COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY

A Senior Scholars Thesis

by

MATTHEW COLTON SPROSS

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2011

Major: Environmental Design

COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY

A Senior Scholars Thesis

by

MATTHEW COLTON SPROSS

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

Approved by:

Research Advisor: Wei Yan
Director for Honors and Undergraduate Research: Sumana Datta

April 2011

Major: Environmental Design

ABSTRACT

Comparing Perception of Real and Virtual Architectural Space
Using Video Game Technology. (April 2011)

Matthew Colton Spross
Department of Architecture
Texas A&M University

Research Advisor: Dr. Wei Yan
Department of Architecture

First person exploration of architectural models using video game technology holds a great deal of promise for the field of architecture. It gives architects and clients an immediate sense of a building that may not have been conveyed by traditional architectural drawings. A video game allows criticism of a building to be based on moving through a 3D space instead of analyzing 2D diagrams. However, to best make use of this technology we must understand how people's perceptions differ between the real and virtual versions of a space. The main objective of this research is to test how perception differs between a real building and a virtual walkthrough of the building in a video game engine. Participants in the experiment were asked a series of identical questions in a virtual and real version of the same building and the results were compared. It was found that in the virtual environment people tended to underestimate and to perceive distance less accurately than in real space. Findings show this underestimation of distance may not only be a product of limited field of view, as has been concluded in previous research, but may also effected by camera height and

graphical quality of the walkthrough. If this technology can be used during the architectural design process it has the potential to fundamentally change the way we create, contemplate and critique architecture.

ACKNOWLEDGMENTS

I would like thank all those who made this thesis possible, in both big and small ways. I am most grateful to my advisor, Dr. Wei Yan. Without his support, direction and advice this thesis would not exist.

I would also like to express my sincere thanks to Tania Althoff, Mark Sullivan, and the firm of Michael Graves & Associates. They made my experiment possible by providing the 3D models used in the design process of the George P. Mitchell Physics Buildings.

I would like to show my gratitude to Mark Clayton for teaching me the ropes of research and helping give my initial ideas focus. I am thankful to him, Rodney Hill and the Texas A&M University College of Architecture for providing the opportunity and encouragement to step outside of the confines of a conventional architecture education and undertake the independently driven research track.

Additionally, it is a pleasure to thank those who made this thesis possible at the Office of Honors and Undergraduate Research for providing practical guidance, deadlines and funding that helped make my thesis a success.

Lastly, I would like to thank my close friends and family who provided an inexhaustible supply of support, eyes to proofread, and listening ears to bounce ideas off of over the past eight months.

NOMENCLATURE

GDC	Game Developers Conference
3D	Three-Dimensional
2D	Two-Dimensional
VE	Virtual Environment

TABLE OF CONTENTS

Page

ABSTRACT iii

ACKNOWLEDGMENTS v

NOMENCLATURE vi

TABLE OF CONTENTS vii

LIST OF FIGURES ix

CHAPTER

I INTRODUCTION 1

- Problem statement and significance 1
- Prior research 2
- Objectives 2
- Overview of methods 3
- Limitations 4
- Literature review 4

II METHODS 11

- Hypothesis 11
- Resources 11
- Recruitment 13
- Survey methodology 14

III RESULTS 17

- Participant demographics 17
- Quantitative factors 18
- Qualitative factors 21

IV CONCLUSIONS 24

- Summary 24
- Possible improvements 25
- Further experiments 27
- Future applications 29

Page

REFERENCES 31

APPENDIX A SURVEY MATERIALS 32

APPENDIX B DATA SET 40

CONTACT INFORMATION 45

LIST OF FIGURES

FIGURE Page

1 Comparison of Real and Virtual Lobby 13

2 Comparison of Real and Virtual Auditorium 13

3 Example of Quantitative Questions Used in the Survey 15

4 Example of Qualitative Questions Used in the Survey 15

5 Quantitative results in the Real and Virtual Lobby 18

6 Quantitative results in the Real and Virtual Auditorium 19

7 Mean of Percentage Difference between Answers and Actual Values 20

8 Qualitative Factors in Virtual Lobby: Mean and Standard Deviation 21

9 Qualitative Factors in Real Lobby: Mean and Standard Deviation 21

10 Qualitative Factors in Virtual Auditorium: Mean and Standard Deviation 22

11 Qualitative Factors in Real Auditorium: Mean and Standard Deviation 22

12 Accuracy of the Virtual Lobby: Mean and Standard Deviation 23

13 Accuracy of the Virtual Auditorium: Mean and Standard Deviation 23

CHAPTER I

INTRODUCTION

Problem statement and significance

First person exploration of architectural models using video game technology holds a great deal of promise for the field of architecture. It gives architects and clients an immediate sense of the spaces in a building that may not have been conveyed by traditional architectural drawings and renderings. In addition, it allows criticism of a building to be based on moving through a 3D space instead of analyzing 2D diagrams like floor plans and sections. However, architects must be mindful of the differences in perception that exist between real buildings and their video game representations. The two may seem analogous in the first person perspective but there are several key differences. In physical space you are able to use sight, hearing, touch and smell to create a perception of a space in your mind, a mental map and impression of its affect. In the digital world each of these senses is affected either acutely or grossly. Not being aware of this gap can lead to unintentionally conveying false information about the building. This research will look into identifying how accurately a building model in a game engine conveys quantitative and qualitative information about a real space. With an understanding of this 3D spatial fidelity architects can not only help convey ideas to

---

This thesis follows the style of *International Journal of Design*.

clients but also use the technology to gain a better understanding of their own designs. These new tools and insight can help the profession progress by enabling new lenses through which to work.

Prior research

Writing from the fields of architecture, video games, and environmental psychology was reviewed as a basis for this research. In analyzing my sources I found four common threads that would be my point of departure. The first area is theory on technology and how it influences creativity and design. The second area is the critical study of video games and how people interact with them. The third area is the study of virtual environments and how people trained in them gain knowledge of the real world. The fourth area is the study of spatial cognition and what effects our perceptions of real space.

These will be covered in greater depth in the literature review located later in this chapter.

Objectives

Research question

What are the significant qualitative and quantitative differences between people's perception of architectural space in a video game environment and the real building?

Hypotheses

When exploring a virtual version of a real building using first person video game technology people will not be able to perceive quantitative factors such as distance as accurately as in the real space but will be able to gauge qualitative factors.

Overview of methods

Data collection

I will be conducting an experiment using a group of ten to twenty Texas A&M students and the Unity 3D game engine. The experiment will involve the students answering question about the qualitative and quantitative nature of a space while in a 3D game engine model of the building. They will answer questions both while exploring the virtual space and after they have left the virtual space. Then they will repeat the same procedure in the actual space of the building and answer the same questions. The method and specifics of the questions will be covered in greater detail in Chapter II.

Analysis

Student's answers to the questions will be compared to look for significant differences between perceptions of the virtual and the real space. Particular attention will be given to determining if there is a difference in perception of quantitative and qualitative factors of the space.

Resources

The experiment was conducted on a freely available platform with freely available or educationally licensed software using personal computers. I used the large knowledge base available to me from the University libraries and from faculty with experience in relevant fields located in the Department of Architecture and the Department of Visualization. In addition, I attended the Game Developers Conference in Austin in October 2011 and found many valuable professional resources there in addition to access to GDC proceeding archive for reference purposes.

Thanks to the help of Michael Graves & Associates I was able to use the new Mitchell Physics Building on the Texas A&M campus for my experiment comparing virtual and real space. They provided me with 3D models of the building for use in my experiment.

Funding

Funding for this research has been provided by the Texas A&M University Undergraduate Research Scholars Program and by the Texas A&M University College of Architecture. The funds have been used to cover incidental costs of running the experiment.

Limitations

This research will not produce any new software but will simply be using an existing game engine in an architectural context. This research will use a small sample size that may not produce a statistically significant result but may show results that can lead to further research with a large sample size. This research will not be testing the software with clients and will not address the potential of this software in persuading clients. This research will not address the usefulness this kind of software could have on design disciplines outside of architecture.

Literature review

The reading and analysis that I have completed is broken into four distinct categories and each plays a foundational role in my research.

Technology

First is the section on technology, which embodies the theoretical base for my research. The first source is “Computer as Paintbrush: Technology, Play, and the Creative Society” by Mitch Resnick of the MIT media lab. In it he says:

> Computers will not live up to their potential until we start to think of them less like televisions and more like paintbrushes. That is, we need to start seeing computers not simply as information machines, but also as a new medium for creative design and expression.(Resnick, 2006)

In the same way, using video game technology in architecture design and analysis will not reach its full potential until it affects the way we think about and create architecture. The next source is an interview with 20th century Egyptian Architect Hassan Fathy. In it he states:

> The architecture of steel or aluminium [sic] and glass has little human reference. This is no longer architecture but engineering. Engineering has taken the upper hand…If you say economy, everybody bows down. We are in need of an era of non-functionalism. We are in need of quality with a humane touch. Most architects today are only trying to remedy mistakes. That is wrong. What architects must do immediately is to think of an ideal solution – not try to weigh compromises. You have only to start with man occupying a household space. Then you must determine his communications. Everything else must then follow harmoniously. (Blumenfeld, 1974)

In architecture, computer technology has been used in many cases as simply a way to cut costs and streamline the production of cheap square footage.

At first, these two sources may seem at odds with each other. One calls for use of computers technology as an expressive medium and the other calls out modern building technology as inhumane. However this is a false dichotomy. Both are extolling the value of craft over a strictly economic perspective. My third source on the topic shows a middle ground where the previous two agree. In the article entitled “The Developing Scientist as Craftsperson” the authors state:

> We do not feel that a love of crafts is incompatible with technophilia, nor that an enjoyment of computer applications must detract from time spent in crafting. The world is not, or should not be at any rate, a battleground between the real and the virtual. (Eisenberg & Eisenberg, 2000)

The immersive technology that computers provide can help enhance the cognitive process and the physical final result of architecture. In addition this technology can and must be used to correct the course of the current economy obsessed paradigm of professional architecture practice.

Video games

It is an article written by Ian Bogost titled “Video Games and the Future of Education” he laments the currently stale and risk averse state of both the commercial video game industry and the primary educational institutions. He then outlines how the uses of educational video games that break the typically mold can change this.

> The very notion of ‘‘educational video games’’ represents a massive rejection of the customs of both videogames and education. I am serious about this. If we want to have educational videogames, we are using games against the grain, and education against the grain. And the fact that the one fight takes on two standards at once suggests that there may be some utility in combining those conflicts together. (Bogost, 2005)

That immersive video game technology can also be used to improve an architecture industry that suffers from the same stagnation that Bogost laments in current education and video games. How this technology can be used is explained in my next video game source, a paper titled “Immersion, Interaction, and Collaboration in Architectural Design Using Gaming Engines” written by Michael Hoon and Wassim Jabi of the New Jersey School of Architecture. The paper covers what they have learned through teaching a design studio that uses game engines to design, explore and critique students work. It also explores the impact that having multiple people in the same virtual space communicating with voice chat has on architectural criticism. During the final design review the critics were asked to enter the building in the video game environment, explore it at will and interact with the student as well as others present in the same virtual space. The paper shows the possibilities and limitations of this type of immersive design experience. One of the advantages they put forth is that exploring a building in a video game engine is “fully interrogative”, meaning the player has full control on where they go. Another related advantage is the simulation provides “tactile solidity”. This means that the physics of the virtual space behave in a way that the player would expect:

Walls stop movement, stairs are climbable, and windows let in light for outside. However, the paper acknowledges that the architecture that can be explored with this technology faces the same limitations that geometry in video games face. This means that highly complex and curved shapes will not work due to technological limitations (Hoon, Jabi, & Goldman, 2003). This is a significant hurdle since a large segment of the contemporary architectural avant-garde favors curvilinear forms.

Virtual environments

The use of video games as an immersive medium for architectural design and collaboration requires that the transfer of spatial knowledge is analogous between the virtual and real worlds. My first source on virtual environments explores this. The paper by David Waller, Earl Hunt, and David Knapp, is titled "The Transfer of Spatial Knowledge in Virtual Environment Training." They report the results of an experiment in which groups were trained in six different environments (no training, real world, map, VE desktop, VE immersive, and VE long immersive) and then had to test what they had learned to real-world maze while blindfolded. Short periods of VE training were no more effective than map training; however with sufficient exposure to the virtual training environment, VE training eventually surpassed real-world training. While their experimental methods of using blindfolded navigation of a real world space may not be a method I can use, their findings may be helpful. One result that could prove particularly important for my research shows that desktop setup of a virtual environment may be just as effective as a more immersive virtual reality setup.(Waller, Hunt, & Knapp, 1998)

Another of my sources on virtual environments is “Spatial Perception in Virtual Environments” by Daniel Henry. He evaluates the participant’s perception of a virtual space by asking them questions during their immersion in the virtual environment, not by recalling from memory after the immersion. In his findings, made using mid 90’s virtual reality technology, he concludes:

> Virtual environments do not fully satisfy the requirements for completely replacing those forms of architectural representations which are meant to convey the basic spatial characteristics of proposed spaces. The virtual interface used in this study is not quite good enough for making quantitative judgments of spaces. It is difficult to orient oneself in virtual spaces and distances are underestimated. However, the interface is adequate for making qualitative evaluations of architectural spaces. Using this interface, people's perception for the way the modeled spaces feel would rather accurately predict their perception of the feel of the real space.(Henry, 1992)

He believes the underestimation of distance is due to participant’s smaller field of view. His method of testing people’s spatial perceptions while in an expensive VR setup is not useful for my experiments. However, his technique of asking participants questions while they are in the virtual environment, not afterwards, will prove useful in getting a more accurate reading of people’s perception in my experiment.

Spatial cognition

The differences in qualitative judgment of space may be explained by previous research on spatial cognition that does not directly deal with virtual environments.

One paper that I will reference is Alfano and Michel's study titled "Restricting the field of view: perceptual and performance effects." They studied "The role of peripheral vision in competent performance of the adult visuomotor activities of walking, reaching, and forming a cognitive map of a room." (Alfano PL & Michel GF, 1990) They did this by using goggles which limited the scope of the normal field of view to 9 degrees, 14 degrees, 22 degrees, or 60 degrees. They found that as the field of view became smaller participants had an increasingly hard time with the tasks. Some subjects even experienced "bodily discomfort, dizziness, unsteadiness and disorientation." (Alfano PL & Michel GF, 1990) This is especially significant because first person video games usually have a 60 degree cone of vision. This could have significant impacts on perception of space.

CHAPTER II

METHODS

Hypothesis

When exploring a virtual version of a real building using first person video game technology people will not be able to perceive quantitative factors such as distance as accurately as in the real space but will be able to gauge qualitative factors.

Resources

The experiment was conducted in the lobby and auditorium of the Mitchel Physics Building on the Texas A&M Campus. The lobby is an oval shaped space that is 85 feet tall with five floors of offices opening up to the space. In the center of the space there is a pendulum that hangs from the ceiling and swings in a glass enclosure at floor level. The auditorium is a small space with seating for about two hundred. There is a rectangular, wooden desk at the front of the space in front of three large chalkboards. 3D models of the lobby and auditorium were provided by Michael Graves & Associates. They were used by the architects during the building design process to produce renderings. The 3D model of the lobby was very similar to the real space, even though it was from an earlier stage in the design process. There were some minor changes made to the geometry of the space of the real lobby. The most significant of the changes was a lobe shaped protrusion added to one wall of the built lobby. The 3D model of the auditorium was actually of a much larger size than the real auditorium. However, this was useful for testing if the participants would pick up on the discrepancy in size between the virtual and real versions of the space. These 3D models were given to us as AutoCAD .DWG files. In order to make them useable in the Unity game engine I imported them into Maya. After correcting a few flaws in the geometry caused by the importing process I was able to easily import the 3D models into Unity. Additionally, I modeled the couch, trashcan, and pendulum to make the virtual environment as similar to the real space as possible. Once the models were in Unity, I worked from photo references to create textures that reflect the materials of the real space as closely as possible (See Figures 1 and 2). I then created a first-person camera controller in Unity that allowed the user to walk through the virtual environment at human scale. The controller was 2 meters high and had a field of view of 60 degrees. Any field of view greater than this begins to look distorted on a single computer screen. Finally, I created light maps for both the lobby and auditorium that approximated lighting conditions in the real space. The virtual environment was designed to only test visual perception of space. Auditory results would have been possible to test but it would be difficult to control for the noise levels in the publically open lobby of the Mitchell Physics building. Olfactory and tactile testing would not have been possible with the available resources and technology.

For video comparison of the virtual and real spaces please visit:

http://www.mcspross.com/walkthrough/

Figure 1. Comparison of Real and Virtual Lobby

Figure 2. Comparison of Real and Virtual Auditorium

Recruitment

The experiment required 10-20 Texas A&M students. Participants were recruited in person by speaking to architecture classes and students organizations about the experiment. Recruitment effort was split evenly between architecture and non-architecture students. I was interested in comparing the results of the two groups. No e-mail or flyer recruitment was used.

Survey methodology

The methodology of my experiment involved the participants first exploring a virtual model of the Mitchel Physics Building and answering questions while in the virtual environment, then having them follow the same procedure in the real space. The process of having the participants answer the questions whilst in the spaces, both virtual and physical, was influenced by the research of Daniel Henry in "Spatial Perception in Virtual Environments." He evaluates the participant's perception of a virtual space by asking them questions during their immersion in the virtual environment. (Henry, 1992) This method allows for the participants to answer as accurate as possible without having to recall distances from memory. Figure 3 shows a few of the questions used. A full copy of the survey is located in Appendix A.

First, participants were given Page 1, a preliminary survey about their major, knowledge of the Mitchell physics building, and their familiarity with computers and with First Person Perspective video games. They were then taken to laptops with the virtual environment installed. The controls were explained to participants and they were given one minute to acclimate and ask questions. They then entered the Lobby in the virtual environment and were given Page 2, a series of eleven questions about the space, and told they had six minutes to answers.

1. How far is it from the blue circle on the floor to the green circle on the far wall?
2. How many of these red couches would fit lengthwise between these two points?
3. How tall is the first floor ceiling?
4. How many of the black trash cans would you need to stack to be as tall as the first floor ceiling?
5. How tall is the high ceiling in the center of this space?
6. How many of the black trash cans would you need to stack to be as tall as the high ceiling?

Figure 3. Example of Quantitative Questions Used in the Survey

The questions covered qualitative perception of the virtual environment by asking the participants to gauge distance between two points. There were several questions involving both horizontal and vertical distances that ranged from nine to eighty-five feet. For each distance they were asked to provide an estimate using the measurement system they were most comfortable with (imperial or metric) and an estimate using a reference object in the space (e.g. "How many of these black trashcans would be required to be as tall as the first floor ceiling?") A six minute time limit was imposed on the question answering in order to prevent participants from overthinking their answers.

7. This space is (mark a point between the two)

Small ☐—☐—☐—☐—☐—☐ **Large**

Figure 4. Example of Qualitative Questions Used in the Survey

The participants were also asked a set of questions that gauged their perception of qualitative factors in the space. They were asked to indicate on a non-numerical scale how they perceived the lighting, size, interest, and beauty of the space (See Figure 4). Once the six minutes had elapsed Page 2 was collected and Page 3, about the virtual auditorium, was handed out. The questions on Page 3 were analogous to those about the virtual lobby with one additional question asking the participant to estimate the number of seats. The participants then entered the auditorium in the virtual environment and had another six minutes to explore the model and answer the questions. Once this part of the experiment was concluded participants were given Page 4 asking which of the two spaces they perceived to be bigger, brighter, more interesting, more beautiful and better designed. At this stage in the experiment the participants were taken to the real lobby space where they were given Page 5, with the same questions asked of the virtual lobby, and given six minutes to answer the questions as they related to the real space. Next, they were taken to the real auditorium and given Page 6 and six minutes to answer. After this the participants were given Page 7, one last set of questions to see how accurately they felt the virtual spaces represented the real space.

CHAPTER III

RESULTS

Participant demographics

The participants in the experiment consisted of six students from the college of architecture and five students from other colleges. This allowed me to see if architecture students appeared to be better at gauging qualitative and quantitative factors. After comparing the answers for both groups neither seemed to be significantly better. The relatively small sample size meant that the results would not be statistically significant but would give indications of trends in the differences in perception of real and virtual spaces. Eight of the participants had been to the Mitchel physics building before, five of those said they were very unfamiliar with the space, two said they were somewhat unfamiliar and two said they were somewhat familiar.

All participants answered that they spent over five hours a week on the computer and more than seventy percent of them spent over nine hours a week on the computer. The majority of the group said they had never played first person perspective video games, one said they played them seldom, and three said they played occasionally. Overall none of the participants spent more than three hours a week playing first person games. Eight of the participants were most familiar with the imperial system of measurement and three were more comfortable with metric. They were allowed to answer questions in whatever system they were most comfortable with and I converted all answers to feet.

Quantitative factors

In comparing the quantitative questions in the real and virtual lobby we see three clear trends (See Figure 5). First, in the virtual environments participants tended to underestimate distances. This is evident because in the virtual lobby the mean estimate for all distances is underestimated by an average of 15%. Second, in virtual and real environments of the same size participants underestimated to a greater degree in the virtual environment. In 7 of 13 quantitative questions the mean of the answers in the virtual space was at least 8% lower than the actual value than the same questions in the real space. A copy of the survey used is located in Appendix A.

	Virtual Lobby				**Real Lobby**			
#	Mean Answer	Correct Answer	% Difference	Standard Deviation	Mean Answer	Correct Answer	% Difference	Standard Deviation
1	41.84ft	60.7ft	31%	19.26	45.62ft	60ft	23%	8.71
2	8.55	10	14%	3.62	10.00	10	<1%	1.18
3	11.14ft	11.15ft	<1%	2.32	9.25ft	9ft	3%	1.21
4	4.18	4.5	7%	.87	3.35	3.6	7%	.67
5	61.56ft	75.5ft	18%	24.17	80.32ft	85ft	6%	17.07
6	24.36	30	19%	9.35	39.30	34	16%	39.22

Figure 5. Quantitative results in the Real and Virtual Lobby

Third, the estimates in virtual environments have more significant variations than their real counterparts. For the virtual lobby, the standard deviation of all but one question in the real space is at least 20% smaller. Overall, the answers in the virtual lobby were less accurate than guesses in the real world. There was one exception here; the average guess for the 1st floor ceiling in the virtual space was less that 1% off whereas the average guess for the 1st floor celling in the real space was 3% off. Despite this, the standard deviation for the virtual space was 2.32 compared to 1.21 for the real space.

	Virtual Auditorium				Real Auditorium			
#	Mean Answer	Correct Answer	% Difference	Standard Deviation	Mean Answer	Correct Answer	% Difference	Standard Deviation
1	53.29ft	62ft	14%	21.04	45.42ft	46.33ft	2%	17.33
2	52.55	31	69%	82.89	23.27	23.20	<1%	11.46
3	12.06ft	11.5ft	5%	6.26	11.97ft	11.5ft	4%	2.85
4	4.27	4.6	7%	2.72	4.73	4.6	3%	2.15
5	23.73ft	26.25ft	10%	7.99	20.27ft	15.83ft	28%	5.19
6	8.00	10.5	24%	3.19	8.00	6.33	27%	5.62
7	363.00	533	32%	119.78	177.27	191	7%	59.51

Figure 6. Quantitative results in the Real and Virtual Auditorium

Comparison between the virtual and real auditorium proved more ambiguous (See Figure 6). The average guess for the width of the space was underestimated by 14% in the virtual space but by only 2% in the real space. This conformed to the trend of distances being underestimated we saw from the lobby. However, answers to the next question, which asked the participants to estimate the number of auditorium seats that would fit across the width of the space, varied widely in the virtual space with a standard deviation of 82.89 and an average that overestimated the number by 69%. This is a sharp contrast to the same question in the real space where the standard deviation was 11.46 and the average was less than 1% off from the real value.

Exceptions

However, for question 2 in the virtual auditorium one participant's estimate was significantly inconsistent with the average. If we recalculate the mean with the highest and lowest value removed we get answers that are in line with the previous trends with a mean that is 5% under the actual value. Question asking for the height of the lowest point on the auditorium celling conform to the lobby's patterns. The mean of answers in the virtual space are further from the actual values and have a larger standard deviation than their real counterparts.

The patterns begins to break when looking at the average guesses from questions 5 and 6 which asked for the highest point in auditorium. The mean of answers in the real space overestimates the ceiling height by 28%, whereas in the virtual space the mean answer was underestimated by 10%. The guesses in the real space were fairly consistent with a standard deviation of 5.19 compared to 7.99 in the virtual auditorium. It is unclear why this one answer defies the patterns of the rest of the data. The last question returns to the previous patterns with the mean of answers in the virtual space being far less accurate and having a wider standard deviation. This conforms to the trend shown in Figure 7.

Space	Mean % Difference From Actual Value
Virtual Lobby	15%
Real Lobby	9%
Virtual Auditorium	23%*
Real Auditorium	10%

Figure 7. Mean of Percentage Difference between Answers and Actual Values. *If the outlying data of 69% difference is readjusted to 5% as discussed in the *Exceptions* sub-section, then the value for Virtual Auditorium is 13%.

Qualitative factors

Looking at Figure 8 and 9 we see that the real space was perceived as slightly bigger, brighter and more interesting than the virtual space. The beauty was perceived to be almost the same.

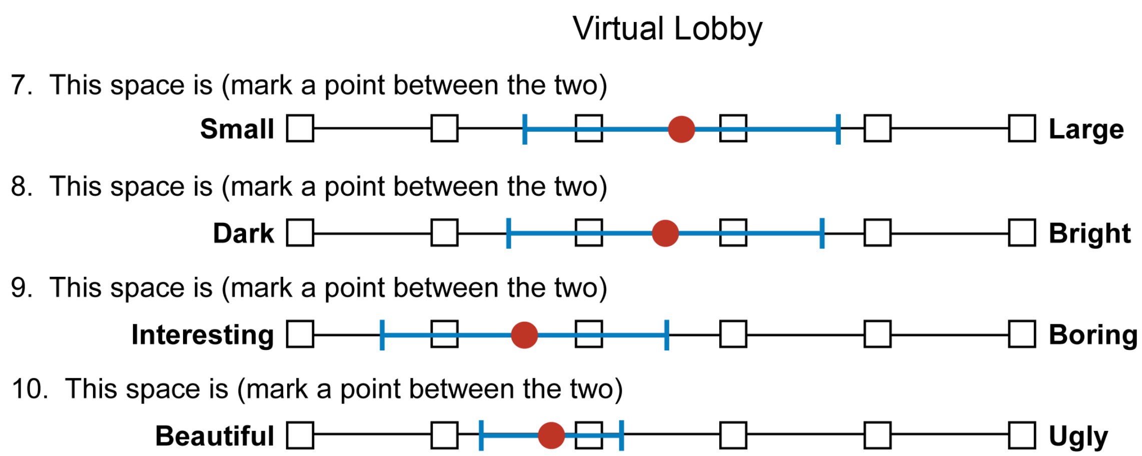

Figure 8. Qualitative Factors in Virtual Lobby: Mean and Standard Deviation

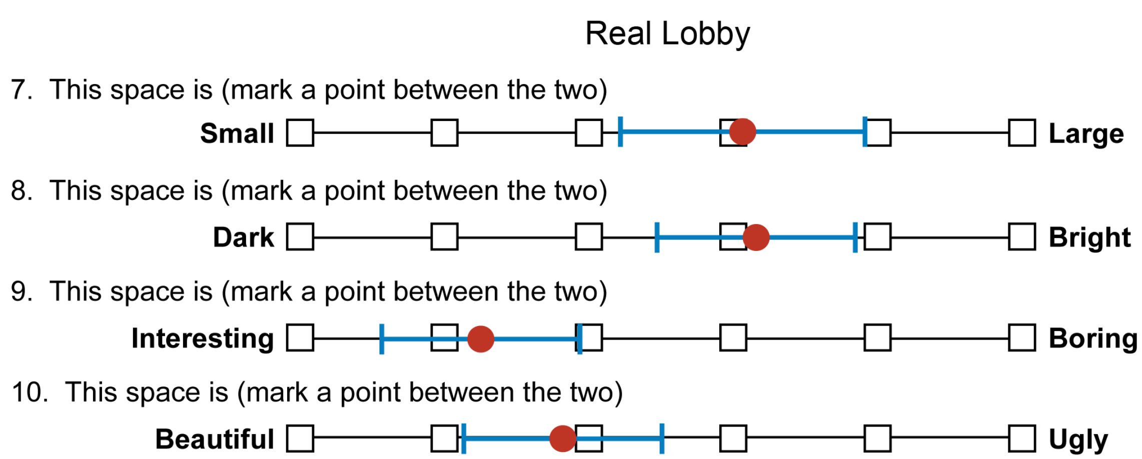

Figure 9. Qualitative Factors in Real Lobby: Mean and Standard Deviation

For the auditorium, there was significant change in qualitative perception between the virtual and real spaces. Comparing Figures 10 and 11 shows that the real size was perceived to be significantly smaller than the virtual. This is true as the model is much larger than the actual space. Additionally, the real auditorium was perceived as brighter, more boring, and as slightly uglier than the virtual auditorium.

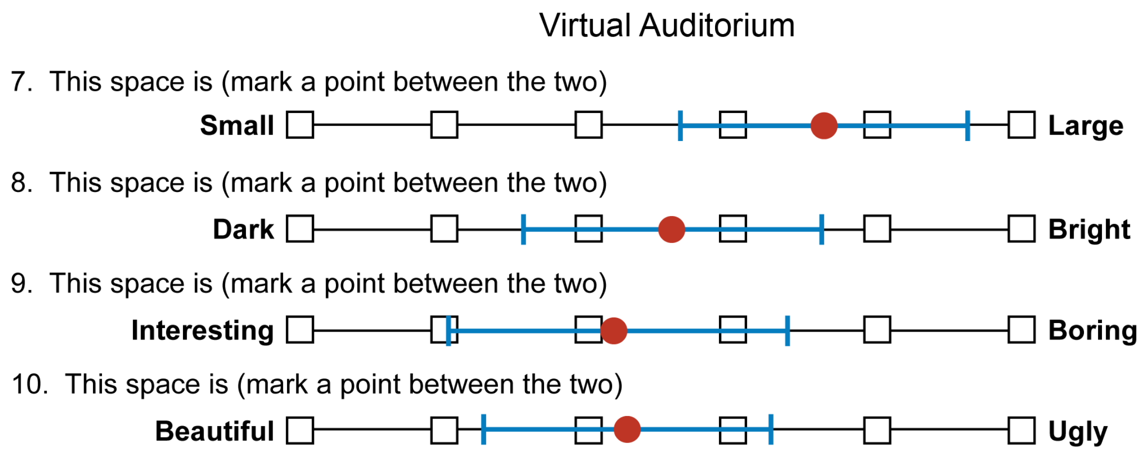

Figure 10. Qualitative Factors in Virtual Auditorium: Mean and Standard Deviation

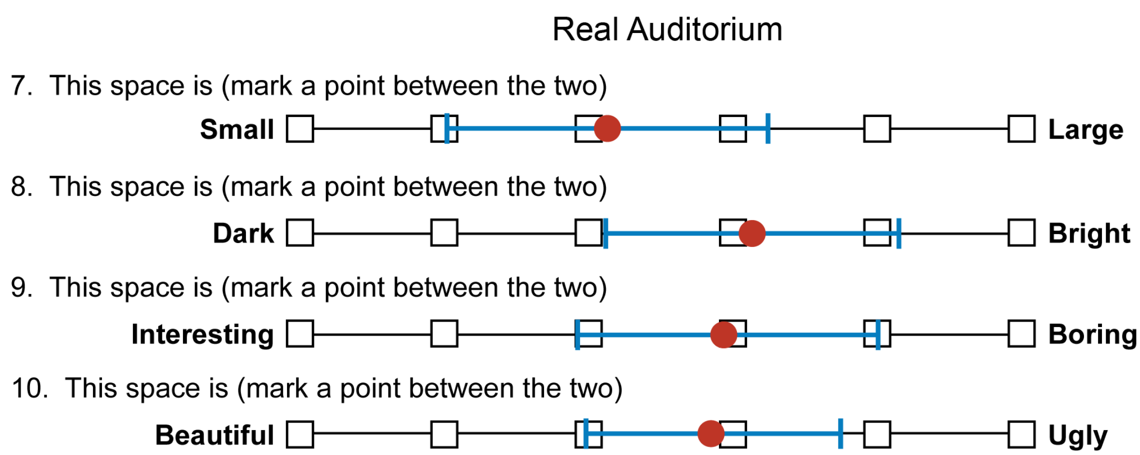

Figure 11. Qualitative Factors in Real Auditorium: Mean and Standard Deviation

Participants were asked how accurately the virtual models had conveyed specific qualities of the real spaces (See figures 12 and 13). They perceived that, out of size, lighting, materials and beauty, the virtual environments best represented the materials. Answers indicate that beauty was represented consistently between the two environments and both spaces had the identical, relatively small standard deviation of 0.83. Lighting was less consistent between the two spaces. The accuracy of its representation was perceived as mediocre in the lobby and as only slightly better in the auditorium. The perception of the accuracy of size fluctuated the most between the two virtual environments. Users rated the accuracy of the virtual space much lower for the auditorium. This may be due to the fact that a 3D model was much larger than the actual auditorium.

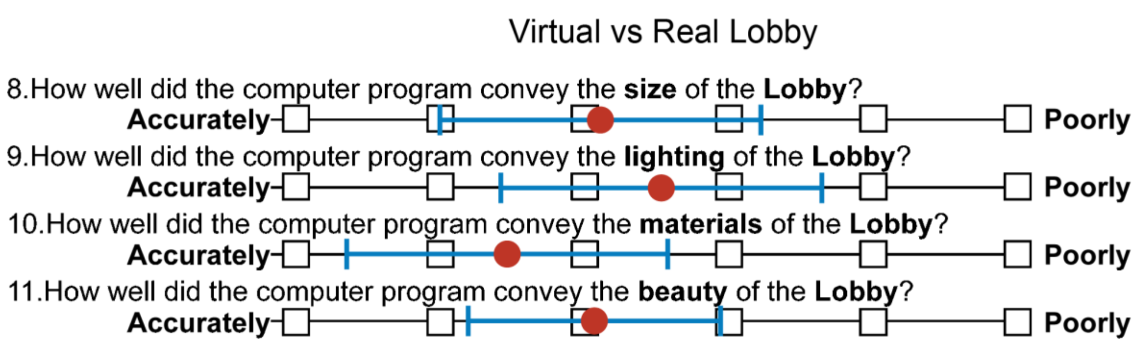

Figure 12. Accuracy of the Virtual Lobby: Mean and Standard Deviation

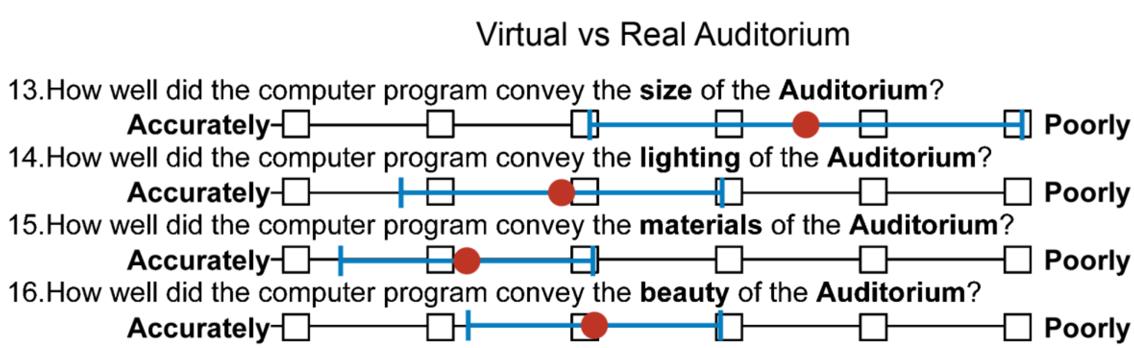

Figure 13. Accuracy of the Virtual Auditorium: Mean and Standard Deviation

CHAPTER IV

CONCLUSIONS

Summary

In the virtual environment people tended to underestimate and to perceive distance less accurately than in real space. The findings of the quantitative questions confirm my hypothesis and reaffirm results from previous research by David Henry and others. Why it is that participants tended to underestimate distances in the virtual environment? There are several possible explanations. One is that the restricted 60 degree field of view affects people's ability to accurately perceive distance. This may be a contributing factor. However, Henry's research, which used a virtual reality setup with a 90 degree field of view, found similar results in which participants tended to underestimate distance by around 20%.(Henry, 1992) For my experiment participants underestimated by a mean of 15% in the virtual lobby and a mean of 13% in the virtual auditorium, if outliers are adjusted as discussed in the *Exceptions* sub-section in Chapter III. Improvements in graphical quality since 1992 may contribute to the increase in accuracy. However, the fact that participants in my experiment had a smaller viewing angle than those in Henry's yet guessed more accurately indicates that restricted viewing angle is not the only reason for distance underestimation.

Another possible explanation is the height of the camera in the virtual walkthrough. The height I used was 2 meters which is standard for the Unity game engine's first-person camera controller. This may have caused people who are shorter than 2 meters to underestimate distances by assuming the camera was their own height.

For qualitative questions the mean answerers shifted less between the real and virtual lobby than they did between the real and virtual auditorium. This would seem to indicate that the lobby was more successful in conveying the qualitative factors that the auditorium. One conclusion that can be made is that future versions should endeavor to improve representation of the space. For materials, efforts should be made to improve the quality and fidelity of textures. For lighting, more attention should be paid to type, intensity and color of lights in a space. One possible strategy would be making a map of a space that labels the location, color and intensity of all lights in a space. These steps can improve the virtual representation of the real space.

First person exploration of architectural models using video game technology holds a great deal of promise, but there are still improvements that need to be made to help accurately convey qualitative and quantitative factors.

Possible improvements

There are several possible improvements that can be made to this virtual walkthrough using video game technology. Here are a few that could increase the accuracy of people perception of the virtual space.

Increase graphical fidelity

The most obvious improvement would be to increase graphical fidelity between the virtual and real spaces. This may yield improved results but will become prohibitively more expensive the closer the two become. It would take a large amount of work and investment to create 3D models of the caliber used in today's movies and bestselling games.

Implement 3D audio

The use of 3D sound represents another possible improvement to the technology. While it was not tested in this experiment it could be a big boon to perception in the virtual environment. If implemented correctly, walking on different types of flooring would produce different sounds and the level or reverberation would reflect the size and materials of a room. Walking through a large room with tile flooring would produce a very different sound than walking down a carpeted hallway. This could help people understand the materiality and size of a space.

Use variable camera height

Allowing the user to match the virtual camera height to their own eye levels would allow for them to experience the space in a way closer to real life. This could possibly make users quantitative guesses more accurate.

Incorporate mini-map

Many of today's most popular first person video games have a small overhead map in one corner of the screen, referred to as a mini-map. This orients players in complex 3D spaces and helps compensate for the lack of peripheral vision. Mini-maps could be used with this virtual walkthroughs technology to make the space easier to understand. Mini-maps have many things in common with traditional architectural floor plan drawings. Using them in conjunction with virtual walkthroughs is a way that this new interactive form of representation can work in harmony with traditional architectural representation.

Further experiments

Based on the results of this experiment there are several further experiments that could yield significant results. For all future experiments it would be best to increase fidelity between the 3D model and the real space. Although our models were very similar to the built lobby, there were still some differences. It would be worthwhile to invest the additional time and resources necessary to create a geometrically identical model of the real space. Unless otherwise noted these suggested experiments would follow a similar procedure based on my first experiment; participants would take real and virtual walkthroughs of the same space and answer a similar series of questions.

One possible experiment would be testing the impact that variable camera heights have on people's perception of a virtual environment. One group in the experiment might enter their height and the camera would conform to this height. A second group might do the same but the camera would actually be taller than their entered height. For a third group the camera would be shorter than their entered height. The three groups could then be compared to see the impact that camera height, as it relates to a person's actual height, has on distance perception in virtual environments.

A second possible experiment would test the impact that immersive 3D audio has on perception of space. One group in the experiment would be tested in a virtual space with audio design that reflects the size and materiality of the space. A second group would be tested in a version of the space without audio. Results from the two groups could be compared to see what kind of impact audio has on spatial perception.

A third possible experiment could test the effectiveness of using a mini-map with 3D video game walkthroughs of architectural space. One group would gauge distances in a virtual environment. A second group would gauge distances based a plan drawing of the same space. A third group would gauge distance in the same virtual environment with the aid of a mini-map. The groups could then be compared to understanding if a mini-map helps people to gauge distance more accurately in a virtual environment.

Another possible experiment could test the impact that high quality textures have on perception in virtual environments. Three groups would go through a geometrically identical space with different levels of texturing: one with photorealistic textures, one with abstract textures, and one with blank white textures. Their responses would be compared to see if one group is able to gauge distance more accurately. A similar experiment could be done with photorealistic, stylized and universal lighting setups. No experiments like these were conducted in any of the literature I reviewed. These are but a few possible experiments that could expand the knowledge base of this field of research. New insight gained from any of these would help improve the quality of 3D architectural walkthroughs and shrink the gap between the virtual and real worlds.

Future applications

This virtual walkthrough technology represents a new frontier for architectural representation. Use of 3D models for architectural presentations has previously been limited to static 2D images or pre-rendered fly through. Now we can walk around in a fully interactive version of the 3D model.

Right now the pipeline between video game engines and architectural modeling packages is anything but streamlined. Getting a building model into a game engine can be a long and arduous process that requires remodeling low-poly versions of spaces and baking light maps; The higher the graphical quality the more complex the process. This unfortunate barrier means that even in the cases where this technology might be used it is usually pushed to the end of the design cycle and only used in presentations to the client.

There is also the additional barrier of perception discussed in this research. In order for this technology to be useful in architectural design we must make virtual walkthrough technology more accurately reflect real space. At this point it can be useful for understanding a space to some degree, as long as the user is aware of the differences in perception that exist. But making improvements like the ones described in this chapter will vastly improve the potential applications of virtual walkthroughs using video game technology.

We may never reach a point where a virtual walkthrough is exactly the same as being in the real space but we can aspire to make the two as similar as possible. Additionally, we should aspire to integrate this technology into the design and criticism process, not use it simply as a new way of selling architecture. If we can streamline this technology so that it easily integrates into the design process it could have a profound impact. It would shorten the feedback loop between designing and testing what you have made. This could help architects quickly throw out ideas that don't work and brainstorm new solutions. Imagine a scenario where you can model a preliminary design for a space and then instantly jump in and walk around in first person. You set the time of day and see how the light shines into the room. You run an algorithm that represents how air will move through the space with a cloud of bubbles. At the press of a button you summon a rain storm and see how the shape of the roof handles the runoff. If you notice something wrong at any point then you can jump back out of the first person mode and edit the geometry and material of the space. After many iterative cycles like this you give the model a bit more polish for a review with a critic or a client. Both of you can jump in and explore the same space simultaneously. You can even make real time changes based on the feedback they give you.

This scenario is not far out of our reach; the uncanny valley between virtual and real space is shrinking every day. Real-time walkthroughs using video game technology can be a tool that helps the designer think about and convey the immediate sensory experience of the architectural space they are designing.

This technology is not limited to any one building typology or aesthetic style. First person exploration of architectural models using video game technology is a tool that represents a new, more immediate way of looking at what we design. It has the potential to fundamentally change the way we create, contemplate and critique architecture.

REFERENCES

1. Alfano PL, & Michel GF. (1990). Restricting the field of view: Perceptual and performance effects. *Perceptual and Motor Skills, 70*(1), 35-45.

2. Blumenfeld, Y. (1974). Beyond human scale - hassan fathy. *Architectural Association Quarterly, 6*(3-4), 53-57.

3. Bogost, I. (2005). Videogames and the future of education. *On the Horizon, 13*(2), 119-125.

4. Eisenberg, M., & Eisenberg, A. (2000). The developing scientist as craftsperson. In N. Roberts, W. Feurzeig & B. Hunter (Eds.), *Computer modeling and simulation in pre-college science education* (pp. 259-281). New York: Springer-Verlag.

5. Henry, D. (1992). Spatial perception in virtual environments: Evaluating an architectural application. M.S. thesis, Dept. of Engineering, University of Washington, Seattle.

6. Hoon, M., Jabi, W., & Goldman, G. (2003). Immersion, interaction, and collaboration in architectural design using gaming engines. Paper presented at CAADRIA 2003. Bangkok Thailand. 721-738.

7. Resnick, M. (2006). Computer as paintbrush: Technology, play, and the creative society. In D. G. Singer, R. M. Golinkoff & K. Hirsh-Pasek (Eds.), *Play=learning: How play motivates and enhances children's cognitive and social-emotional growth*. (pp. 192) New York: Oxford University Press.

8. Waller, D., Hunt, E., & Knapp, D. (1998). The transfer of spatial knowledge in virtual environment training. *Presence Teleoperators and Virtual Environments, 7*(2), 129-143.

APPENDIX A

SURVEY MATERIALS

ID

COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY
FEBRUARY 26, 2011

1: Preliminary Questions

1. Is Architecture your primary field of study? ☐**Yes** ☐**No**

2. If not, what is your primary field of study? ____________________

3. Have you visited the Mitchell Physics Building before? ☐**Yes** ☐**No**

4. If so, how would you rate your familiarity with the building?

☐**Very Familiar** ☐**Somewhat Familiar** ☐**Somewhat Unfamiliar** ☐**Very Unfamiliar**

5. During an average week, how many hours will you spend on a computer?

☐**>1** ☐**1-3** ☐**3-5** ☐**5-7** ☐**7-9** ☐**<9**

6. How often do you play **First Person Perspective** video games or simulations?

☐**Never** ☐**Seldom** ☐**Occasionally** ☐**Frequently**

7. During an average week, how many hours will you spend playing **First Person Perspective** games or simulations?

☐**>1** ☐**1-3** ☐**3-5** ☐**5-7** ☐**7-9** ☐**<9**

8. What system of distance measurement are you most familiar with?

☐**Imperial units (ft,in)** ☐**Metric units (m,cm)**

ID

COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY
FEBRUARY 26, 2011

2: **Virtual** Lobby Questions
(6 minutes)

1. How far is it from the blue circle on the floor to the green circle on the far wall?

2. How many of these red couches would fit lengthwise between these two points?

3. How tall is the first floor ceiling?

4. How many of the black trash cans would you need to stack to be as tall as the first floor ceiling?

5. How tall is the high ceiling in the center of this space?

6. How many of the black trash cans would you need to stack to be as tall as the high ceiling?

7. This space is (mark a point between the two)
   Small ☐—☐—☐—☐—☐—☐ **Large**
8. This space is (mark a point between the two)
   Dark ☐—☐—☐—☐—☐—☐ **Bright**
9. This space is (mark a point between the two)
   Interesting ☐—☐—☐—☐—☐—☐ **Boring**
10. This space is (mark a point between the two)
   Beautiful ☐—☐—☐—☐—☐—☐ **Ugly**
11. List 3 adjectives previously not mentioned to describe the space.

____

ID

COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY
FEBRUARY 26, 2011

3: Virtual Auditorium Questions
(6 minutes)

1. How far is it from the blue circle on the floor to the green circle on the far wall?

2. How many of these blue seats would fit between this point and that wall?

3. How tall is the ceiling at the lowest point?

4. How many of these trash cans would you need to stack to be as tall as the lowest point?

5. How tall is the ceiling at the highest point?

6. How many of these trash cans would you need to stack to be as tall ceiling at the highest point?

7. Estimate how many seats are in the auditorium. (do not use longer than 30 seconds)

8. This space is (mark a point between the two)

   Small ☐—☐—☐—☐—☐—☐ **Large**

9. This space is (mark a point between the two)

   Dark ☐—☐—☐—☐—☐—☐ **Bright**

10. This space is (mark a point between the two)

    Interesting ☐—☐—☐—☐—☐—☐ **Boring**

11. This space is (mark a point between the two)

    Beautiful ☐—☐—☐—☐—☐—☐ **Ugly**

12. List 3 adjectives previously not mentioned to describe the space.

____

ID ☐

COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY
FEBRUARY 26, 2011

4: Post **Virtual** Space Questions

1. Which space was bigger? ☐**Lobby** ☐**Auditorium**
2. Which space was brighter? ☐**Lobby** ☐**Auditorium**
3. Which space was more interesting? ☐**Lobby** ☐**Auditorium**
4. Which space was more beautiful? ☐**Lobby** ☐**Auditorium**
5. Which space is better designed for its intended use? ☐**Lobby** ☐**Auditorium**

ID

COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY
FEBRUARY 26, 2011

5: **Real** Lobby Questions
(6 minutes)

1. How far is it from this point to the wall on the other side of the lobby?

2. How many of these red couches would fit between this point and that wall?

3. How tall is the first floor celling?

4. How many of these trash cans would you need to stack to be as tall as the first floor ceiling?

5. How tall is the high ceiling in the center of this space?

6. How many of the black trash cans would you need to stack to be as tall as the high ceiling?

7. This space is (mark a point between the two)

   Small ☐—☐—☐—☐—☐—☐ **Large**

8. This space is (mark a point between the two)

   Dark ☐—☐—☐—☐—☐—☐ **Bright**

9. This space is (mark a point between the two)

   Interesting ☐—☐—☐—☐—☐—☐ **Boring**

10. This space is (mark a point between the two)

    Beautiful ☐—☐—☐—☐—☐—☐ **Ugly**

11. List 3 adjectives previously not mentioned to describe the space.

___

ID

COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY
FEBRUARY 26, 2011

6: Real Auditorium Questions
(6 minutes)

1. How far is it from this point to the far wall?

2. How many of these blue seats would fit between this point and that wall?

3. How tall is the ceiling at the lowest point?

4. How many of these trash cans would you need to stack to be as tall as the lowest point?

5. How tall is the ceiling at the highest point?

6. How many of these trash cans would you need to stack to be as tall ceiling at the highest point?

7. Estimate how many seats are in the auditorium. (do not use longer than 30 seconds)

8. This space is (mark a point between the two)

   Small ☐——☐——☐——☐——☐——☐ **Large**

9. This space is (mark a point between the two)

   Dark ☐——☐——☐——☐——☐——☐ **Bright**

10. This space is (mark a point between the two)

    Interesting ☐——☐——☐——☐——☐——☐ **Boring**

11. This space is (mark a point between the two)

    Beautiful ☐——☐——☐——☐——☐——☐ **Ugly**

12. List 3 adjectives previously not mentioned to describe the space.

____

ID

COMPARING PERCEPTION OF REAL AND VIRTUAL ARCHITECTURAL SPACE USING VIDEO GAME TECHNOLOGY
FEBRUARY 26, 2011

7: Post **Real** Space Questions

1. Which room was bigger? ☐**Lobby** ☐**Auditorium**
2. Which room was brighter? ☐**Lobby** ☐**Auditorium**
3. Which room was more interesting? ☐**Lobby** ☐**Auditorium**
4. Which room was more beautiful? ☐**Lobby** ☐**Auditorium**
5. Which space is better designed for its intended use? ☐**Lobby** ☐**Auditorium**

6.On a scale of 1 to 4, how do these aspects of the **Real Lobby** compare to the **Virtual Lobby**?
(1 is most accurate, 4 is least accurate) Use each number only once.

Beauty ___ **Lighting** ___ **Materials** ___ **Size** ___

7.How well did the computer program convey the **size** of the **Lobby**?
Accurately ☐—☐—☐—☐—☐—☐ **Poorly**

8.How well did the computer program convey the **lighting** of the **Lobby**?
Accurately ☐—☐—☐—☐—☐—☐ **Poorly**

9.How well did the computer program convey the **materials** of the **Lobby**?
Accurately ☐—☐—☐—☐—☐—☐ **Poorly**

10.How well did the computer program convey the **beauty** of the **Lobby**?
Accurately ☐—☐—☐—☐—☐—☐ **Poorly**

11.On a scale of 1 to 4, how do these aspects of the **Real Audiotorium** compare to the **Virtual Auditorium**?
(1 is most accurate, 4 is least accurate) Use each number only once.

Beauty ___ **Lighting** ___ **Materials** ___ **Size** ___

12.How well did the computer program convey the **size** of the **Auditorium**?
Accurately ☐—☐—☐—☐—☐—☐ **Poorly**

13.How well did the computer program convey the **lighting** of the **Auditorium**?
Accurately ☐—☐—☐—☐—☐—☐ **Poorly**

14.How well did the computer program convey the **materials** of the **Auditorium**?
Accurately ☐—☐—☐—☐—☐—☐ **Poorly**

15.How well did the computer program convey the **beauty** of the **Auditorium**?
Accurately ☐—☐—☐—☐—☐—☐ **Poorly**

Write any additional comments about the study: ____
____
____
____
____

APPENDIX B

DATA SET

This is the data set that was collected during my experiment. Each row corresponds to one participant's answers and each column corresponds to once question and is labled by page number and question number(e.g. 3.5 is page 3, question 5). On questions where there were non-numeric blanks to check (for example, qualitative questions) answers were labeled thusly: The farthest left blank was assigned the value of 0 and they were numbered in acceding order from left to right. This was used as a convenient label and these values were not used in any calculations. For example on page 7, question 15 "Accurately" is not presumed to have a mathematical value of 0 and "Poorly" is not presumed to have a mathematical value if 5. These were simply values used to label the answer.

Page 1

ID	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
AA	yes	n/a	yes	1	5	2	1	Imperial
AB	no	Psychology	no		4	0	0	Imperial
AC	no	Biomedical Engineeri	yes	1	5	1	0	Metric
AD	yes		yes	2	3	0	0	Metric
AE	yes		yes	3	5	0	0	Metric
AF	no	Elementary Education	yes	2	5	0	0	Imperial
AG	no	Health & Kineseology	no		5	2	0	Imperial
AH	no	Aerospace Engineerin	yes	3	3	2	1	Imperial
AI	yes		yes	3	5	0	0	Imperial
AJ	yes		yes	3	5	0	0	Imperial
AK	yes		no		5	0	0	Imperial

Page 2

2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10.
75	12	12	5	75	30	3	2	1	2
30	8	10	4	80	40	2	2	1	2
60	10	15	5		24	4	4	1	2
19.6	2	9.8	3	82	15	1	2	1	1
65.62	6	15.75	6	22.64	7	3	4	2	2
40	8	9	4	36	16	3	2	2	1
30	9	10	3	100	33	2	1	3	2
30	7	10	4	50	20	4	4	2	2
15	10	12	4	40	25	1	3	0	2
45	6	10	4	60	28	4	3	2	2
50	16	9	4	70	30	3	1	3	2

Page 3

3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10.	3.11
60	40	12	4	30	12	300	5	4	1	1
50	17	10	4	30	12	350	4	2	4	3
100	50	15	5	25	8	648	5	1	4	4
82	300	9.8	2	39.37	2	300	3	1	1	1
49.2	12	10.83	4	24.61	10	320	3	2	4	3
30	15	9	2	15	5	200	3	3	2	2
45	35	10	3	25	8	425	4	3	2	2
50	35	10	4	24	10	450	3	3	2	2
30	30	8	3	20	8	250	2	4	2	2
50	20	30	12	10	4	350	5	4	2	2
40	24	8	4	18	9	400	4	2	4	3

Page 4

4.1	4.2	4.3	4.4	4.5
1	1	0	0	1
1	0	0	1	1
1	0	0	0	1
1	0	0	0	0
0	0	0	0	0
1	1	1	1	1
1	1	1	1	1
0	0	0	0	1
1	1	0	0	1
0	1	1	1	1
0	1	0	1	1

Page 5

5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	5.10.
50	10	9	3	80	25	4	3	1	1
60	10	8	3	70	150	3	4	1	1
60	12	12	4	100	33	2	4	3	3
52.49	12	7.87	5	114.83		3	3	0	1
39.37	10	8.86	3.5	78.74	30	2	3	1	1
40	10	9	3	70	35	2	3	2	2
40	9	9	3	90	30	3	2	2	3
45	9	10	3	80	24	4	3	1	2
40	10	10		50	20	3	2	1	2
35	8	10	3	70	20	4	4	1	2
40	10	8	3	80	26	4	4	1	2

Page 6

6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.10.	6.11
60	50	10	4	15	6	120	3	5	3	3
60	16	10	3	30	5	200	4	4	3	2
50	25	12	4	20	7	80	1	2	5	4
85.3	12	9.84	10	26.25	24	280	4	4	2	2
39.37	12	9.84	7	18.7	11	200	2	4	3	3
30	10	15	3	20	5	200	1	2	1	1
45	30	11	4	25	8	250	2	2	3	4
35	30	15	4	20	6	200	1	4	2	2
30	25	12	4	20	6	120	1	3	2	3
30	20	18	6	12	4	150	3	2	4	2
35	26	9	3	16	6	150	2	3	4	2

Page 7

7.1	7.2	7.3	7.4	7.5	7.6B	7.6L	7.6M	7.6S	7.7	7.8
0	0	0	0	1	3	2	3	3	1	3
1	0	0	0	1	3	4	1	3	3	4
0	0	0	0	1	2	2	1	1	1	2
0	0	0	0	0	1	3	4	2	1	4
0	0	0	0	0	2	4	2	2	3	1
0	0	0	0	0	2	3	2	2	2	3
1	0	0	0	1	2	3	4	3	1	2
0	1	0	0	1	1	2	4	3	2	1
1	0	0	0	1	3	2	1	4	4	3
0	0	1	0	1	2	1	3	4	4	1
0	0	0	0	1	3	4	2	1	1	4

7.9	7.10.	7.11B	7.11L	7.11M	7.11S	7.12	7.13	7.14	7.15
1	2	3	4	4	3	1	1	1	2
0	3	2	3	1	4	5	2	0	2
0	3	2	2	2	4	5	2	1	2
3	1	1	4	3	2	1	3	2	2
2	2	4	2	3	3	2	4	1	3
3	3	3	3	3	3	4	3	3	4
0	2	2	3	4	1	3	2	1	2
3	1	3	1	2	4	4	1	1	2
1	2	2	1	3	4	4	2	2	2
1	1	2	3	1	4	5	0	1	1
2	3	3	1	2	4	5	0	1	1

CONTACT INFORMATION

Name:	Matthew Colton Spross
Professional Address:	Wei Yan, Ph.D. Department of Architecture Pavilion 110D Texas A&M University College Station, TX 77843
Email Address:	colton76065@tamu.edu
Education:	B.ENDS., Environmental Design, Texas A&M University, May 2011 Magna Cum Laude Undergraduate Research Scholar