most rough texture.



9. *In the simulation, you will go to the presentation room from the reception room. Look at the chairs carefully and answer the following question.*

Which of the four chairs is the closest to you? (CIRCLE ONE)

a. BEIGE CHAIR b. GREEN CHAIR c. YELLOW CHAIR d. BLUE CHAIR

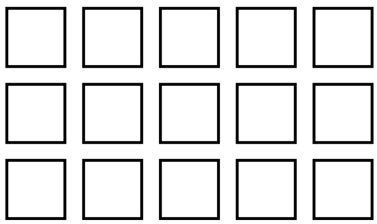
10. *The simulation will take you close to the desks in the presentation room. Look at the tops of the desks carefully and answer the following question.*

Which of the four desks has the largest top? (CIRCLE ONE)

a. LEFT b. MIDDLE LEFT c. MIDDLE RIGHT d. RIGHT

11. *In the simulation, you will go close the wall with texture tiles. Look carefully at the texture tiles and answer the following question.*

The tiles have four kinds of texture patterns. Mark all tiles which have the smallest pattern.



APPENDIX D

Interview

Think about your walk-through in the Visualization and Animation Laboratory and answer the following questions based on your best recollection of that experience.

12. Describe in as much detail as possible what you saw in the simulation starting at the beginning.

13. How did you feel while you watched the simulation of the lab?

14. How close was the simulation to reality?

15. What should be made different to improve this simulation?