LumiSpace: A VR Architectural Daylighting Design System

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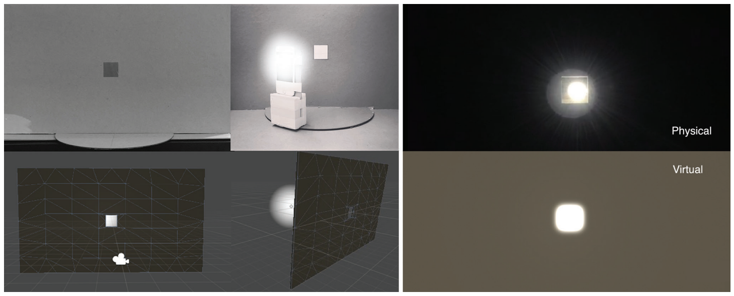

Figure 1: *Physical vs. virtual lighting experience experiment has been conducted in order to achieve realistic lighting sensations in virtual reality. Lighting experiment installation (Up) and its digital version in Unity3D (Down).*

Abstract

We built a VR daylighting design system for architects to design an indoor daylighting experience. With this system, users can import 3d models or meshes, and interact with the architecture in space. In particular users can draw the lighting areas they want and receive system-generated window opennings, given the sunlight conditions of a specific time and location. This research proposes a reversed design paradigm empowered by virtual reality technology, which puts the design of spatial experience first rather than the design of physical objects. That is, window design is determined as a result of daylighting experience.

Keywords: architectural perception, design tool, virtual reality

Concepts: •**Applied computing** → **Computer-aided design;** •**Human-centered computing** → *Empirical studies in HCI;*

1 Introduction

Light has been historically important in architectural design and discourse. In the traditional architectural design process, designers focus on designing physical openings like windows. Users can only experience the lighting effects after the building is constructed, so there is no way that designers can design lighting experience. The existing lighting design research in computer graphics focus on the simulation and visualization of lighting, and not about the specific and transient experience of light. However, the innate properties of VR (immersive and interactive) can help people experience architectural design in different times of a day or in different seasons. In this research, the authors propose a system where architects can design daylighting effects rather than architectural openings. In this system, users are able to import their design into the application, experience the space inside of VR, create or alter day-lighting patterns they desire, experience the light transience in different times of a day or season and design artificial light system at night. In order to give users realistic sensations about lighting, the authors conduct an experiment to replicate physical lighting experience in the virtual environment. A user study has also been conducted to evaluate VR's design value in helping designers understand architectural space by perceiving scale and distance.

Figure 2: *With this system, users can import 3d models or meshes, interact with the architecture in space, draw lighting areas they want and system will generate windows/ opennings according to the sunlight condition in specific time and location.*

2 Interactive System

In order to implement the application, we created a solar model inside of Unity3D by concluding research results about sun position and its direction on the sky dome and its ratio of luminance of sunlight. We deploy the application in Samsung Gear VR and use a gamepad as an input controller. Users can set specific time and location and the condition of sunlight will be generated. Then users can specify where on the floor they want sunlight to fall and a corresponding window design will appear as a result of calculating the sunlight direction and location (on the floor) through the suggested openings.

In this system, users can import 3d models or meshes from 3D softwares like Rhino into the VR system, experience it, interact, and make changes in space. There are several major interactions in the system: 1) Users can designate lighting areas and the system will generate opening (window) options with specific location and size. 2) Users can point to eliminate lighting areas so the system will

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VR Meets PR 2016, December 05-08 2016, , Macao
ACM 978-1-4503-4548-4/16/12.
http://dx.doi.org/10.1145/2992138.2992140

close the openings. 3) Users will be able to experience lighting transience in different times of the day. 4) During the night, users can create artificial light sources to inform future design decision. 5) Users will also be able to experience the space in different seasons.

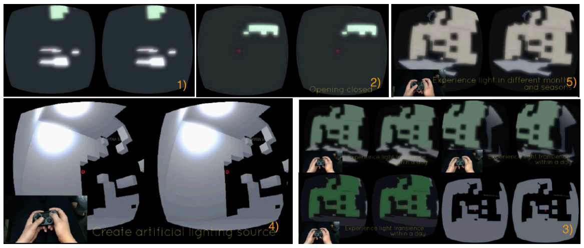

Figure 3: *There are several major interactions in the system: 1) designate lighting areas and system generates window options; 2) eliminate lighting areas and system closes openings; 3) experience lighting transience in different times; 4) create artificial light source at night; 5) experience in different seasons.*

3 Experiments: Physical vs. Digital Experience of Lighting

In order to replicate people's physical lighting experience in VR, We've conducted an experiment to understand sensations about light. We made an installation, which represents a mini version of a room with a window opening. There is a lighting source moving in the back. We used this experiment setup to observe people's perception and sensations of lighting in different directions and positions. We also created a digital counterpart in Unity3D.
There are two major observations coming out of this experiment: first, when the light comes to the window, the brightness bleeds out to the surroundings; second, when the light comes, the human eye perceives everything else to be darker.
The reasons are twofold: firstly, the world has a large range of light intensities but the screen has a limited range; secondly, the human eye adapts dynamically to different lighting conditions. There are solutions in computer graphics that can solve these problems, which are Bloom and HDR (high dynamic range rendering). By applying the two effects into the digital camera, we were able to gain more realistic sensations that are more similar to the physical lighting experience (Figure 1).

4 Scale + Distance Perception User Study

In building an architectural daylighting design application, it is essential to understand if VR has the design values in helping people understand space. A user study about people's perceptions of scale and distance has been conducted.
In this experiment, I've designed a scene of a room with 2 cubes inside. The two cubes are of different sizes and they are positioned at different distances from the camera. The research focus is architects' perceptions of scale and distance of space in VR vs. Rhino. No texture is applied here in case users can tell the sizes by distortions of texture patterns. Any other parameter that can potentially be used as a reference like grid or reference line has also been eliminated. Users see the exact same scene in VR and Rhino. 20 designers have been tested and interviewed - 10 for each platform. The camera is set at each user's own height. Four questions have been designed: 1) How big is the front cube and back cube? 2) Which cube is bigger? 3) What is the distance between the camera and each cube? 4) What's the distance between the two cubes?
In analyzing the study, we used Average Absolute Deviation (AAD)

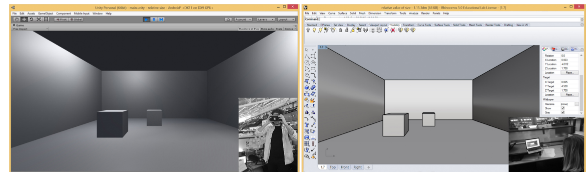

Figure 4: *Exact same scenes are created in VR and Rhino. The camera height is set as the user's own height in both situations.*

Table 1: *Scale+Distance Perception User Study Results (the following numbers are Average Absolute Deviations which are used to measure how different are users' answers with the correct answers).*

Questions	VR	Rhino
What's the size of the front cube?	0.28836	0.38
What's the size of the back cube?	0.31056	0.335
Distance from the camera to the front cube?	3.3502	2.918
Distance from the camera to the back cube?	4.22168	3.641
Distance between 2 cubes?	1.49976	1.419

to measure how different are users' answers with the correct answers (the smaller the value the better). The average absolute deviation (or mean absolute deviation) of a data set is the average of the absolute deviations (for each question in each platform, there are 10 deviations/ answers) from a central point.
As for question 2), in VR, everyone thinks the front cube is bigger than the back cube (correct answer), but in Rhino 5 people think the two cubes are equal in size and the other 5 think the front cube is bigger.
Interesting feedbacks that have been gathered include: "Rhino is hard/ almost impossible to tell scale. In VR, it's so much easier since you know how high you are - it helps a lot. VR removes one layer of abstraction. It helps you understand what it feels like when design this building." - A designer who has 3 years' experience in architectural design.
In conclusion, we can tell that VR has a very obvious advantage over Rhino in helping people determine scale. Regarding the perception of distance, Rhino seems to do slightly better, but no conclusion can be made here since the difference is trivial and there are limited samples.

Acknowledgements

Special thanks to Rus Gant for lending me the VR headset and to all the architects and students who participated in the user study.

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