

Augmented Light:  
Advancing Window & Lighting Technology

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**ABSTRACT**

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Advancing Window & Lighting Technology

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Light has an innate ability to impact the physiological state of human beings. Although, modern day architecture has made immense strides in lighting design, little has been done to leverage this unique characteristic of light. A growing body of research has successfully qualified these non-quantitative effects of light into a new conceptual framework called the Human Centric Lighting Model. This new model considers the impacts of interior lighting as threefold: Visual, Biological and Emotional. Working within this new framework, this thesis explores the possibility of creating richer interior experiences by leveraging current day lighting and sensor technology in hopes of enriching the rudimentary dialogue between interior and exterior lighting. Additionally, it considers technology's role in shaping future cities as virtually augmented spaces that intermix physical and virtual components to create a new kind of urban environment that is shaped as much by physical architecture as it is by informational and cultural; these cities exist as physical places with augmented digital overlays. It aims to assist architecture in resolving the growing tension between physical and virtual spaces by re-establishing the role of the window as a liminal point of transition between not only interior and exterior space but physical and virtual as well.

Thank You:

To Rob Corser for his steadfast guidance & design perspective during these unusual and trying times. I am lucky to have connected with you during my time here at the University of Washington.

To Roark Congdon for his wit, humor and guidance in helping to actualize what were once fuzzy and incoherent ideas on lighting and design.

To my incredible brother Gbenga, who has mentored me my entire life, I don't know where I would be without you.

To every one of my family and friends who supported, loved, encouraged and empowered me to finish this degree program.

A close-up profile of a woman's face, looking out a window at a city at night. Her face is overlaid with a vibrant, multi-colored light effect, resembling a rainbow or a spectrum of colors. The background shows a blurred cityscape with lights from buildings and windows, creating a bokeh effect. The overall mood is contemplative and artistic.

# Augmented Light

Bukola Badipe-Hart

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# Introduction

*Our Modern World...*



*Figure #1 Times Square circa 2015*

# Introduction

## THESIS OVERVIEW

Our modern world is a high intensity saturated place of media, color, and digital noise. As depicted in *Figure #1* cityscapes that were once dominated by buildings, now share the skyline with large screens that serve as windows into virtual worlds. As the physical space of our cities share an increasing presence with virtual space, our spatial understanding of the built environment shift and morph alongside it. Not only do screens permeate the skylines of our cities but they also have a ubiquitous presence in our daily lives in the form of cellphones, tablets, and computers. The human body refined by years of the evolutionary process is struggling to keep up with the lightning speed of modernization.

For millions of years our bodies attuned themselves to the cycle of the sun, or the circadian rhythm. Bright sunlight alerted us of when we needed to be awake and the darkness of night let us know when it was time to rest and sleep. However, with the permeation of screen based technology our bodies run on what could be considered a prolonged daily cycle. The blue light of screens send unwarranted signals to our eyes that we should be awake and alert evening during the night hours. The result of disrupting our bodies natural circadian cycle are increased stress, higher risk of disease and accelerated aging. The architecture of the next century must be attuned to the ways in which modernization impact the body and design in a such a way to mitigate those impacts.

The exciting design prospect of future cities is an opportunity to enrich the ways that natural and artificial light, physical and virtual space interface with city inhabitants.

It is the intent of this thesis research to explore what it means to *inhabit* the space between physical and virtual space within the context of interior spaces. This thesis examines the relationship between natural and artificial lighting and uses the architectural principle of liminality to propose an innovative window design that incorporates a virtual component into a physical object (the window). The innovative window, hereby referred to as *Lightbox* would allow users a much broader depth of control over the artificial and natural lighting conditions of their interior spaces. Allowing users to adjust for color temperature and brightness of both natural and artificial lighting. Furthermore, it would provide opportunities for users to experience Augmented Reality (AR) overlays on their window screens when and if desired.

# Background

*Natural & Artificial Light*



# Background

## LITERATURE REVIEW

The following section reviews contextual literature pertaining to the effects of artificial and natural lighting. Since the surrounding literature is quite disparate, the section will review each subject separately and then draw comparisons in the upcoming section titled *The Pros & Cons of Natural & Artificial Light*.

### Natural & Artificial Light

A 2014 study conducted by Queensland University of Technology cited the effects of natural light on building inhabitants. The study explored the health benefits of natural lighting on health and wellbeing for healthcare facility patients and employees (Salonen, Heidi, Lahtinen, Marjaana, Lappalainen, Sanna, Knibbs, Luke D., Morawska, Lidia, & Reijula, Kari, 2014)<sup>1</sup>.

Focusing on the presence on windows in healthcare facilities, the researchers discovered that increased window access resulted in faster patient recovery rates, improved sleep, mood and reduced length of stay. Additionally, employees experienced reduced absenteeism and errors, increased positive attitudes, improved mood, reduced fatigue, less eyestrain and greater job satisfaction” (pg.2). The impact of windows were not only related to their access to daylight but also to the access to views of nature and the ability to control the natural light in the interior space.

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<sup>1</sup> “The Impact of Windows, Daylight and Views of Nature on Health and Wellbeing in Healthcare Facilities” discusses the importance of natural lighting in creating ideal recovery environment. Patients with regular access to natural light had statistically higher recovery rates.

impacted the cognitive and or memory functioning. In a separate study titled *Nature in the Learning Environment*, researchers discovered that exposure to nature via windows “does improve cognitive functions linked with learning, such as attention and memory (Berman et al., 2008,2012; Tennessen & Cimprich, 1995; Wells, 2000)<sup>2</sup>.

Precedent research done on artificial light is mainly centered on blue light and its impacts on human health. In a 2016 publication titled, *Effects of Blue Light on the Circadian System & Eye Physiology*, researchers discovered that blue light within the range of 400-490nm (which are most smart devices) “can affect many physiologic functions” both positively and negatively (Gianluca Tosini, Ian Ferguson, Kazuo Tsubota). Non-image forming photo receptors assist in regulating the circadian cycle and other important biological functions. Due to blue light’s ability to induce alertness in mammals, blue light has the potential to assist the circadian cycle in being alert during the morning hours, however, depending on what time of day the blue light is experienced, it can also cause light induced retinal damage. The study discovered that rats were three times more susceptible to retinal damage at night (1am) then during the day (9am-5pm).

In a separate study on the *Effects of Red Light on Circadian Rhythm* showcased that “spectrum with high blue intensity tended to cause abnormal regulations of melatonin and cortisol, while the abnormalities were likely to be compensated by the 606-635nm red light” (Cai, Jianqi & Hao, Wentao & Zeng, Shanshan & Qu, Xiangyu & Guo, Ya & Tang, Shanshan & An, Xin & Luo, Aiqin, 2021)<sup>4</sup>.

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<sup>2</sup> The study directed 60 random participants to walk in either an urban and or natural environment and then conducted a comprehensive psychological exam on both groups. The exam revealed that participants who walked in the natural environment scored more positively.

<sup>3</sup> The primary concern of the study was the common use of the white LED light and it’s peak blue light emission around (450-460nm) and how unregulated its effects are on the body.

<sup>4</sup> Spectrum plays an important role in the regulation of both melatonin and cortisol.

# The Effects of Light

*Visual, Emotional, Biological*



*Figure #2 Color Temperature & Mood*

on an individual scale. These findings imply that light at various color temperatures, and illuminance experienced at varying times of days have the ability to impact the physiological state of the body and so should be carefully designed to maximize positive impacts on the human body for maximum well-being.

## The Effects of Light: Visual, Emotional, Biological

Historically speaking, architecture has considered interior lighting based solely on its visual effects i.e., the amount of light needed to illuminate the square foot of the building. However, recent research in light's non-visual effects point to a more holistic model. This new approach is called the Human Centric Lighting (HCL) and considers the effects of lighting as threefold: Visual, Biological, and Emotional. Since the visual effects of light are well known and documented, (i.e, lighting needs to be regulated to ensure for visual comfort and low amounts of glare to protect our vision) we will start by examining the biological effects of light. In his article titled *Human Centric Lighting*, Principal of Lighting Wizards, Stan Walerczyk describes the development of this biological reliance on light.

*“Over time, people have evolved in harmony with the Earth’s natural lighting cycle, which has low light levels and low correlated color temperatures (CCT) in the early morning, high light levels and high CCTs at mid-day, low light levels and low CCTs during evening, and extremely low light levels and a medium CCT under moonlight. These varying light levels are at the heart of a human being’s 24-hour internal clock, otherwise defined as circadian rhythm. Until 200 years ago, 90% of our waking time was spent outside. Now most of us spend 90% of our time indoors with electric lighting. While we’re at work, our lighting is usually set at one light level with a constant CCT—this is not consistent with circadian rhythms. Without regular and direct exposure to such dynamic lighting, the circadian rhythm can be disrupted, which could lead to health issues.”<sup>1</sup> (Walerczyk, *Human Centric Lighting*, pg. 20)*

<sup>1</sup> Walerczyk, (pg 20) discusses at length the impact that the shift to spending most of our time in interior lighting has had on the human body..

Our body’s circadian cycle reliance on the dynamic brightness and color temperature changes of exterior lighting is one reason why the light we experience from screens can be so detrimental to our health.

Our bodies have natural responses to both natural and artificial lighting. Primarily, our eyes receive light information through photosensitive retinal ganglion cells which respond to light’s varying color temperatures, then depending on the color temperature (correlated color temperature) and brightness (illuminance) our body releases melatonin which reduces alertness and aids us in falling asleep.

The less known emotional effects of light are closely related with the biological. Cool more blue light, expressed in kelvins between 10K and 6K make us feel alert and vibrant whereas warmer, more red light, makes us feel calm and at ease. This is one of reasons why the different seasons tend to affect our moods in different ways, each season has a different color temperature palette. Figure #2 explores this relationship in more detail.

One breakthrough finding of the HCL model is a key variable, Melanopic Action Factor, which quantifies the relationship between the correlated color temperature and the amount of melatonin the body is producing in response to it. As shown in Figure #3, generally warmer light color temperatures, correlate with higher melatonin production and cooler light color temperatures correlate with lower melatonin production.

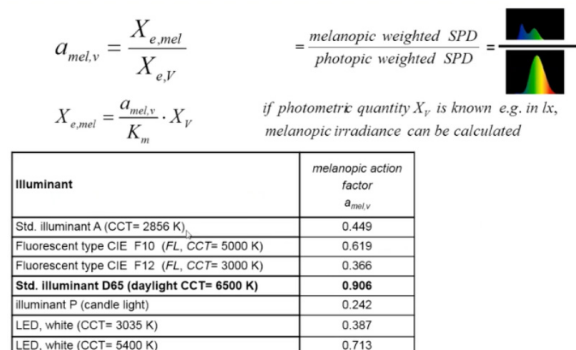


Figure #3 Melanopic Action Factor  
Source: Dr.Dieter Lang, “Measurement & Design for HCL”

# Natural & Artificial Light

*The Pros & Cons*



# NATURAL & ARTIFICIAL LIGHT: THE PROS & CONS

Natural and artificial light are the two primary light sources we encounter on a regular basis. We will examine the advantages and disadvantages of each light source with the HCL categories of our visual, emotional and biological responses to light. However, little research exists on how the two lighting systems might work together synergistically to account for the shortcomings of both. Figure #3.1 provides an overview of our exposure to both light sources.

## PROS OF NATURAL LIGHT

An important visual advantage of natural light is its dynamism. Exterior lighting conditions are rich and dynamic visual experiences that vary throughout the day and assist in creating powerful memories. This is a huge contrast to the light we experience indoors which tends to be quite static. The biological advantage is huge because of our bodies reliance on the sun for vitamin D , the regulating of our circadian cycles and general wellness (reduction of heart disease, cholesterol, blood pressure etc.)<sup>1</sup>(Jason Brainard, M.D., Merit Gobel, B.S., Benjamin Scott, M.D., Michael Koeppen, M.D., Tobias Eckle, M.D., Ph.D, 2015). Finally the emotional benefits of natural light go hand in hand with vitamin D production which boost our mood and helps regulate SAD.

## CONS OF NATURAL LIGHT

Visually natural light can be at a disadvantage because the color temperature and hours of light available in a day is dictated by the seasons. This also means that it certain times of year natural light can be visually displeasing (i.e., gray overcast days and long dark winters). Theses times of year can have huge

1 "Health Implications of Disrupted Circadian Rhythms and the Potential for Daylight as Therapy".

2 "Non-Visual Effects of Light on Melatonin, Alertness and Cognitive Performance: Can Blue-Enriched Light Keep Us Alert?"

## PROS OF ARTIFICIAL LIGHT

One clear advantage of artificial light is its ease of accessibility, most people are exposed to artificial light 6+ hours a day. Additionally there is a high range of lighting options that vary in color and brightness. In terms of biological and emotional impact, artificial blue light can increase our mood and cognitive functioning during the daytime<sup>2</sup> (Sarah Laxhmi Chel-lappa,Roland Steiner,Peter Blattner,Peter Oelhafen,Thomas Götz,Christian Cajochen, 2011.)

## CONS OF ARTIFICIAL LIGHT

A huge visual disadvantage of indoor lighting is it's static nature and lack of variation throughout the day. Blue light makes up most of the artificial light we regularly encounter on screens and devices. Overexposure to blue light at night can lower melatonin production by as much as 85% and throw off our circadian cycle. The likelihood of being overexposed to blue light is high given that 60% of people spend more than six hours a day in front of a screen. Since neither of these light sources are perfect there's a clear opportunity to leverage the advantages of both natural and artificial light in a more systematic way.

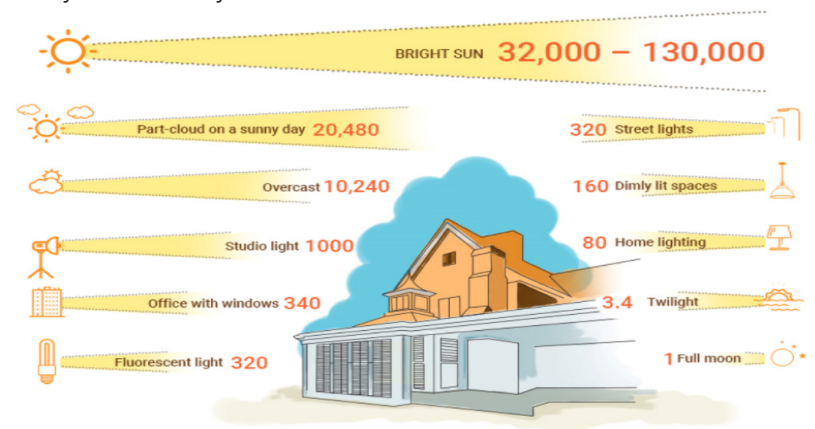
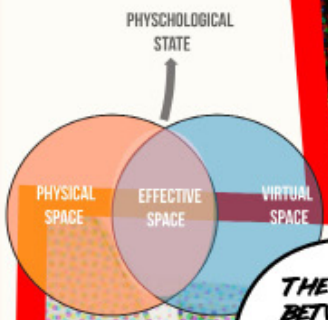
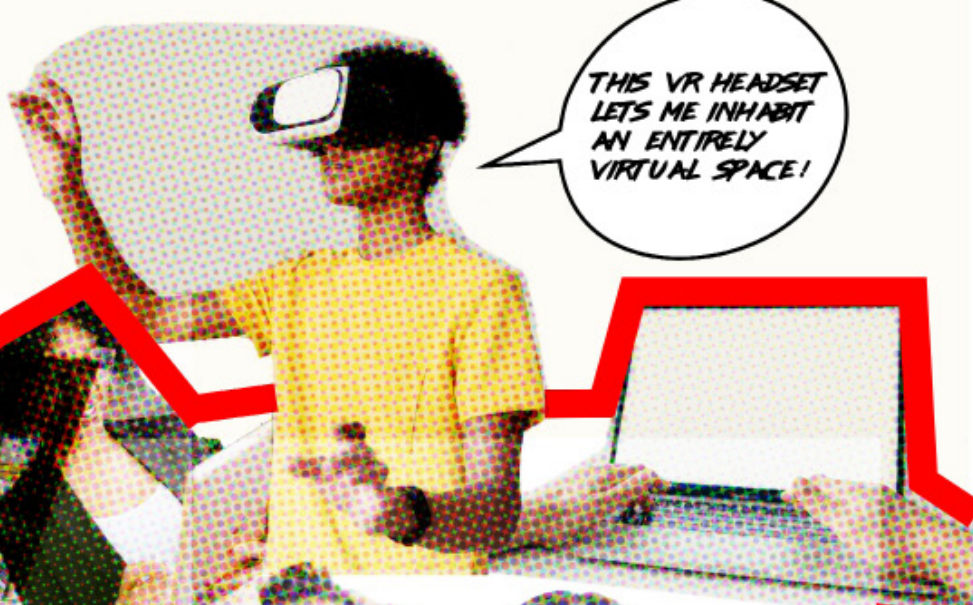
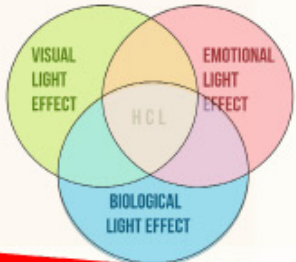


Figure #3.1 Natural & Artificial Light  
Source: Coolshutters.co.uk, "Natural Light"

**NEW FRAMEWORK**

**EXPLORING THE DIFFERENT WAYS PEOPLE INHABIT SPACE**



**THE SPACE BETWEEN MY CLASSES IS WAY TOO FAR!**



**EXPERIMENTATION**

**USING EXISTING TECHNOLOGY IN NEW WAYS**

**PROJECTED TREND**

**THE CONVERGENCE OF PHYSICAL & VIRTUAL SPACE**

Figure #4 A new framework

# Framework

## PRECEDENT ANALYSIS: SAD LAMPS

Both natural and artificial light have an impact on occupants' physiological state through the variables of illuminance, correlated color temperature, and time of day (Yingying Zhu, Minqi Yang, Ying Yao, Xiao Xiong, Xiaoran Li, Guofu Zhou, Ning Ma, 2017)<sup>1</sup>. It is the intent of this thesis research to explore how bridging these two systems together can allow for more occupant control and create a more dynamic and rich interior experience.

However, little research exists on how the two lighting systems might work together synergistically to account for the shortcomings of both. Natural lighting, derived mainly from the sun has great health benefits, but varies seasonally and geographically. Despite our reliance on the sun to maintain our circadian cycle, it is by no means a perfect system. Certain regions, such as the Pacific Northwest, go through long periods without sufficient sunlight causing city inhabitants to suffer from SAD. Conversely, the artificial lighting systems of our interior spaces can be at odds with the existing natural light. For instance, interiors with blue florescent lighting are aesthetically at odds with the orange color temperature of a warm summer day which is disruptive to the mood of the occupant in the interior space.

One pre-existing light solution that takes into account the advantages and disadvantages of both artificial & natural light are sad lamps. These lamps are widely used in regions that have long seasons of insufficient sunlight, such as the pacific northwest and Alaska region. Sad lamps are utilized widely because

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<sup>1</sup> Primarily in pages (1-4) the reserachers discuss the impact of lighting on cognitive performance, mood, and alertness in healthy adults.

when aligned with proper circadian rhythm cycling, so a burst of blue light in the morning as opposed to a different time of day. Not only do these lamps provide supplemental lighting but the spectral quality of the light is fine tuned to assist with heightening the users mood and establish circadian rhythms. Some important aspects of the light therapy boxes are the screen size, spectral color distribution, intensity and angle of light intake.

The success of these lamps provides insight into the ideal conditions for further lighting innovation. Although this research aims for a more systemic solution, sad lamps provide a critical insight on the importance of low entry point solutions.

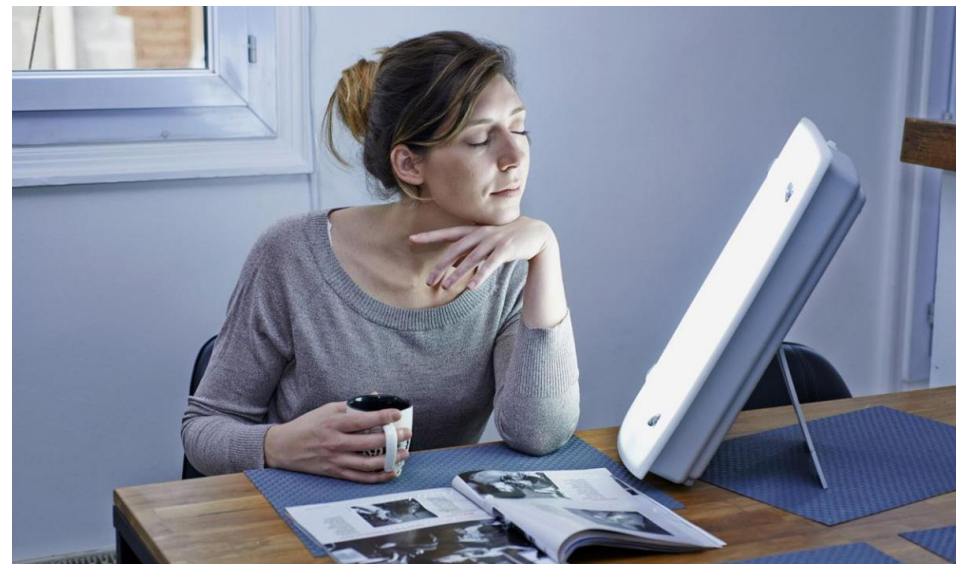


Figure #5 SAD Lamp Precedent

# Light, Memory & the Camera Obscura



## LIGHT, MEMORY & THE CAMERA OBSCURA

A rather neglected aspect of light is the role it plays in memory. “Light activates factors that are essential for memory formation” (Show Inami, Shoma Sato, Shu Kondo, Hiromu Tanimoto, Kitamoto, & Sakai, 2020)<sup>1</sup>. Due to light’s incredible ability to influence our psycho-biological state, memories tend to contain information regarding the exact light conditions of the moment. Light and memory are so connected, that many of the tools we’ve developed for capturing memories are highly attuned at capturing the exact lighting condition of the moments we’re trying to recall i.e, cameras and video cameras.

The foundation for capturing light as memory came via a breakthrough experiment conducted prior to the 6th Century: the camera obscura. Shown in Figure #6, the camera obscura experiment was simple, it took a dark interior room (a camera) and pierced a single hole into an exterior facing wall. Due to the unique way in which light travels, whatever existed outside the room was then projected as an upside-down image onto the interior wall. Today’s cameras still use this principle of light to capture images, keeping the projections as physical and digital photographs and videos

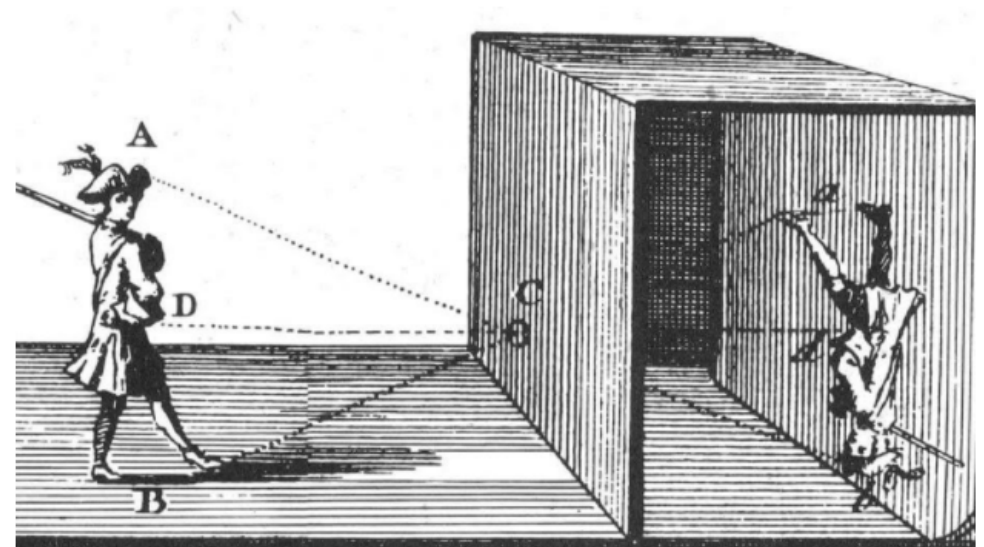


Figure #6 The Camera Obscura

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<sup>1</sup> Light has been shown to be critical in the formation of long-term memory. In a study titled “*Environmental Light Is Required for Maintenance of Long-Term Memory in Drosophila*” researchers tested memory retention in *Drosophila*. This attribute of light is discussed in depth pages (1-3) The formation of memory is actually impaired during pro-longed exposure to darkness.

# Affective Space

## *Bridging Physical & Virtual*



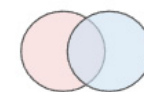
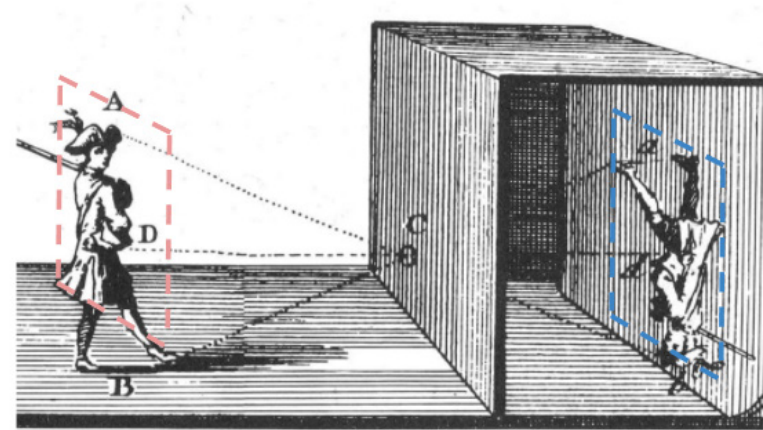
**Figure #7** *Affective Space*

## AFFECTIVE SPACE: BRIDGING PHYSICAL & VIRTUAL

Understanding the role that the camera obscura played in capturing memory became a critical conceptual shift in understanding the relationship between physical and virtual space. In order to bring the camera obscura metaphor into a more architectural framework, we can think of the box as a building and the aperture as a window that allows natural light to reach interior spaces. If the box is a building, and the hole now a window, then the exterior, is physical space and interior projection, virtual. This implies that the window has the potential to not only connect natural and artificial light together but also physical and the virtual space. One of the issues with Figure #1 was the lack of liminality between physical and virtual space. Rather than thinking of the two spaces as entirely separate, it became more appropriate to think of them as opposite ends of a spectrum (as shown in Figure #8), and to consider the modern cityscape of Figure #1 to be in the center of the spectrum, where the virtual and physical co-exist side by side.

The camera obscura became a powerful metaphor to consider the overlap of the two kinds of space as affective space. Affective space is a term coined by this research that refers to how both spaces impact the psychological state of the occupant. A great example of affective space is to glance at Figure #7. Affective space is the impact that the virtual world that's perceived in the television screens and laptops and the physical space of the room the people are inhabiting have on their physiological state during any given moment in time.

Additionally, we can begin to think of both physical and virtual space sharing natural and artificial light sources as the primary force driving our emotional response to both kinds of space. This connection infers that the window has the potential to not only connect natural and artificial light together but also physical and the virtual space and through that connection allow for greater control of affective space.

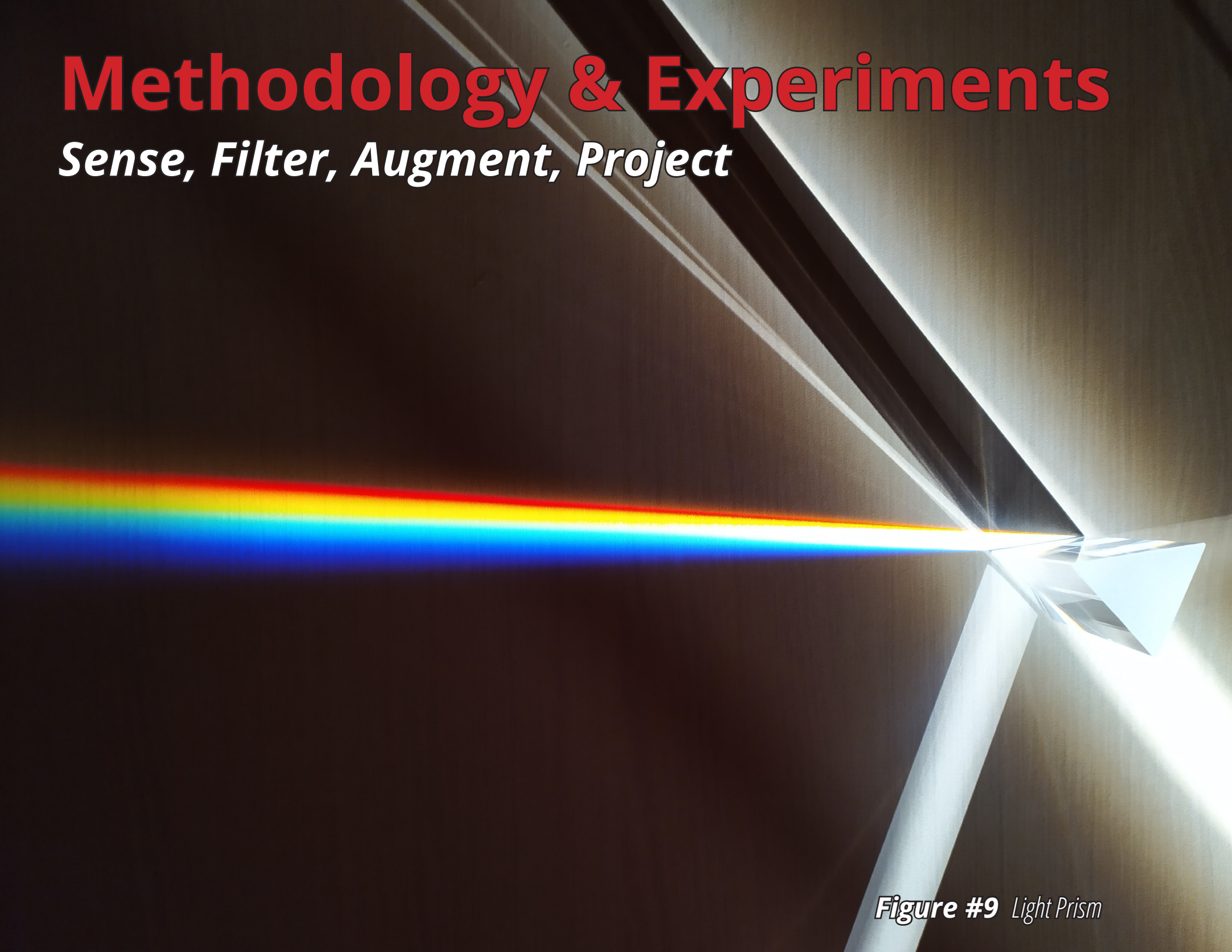


(spectrum)

Figure #8 Spectrum of Physical & Virtual Space

# Methodology & Experiments

*Sense, Filter, Augment, Project*



*Figure #9* Light Prism

# Methodology & Experiments

## THESIS PROBLEM STATEMENT

Currently, natural and artificial light interface in very rudimentary ways: windows allow in light from the exterior, shutters diffuse the amount of light entering the space, curtains block out the view and light allowing for privacy, and interior overhead lights add artificial light to increase brightness in interior spaces. One potential way to begin to connect these two systems together would be to create a richer dialogue between the two fundamentally different light sources.

In order to better understand what this new richer dialogue between the two light sources would be, the question was divided into a three tier problem statement.

1. How do we improve interior access to more dynamic lighting conditions?
2. How can we increase the level of lighting personalization available through dynamic control?
3. How do we factor in the human value for capturing and re-experiencing memories into this new framework?

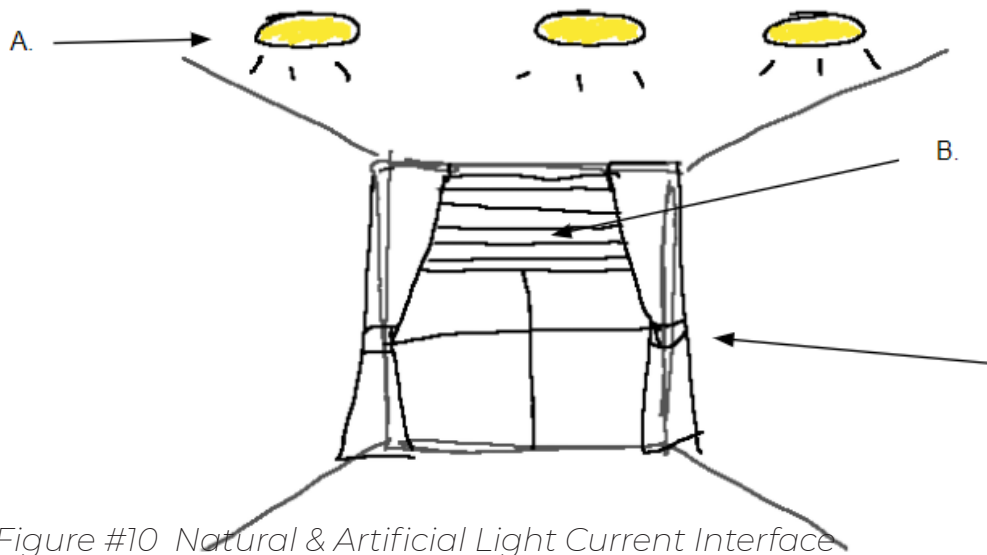


Figure #10 Natural & Artificial Light Current Interface

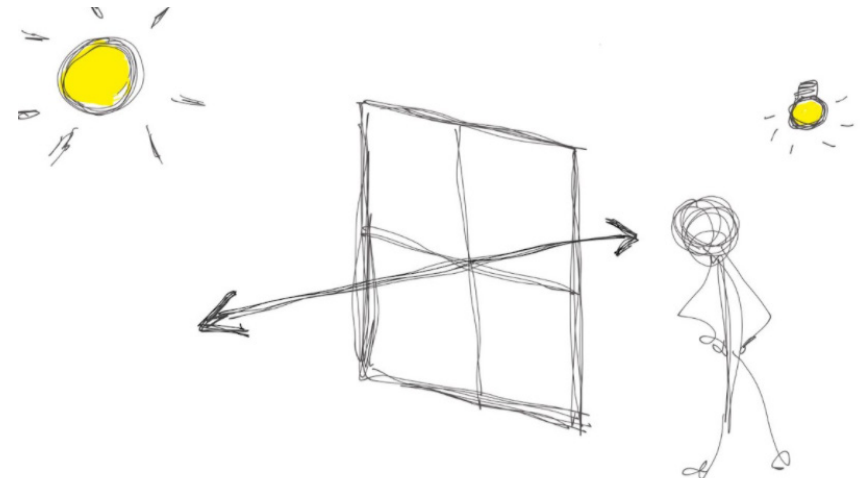


Figure #10.1 Proposed Model

## LIGHT SENSORS EXPERIMENT

Tier #1 How do we improved access to more dynamic lighting conditions?

The first step to accomplishing this is by incorporating light sensors into our interior lighting system. If we lined light sensors along the edges of the window frame it could allow for a communication pipeline for the changing natural lighting conditions. Light sensors could detect the level of brightness and color temperature of natural light and tell overhead artificial lights what color and brightness would be most suited for the current conditions. Additionally, if we replace the window glass with a transparent LCD screen that would allow for more privacy control by increasing and decreasing the opacity of the window, thus eliminating the need for shutters and curtains. In order to better understand the feasibility of this new system, a series of experiments were conducted.

The first of these experiments was the Light Sensor Experiment. By utilizing Arduino Sensor BH1745NUC, a light sensor which detects the brightness and color of light, colored lights and Serial Monitor, I was able to read the colored light sources' RGB and brightness of the environment. For purposes of clarity this is shown using artificial lights, however, in reality this light source would be natural. This experiment was successfully able to confirm the feasibility of creating a richer dialogue between interior and exterior light.



Figure #11.1 Light Filters Experiment

## LIGHT FILTERS EXPERIMENT

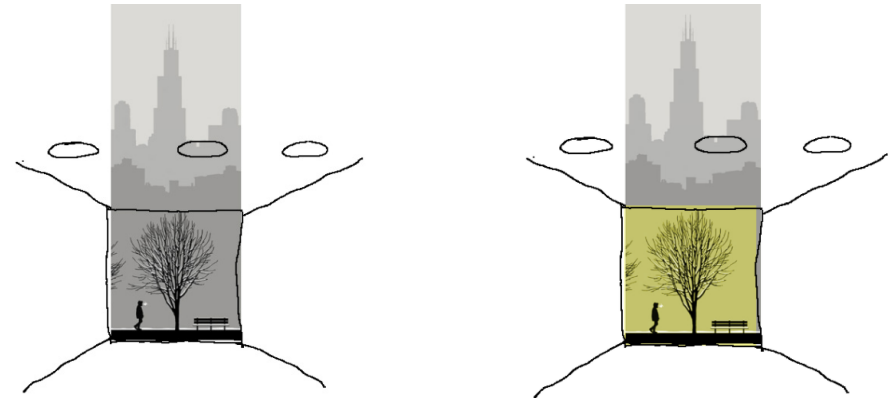
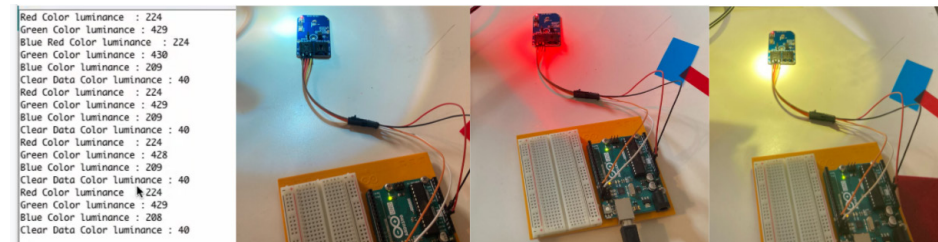


Figure #11 Light Filters Diagram

Onto the second tier of the problem statement: Tier #2 How can we increase the level of lighting personalization available through dynamic control?

One issue we face is that our bodies want and need natural light, but natural light is not always at the desired color temperature for our bodies or preferences. One way to solve this issue is by filtering the natural light to a more desirable color temperature.



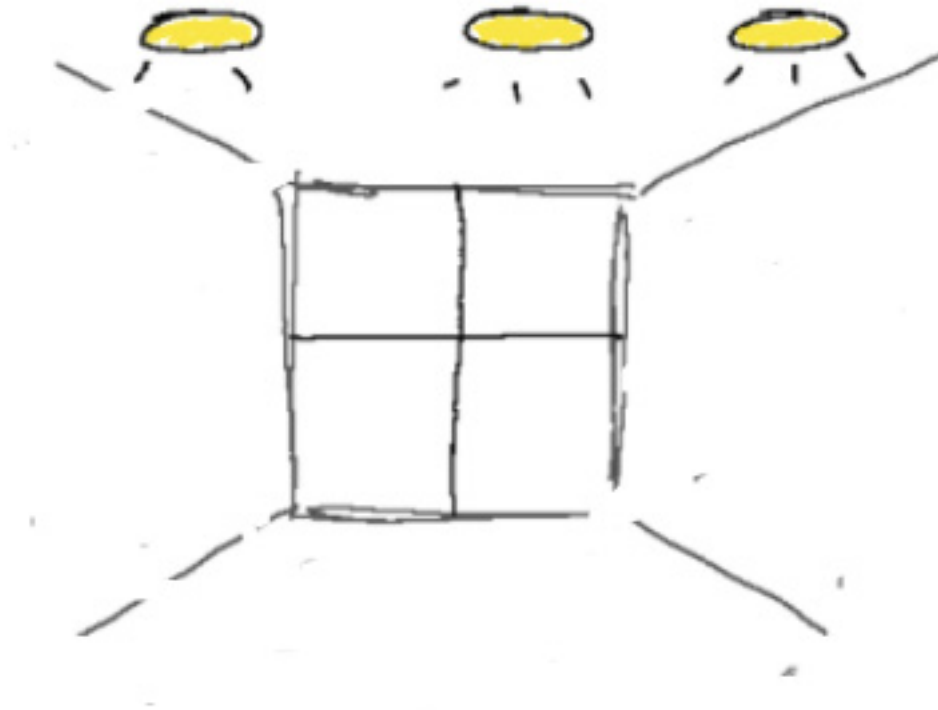


Figure #10.2 Proposed Interface

LIGHT AUGMENT EXPERIMENT

In order to better understand the more qualitative aspects of light's spectral richness a series of experiments were conducted using a dark box, colored filters and a single source of light (a cell phone light) which entered the dark box through a small slit where a colored gel filter allowed the light to pass through and diffusely reflect in the interior of the box. Then after having gained a better understanding secured color filters that were close in temperature to the different seasons. Despite the simplicity of the solution, it has potential to be quite elegant.

Another means of allowing for greater control of the color temperature and brightness of interior lighting conditions is to expand light augmentation options. Currently, light augmentation does not allow for customization and oftentimes the color temperature of the interior light in the room is misaligned with color temperature of the exterior lighting condition. Instead, we could use those same sensors and have them tell the overhead lights the color temperature of the exterior lighting so it could match the interior lighting accordingly.



1 Slip Diagram

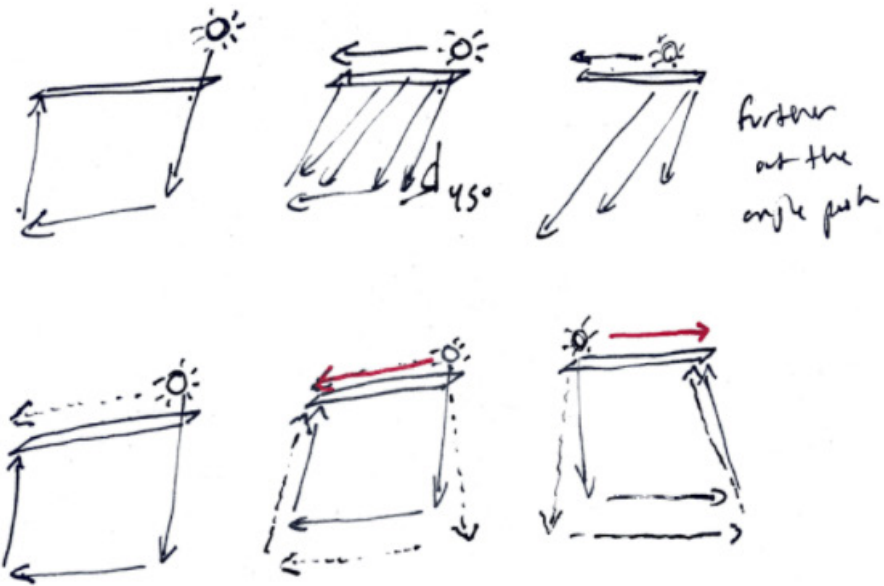
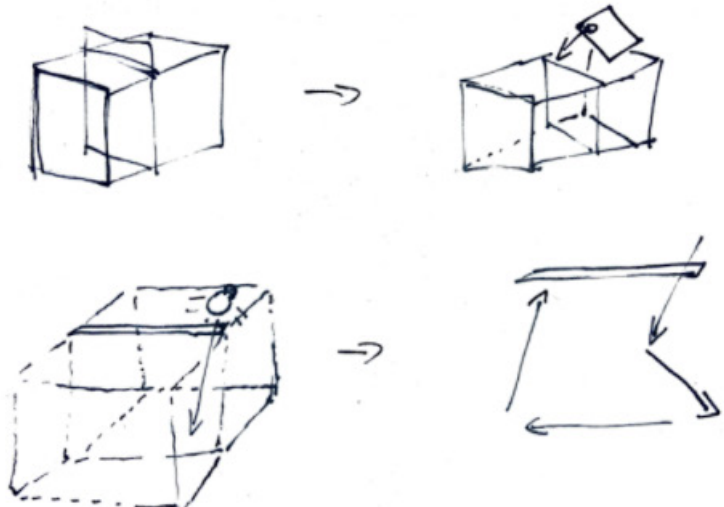


Figure #11.2 Light Filters Experiment

Augmented Light

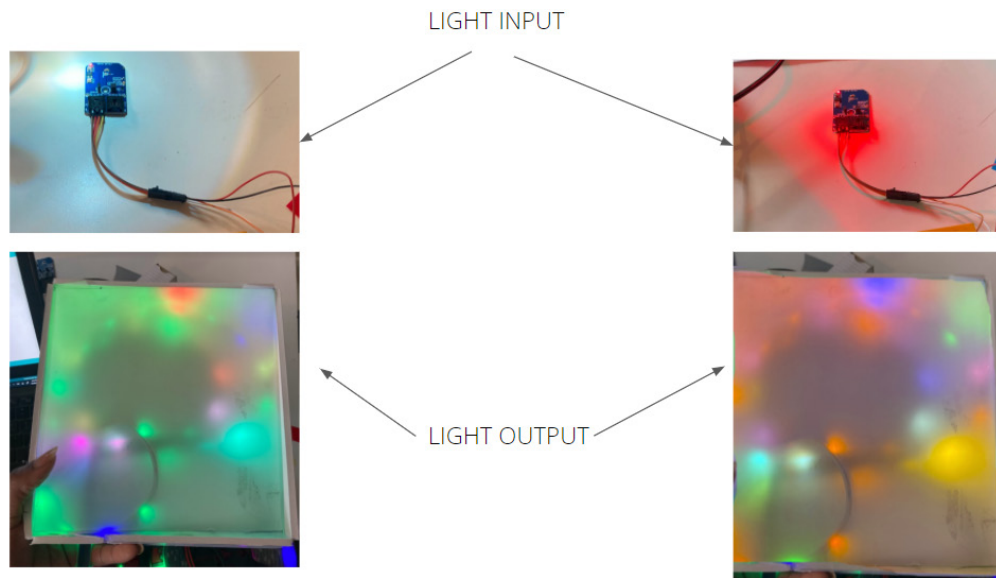


Figure #12 Light Augment Experiment

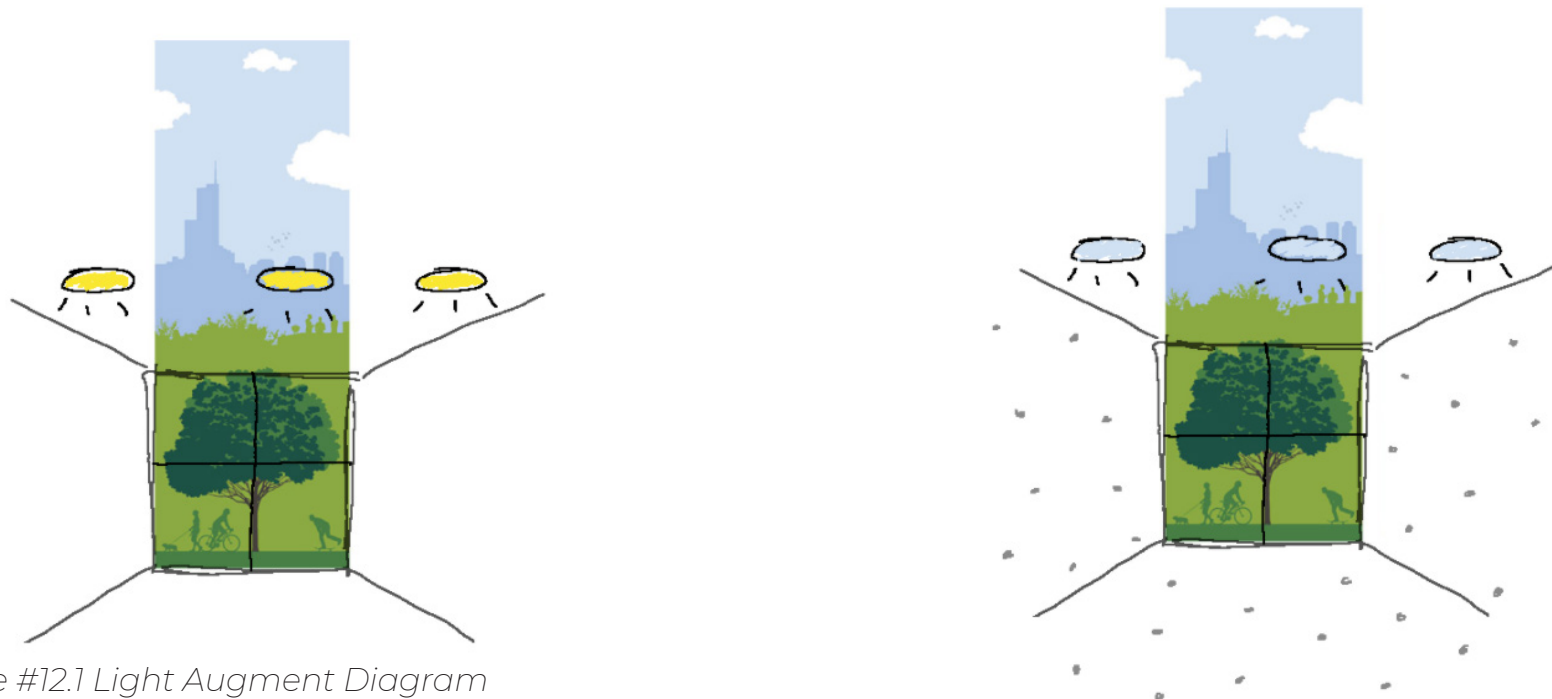


Figure #12.1 Light Augment Diagram

## LIGHT PROJECTION EXPERIMENT

The last tier of the problem statement asks:

Tier #3 how do we factor in the human value for capturing and re-experiencing memories into this new framework?

The last experiment was an exploration of a new way to capture memories. Since our memory of a particular moment have a lot to do with the lighting condition, exploring a way in which we might capture both the image of that moment and the lighting condition was critical. With those same light sensitive sensors and cameras, we could capture the lighting conditions and views of a day we particularly liked and then re-experience both the view and the lighting condition during less favorable days (figure).

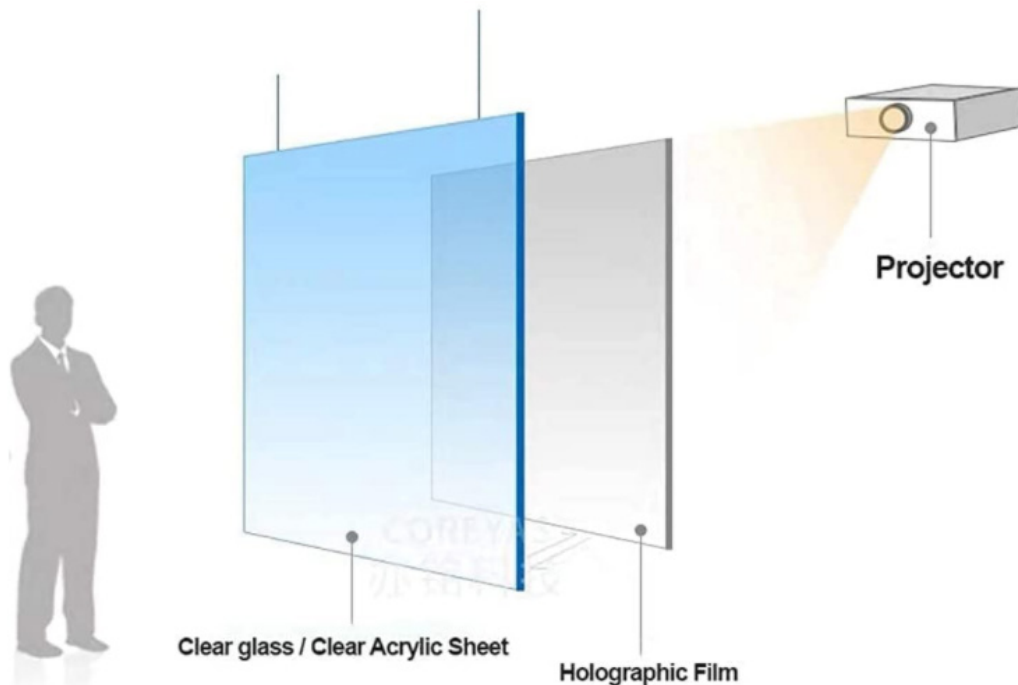


Figure #13 Light Project Diagram

This experiment utilized the Holographic Film Rear Projection Method: a method that allows what would otherwise be a 2D image as a 3D hologram. This method required the use of clear glass, holographic film, and a projector. Since this solution would be existing in a window frame, I used a window in place of clear glass and tested a series of different holographic projections.



Figure #13.1 Light Project Experiment

## A NEW WAY TO CAPTURE MEMORIES

This experiment revealed the potential for a new kind of “photography” one in which a user would not only be able to see the image/video of the previous day but also experience a reenactment of the exact lighting conditions. This kind of function would allow users to feel as if they were living *inside* the memory as opposed to just observing it from the exterior point of a view of a photograph or video.

This would be a new and novel way to experience one of light’s more neglected strengths, as the impressed factor in our memory formation.

## LIMITS OF THE INVESTIGATION

It is important to note that the proposed technological strategies are not comprehensive and are limited to the financial and time constraints. The proposed strategies are a result of the limitations of the University of Washington graduate student resources and the time constraints of completing a thesis proposal. It is assumed that there exist a wide variety of technological strategies that could accomplish the aforementioned functional requirements; future researchers are thus welcomed and encouraged to explore such possibilities.

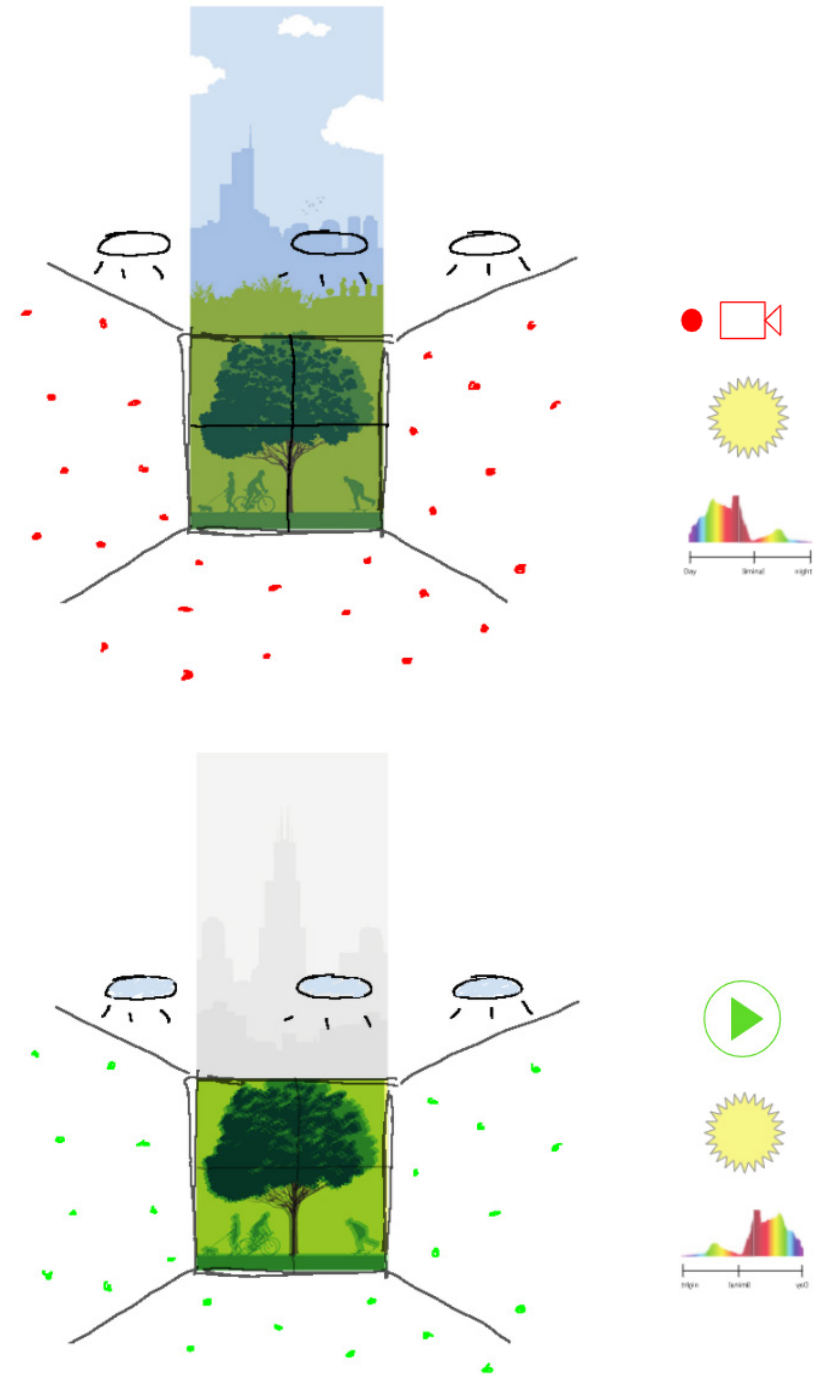
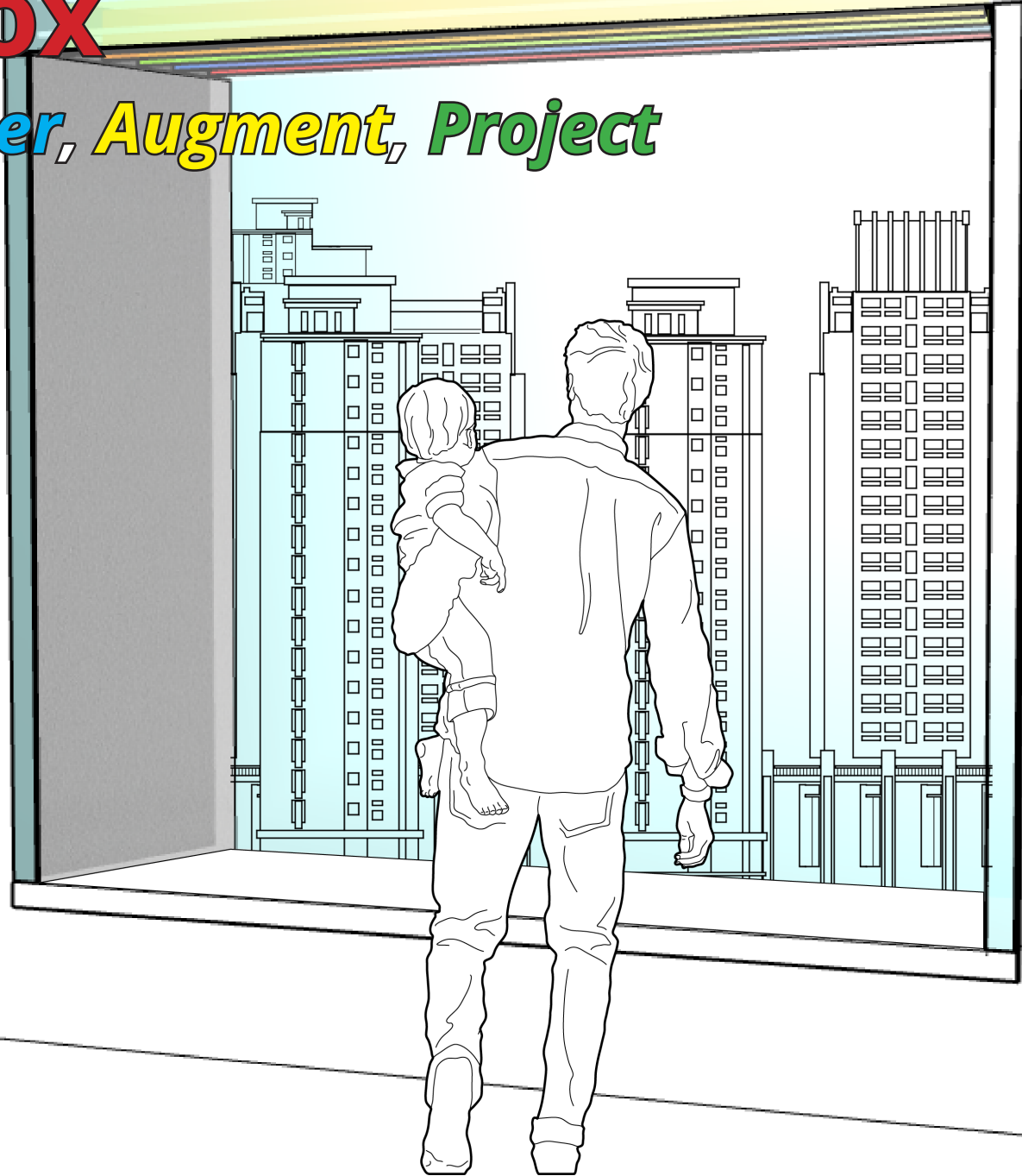


Figure #13.2 Light Project Diagram

# Light Box

*Capture, Filter, Augment, Project*



*Figure #14 Light Box*

# Design Proposal

## LIGHT BOX: CAPTURE, FILTER, AUGMENT, PROJECT

After having conducted all the experiments separately, all the proposed solutions were then integrated into a single prototype called LightBox. Light Box could both act as a liminal transition for both exterior and interior lighting conditions, and it could help integrate virtual space more fluidly into physical, which would ultimately allow an occupant to have greater control over their psychological state. Arduino light sensors along the window frame could capture and analyze the current lighting condition by color temperature and brightness. Additionally, exterior cameras could capture the corresponding views during those lighting conditions.

If a user disliked the current lighting color temperature, they could filter the natural light to more desirable color temperature. If a user disliked the current lighting color temperature, they could filter the natural light to more desirable color temperature. Light filtration could occur via two different methods. The first method is via rotating CCT light filter gels that could be sandwiched between an overhead skylight and rotate horizontally to be turned. Additionally, the places where the gels overlapped would allow for color mixing. The second method is via an LCD light augmenting window screen. Since the window screen contains more functional needs than the skylight, a transparent LCD filter could change the color temperature of exterior lighting and also change in opacity to allow for more privacy, similar to the way blinds and curtains do now.

Light Box could augment with artificial light to dynamically add brightness at the appropriate color temperature. It would also allow for more systematic variation of interior lighting conditions throughout the day to better mimic natural lighting cycles, so instead of having static artificial lighting, the interior light would evolve naturally with the days cycle, being dim in the daytime and bright at night when most needed but still adjusting for circadian cycle needs by varying in color temperature and brightness.

Artificial light augmentation would occur through two primary modes. Firstly, Arduino light sensors would allow Light Box to understand the current brightness and color temperature value of the exterior lighting condition and augment the overhead lights accordingly. Meaning, if it was very dark, the interior lights would be very bright, or if it was very bright outside the interior lights would be very dim or completely off. LED light augmenting panels would work in tandem with overhead lights.

Lastly, users could project previous window views as interactive holograms back onto the windowpane and re-experience previous lighting conditions. The process of capturing and projecting a scene hologram is a level more complex than the single object holograms that were produced in the experiment. When capturing an entire view, there's a need to add a layer of interactivity in order to create what is called a parallax hologram.

# Capture

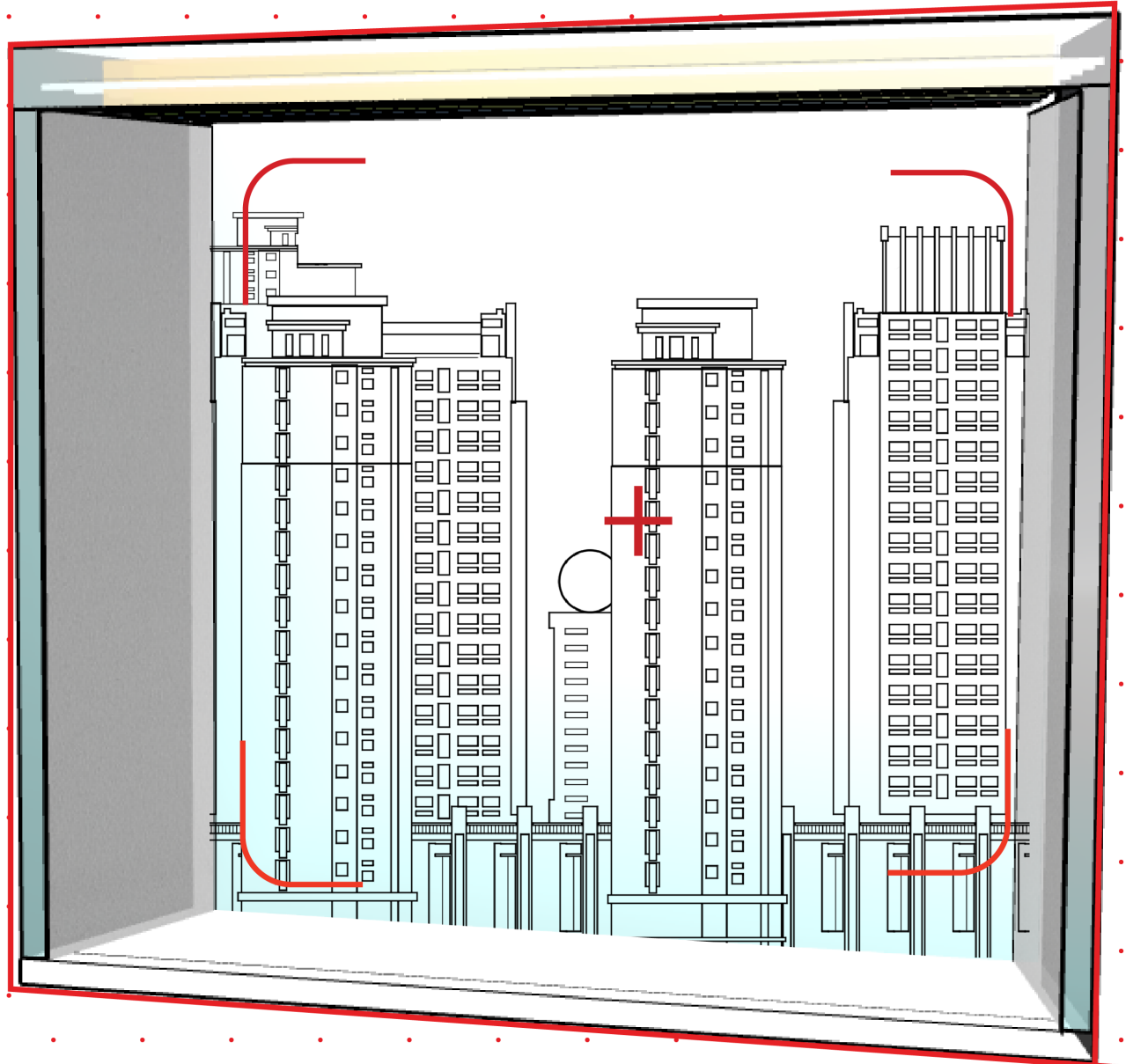
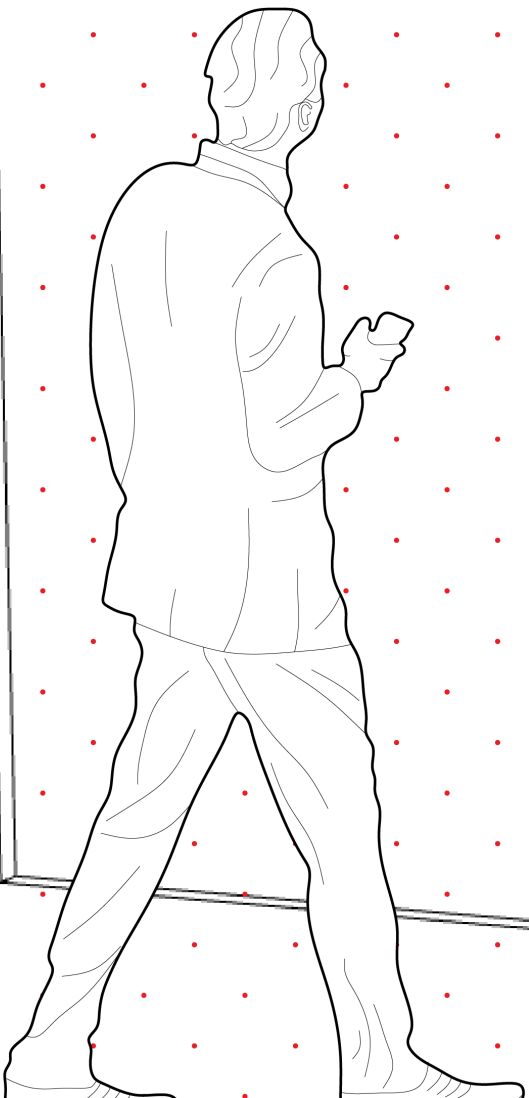


Figure #14.1 Light Box

# Filter

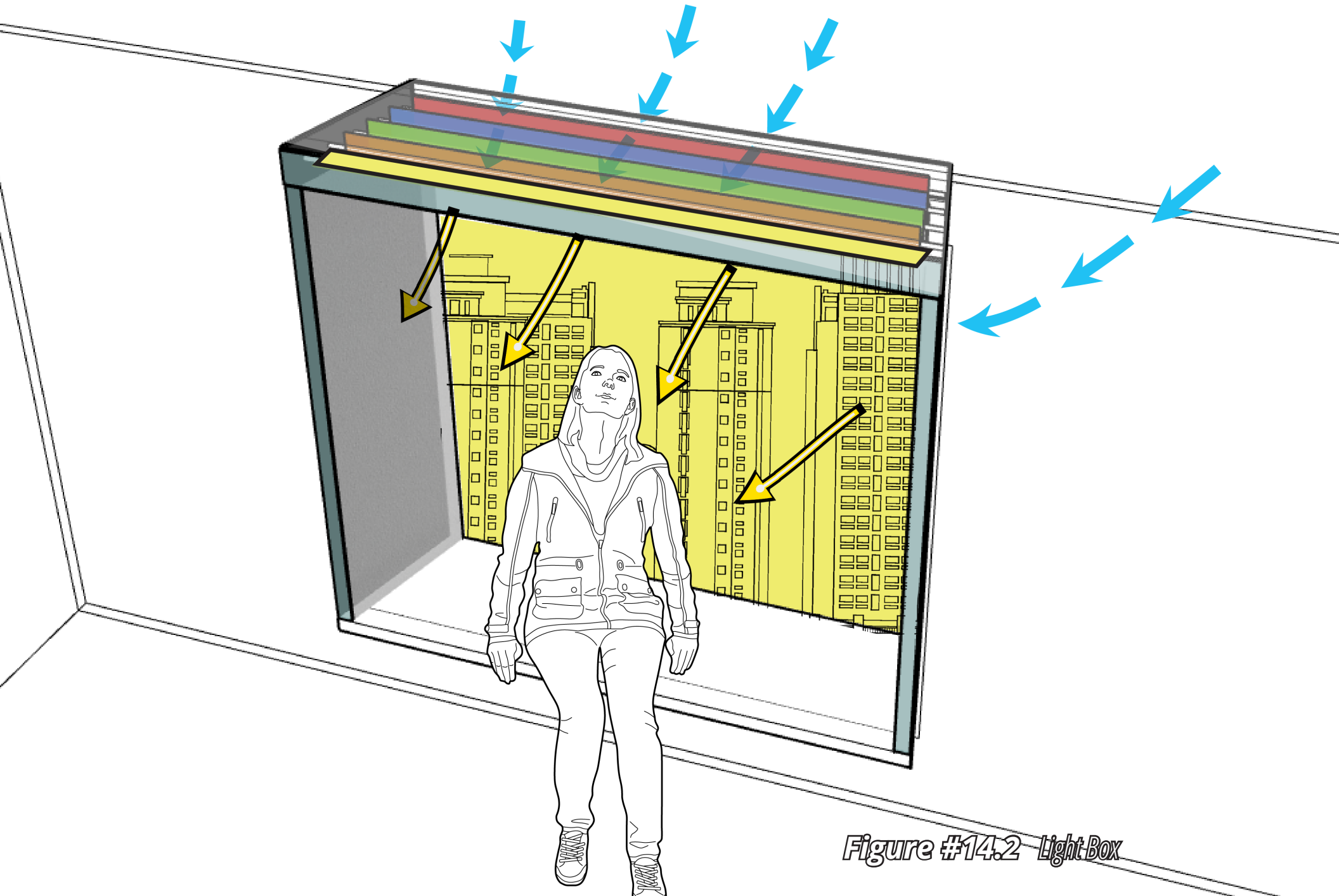


Figure #14.2 Light Box

# Augment



Figure #14.3 Light Box

# Project

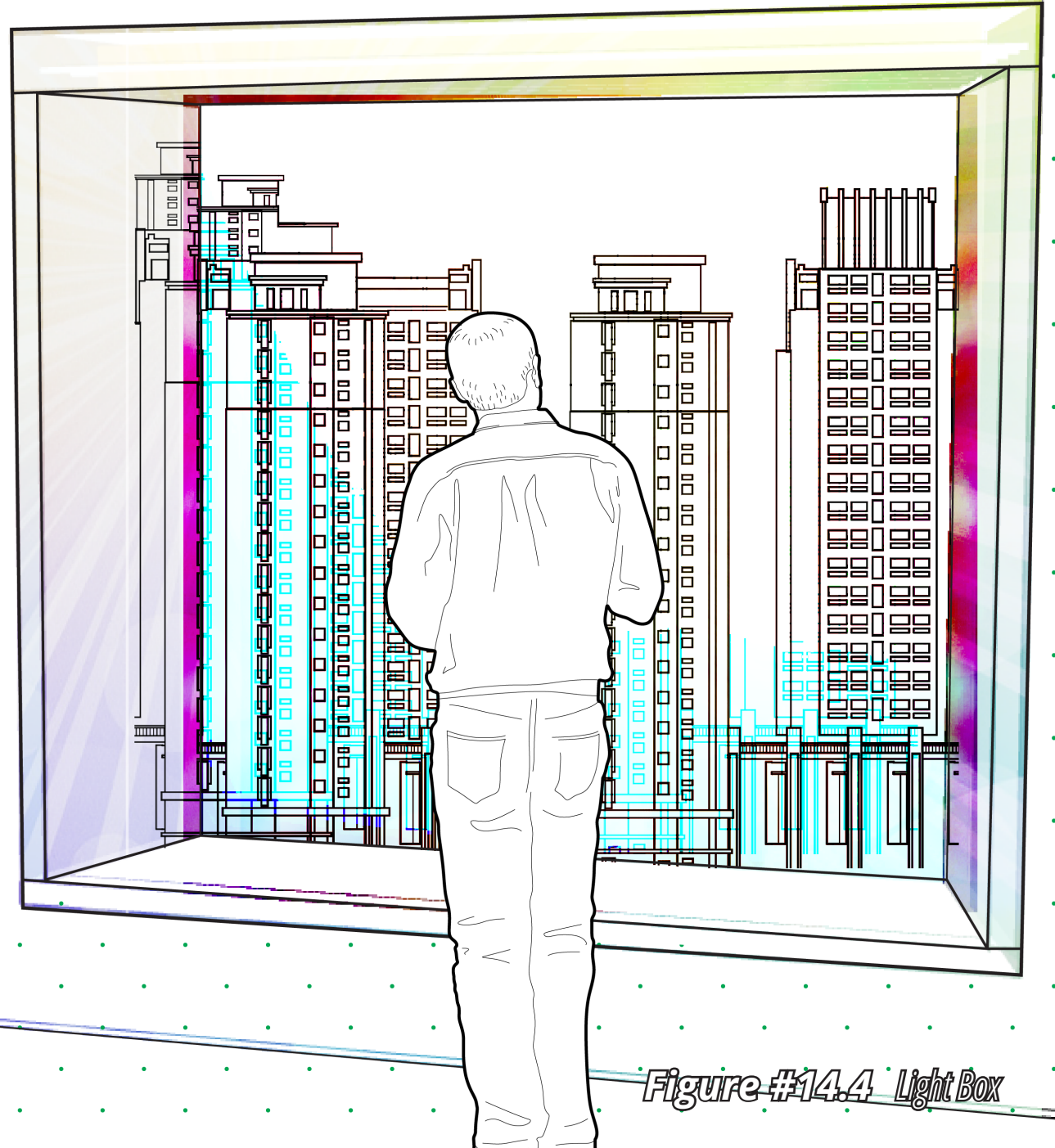
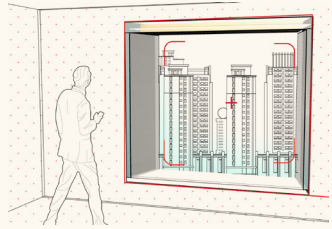
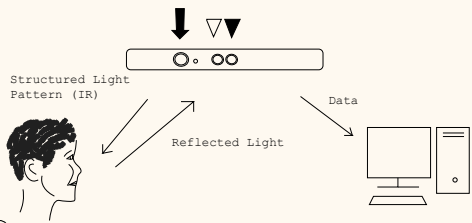
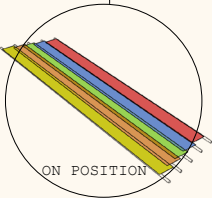
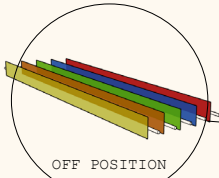


Figure #14.4 Light Box

LIGHT BOX :  
TECHNICAL DIAGRAM



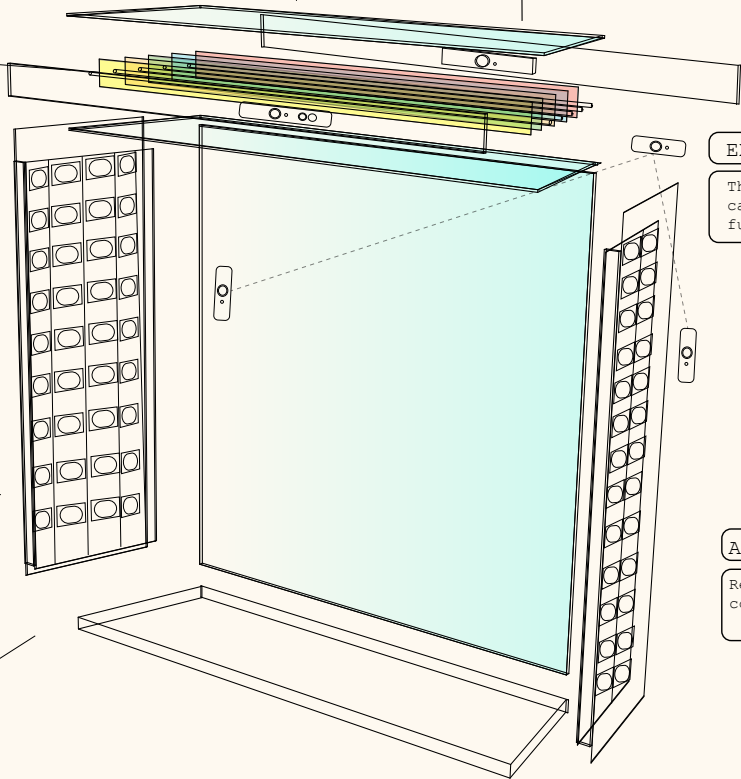
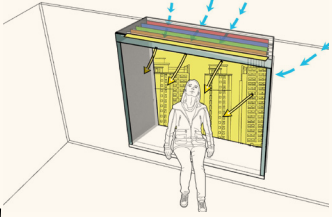
ROTATING CCT LIGHT FILTER GELS  
Rotating gels allow for CCT color mixing



KINECT HEAD TRACKER SYSTEM

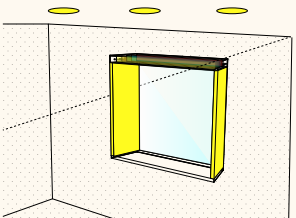
HOLOGRAPHIC PROJECTOR

GLASS SKYLIGHT



EXTERIOR CAPTURE CAMS

Three exterior facing cameras capture 180 degree views for future holographic projection



LED LIGHT AUGMENTING PANELS

ARDUINO LIGHT SENSORS

Read current exterior lighting conditions CCT and Brightness



TRANSPARENT LIGHT AUGMENTING LCD WINDOW SCREEN

Varies in both CCT and opacity to allow for privacy & mood variation

Holographic film lays atop of screen to allow for 3D projections

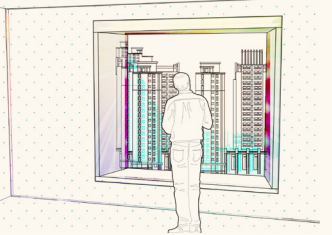
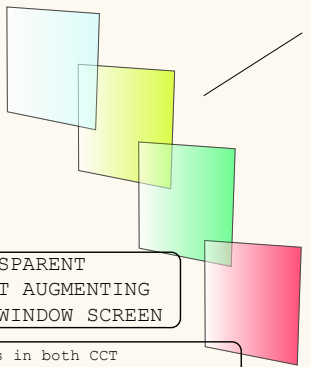


Figure #14.5 Light Box Technical Diagram

Having this level of dynamic control could open a world of possibilities and allow for a much stronger relationship between your physical, virtual and affective space. Users could relive their favorite sunsets, they could share special views and lighting moments with friends in different countries. For instance, if during vacation your hotel room had an excellent view, you could share that view with a friend back at home.

Although this research has focused on residential use case, Light Box could have implications for Educational, commercial and sustainability use cases.

# The Future of Cities

*A Mixed Reality Urban Environment*



*Figure #15 Hyper-Reality Still*

# The Future of Cities

## A Mixed Reality Urban Environment

As the influence of the virtual space become more apparent in our cityscapes, it will become critical for architects to design for affective space by creating architecture that considers both the physical and virtual space. This will be vital in order to keep our cities as healthy vibrant places where people want to be and can thrive. If we continue the thread of our camera obscura metaphor into this future, it operates as an inverse of the device, where the virtual space is no longer just a projection of the physical but is now exists as a virtual projection onto the physical world, not too dissimilar to Figure #15 from Keiichi Matsuda's architectural science fiction explorations in short film, Hyper-Reality.

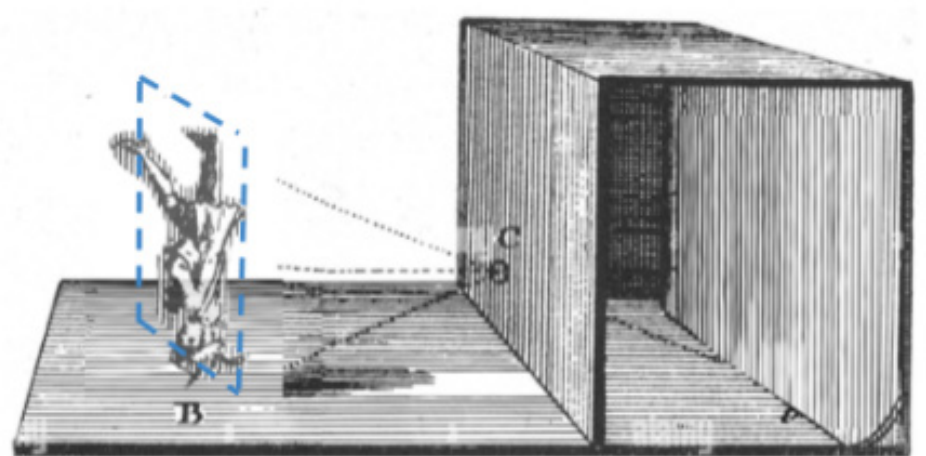
"While many architects and interior designers have actively embraced electronic media, they typically think of it in a limited way: as a screen, i.e., as something that is attached to the 'real' stuff of architecture"(Lev Manovich 27). It is the contention of this research that the architecture of the future will begin to question and alter this paradigm, where the digitally augmented architecture has just as much significance and presence as the physical. "This does not mean that the physical space becomes irrelevant; on the contrary, as the practice of Cardiff and Libeskind shows, it is through the interaction of the physical space and the data that some of the most amazing art of our time is being created." (Manovich27)<sup>1</sup>.

1 *The Poetics of Augmented Space, 2005*

2 *Domesti/City: The Dislocated Home in Augmented Space, 2010*

In his architecture thesis publication, *Domesti/City: The Dislocated Home in Augmented Space*, Designer and film-maker Keiichi Matsuda, describes the future of urbanism as "a future where built space and corresponding contextual information together define a spatial experience...is an exciting prospect for the architect, who may start to operate increasingly within the virtual sphere, the practice shifting into new and unexplored territories." (Matsuda pg.12)<sup>2</sup>

Rather than shying away from the changing cityscape, there is an opportunity for the field of architecture to lean into the untapped potential of a changing world.



# LIGHT BOX

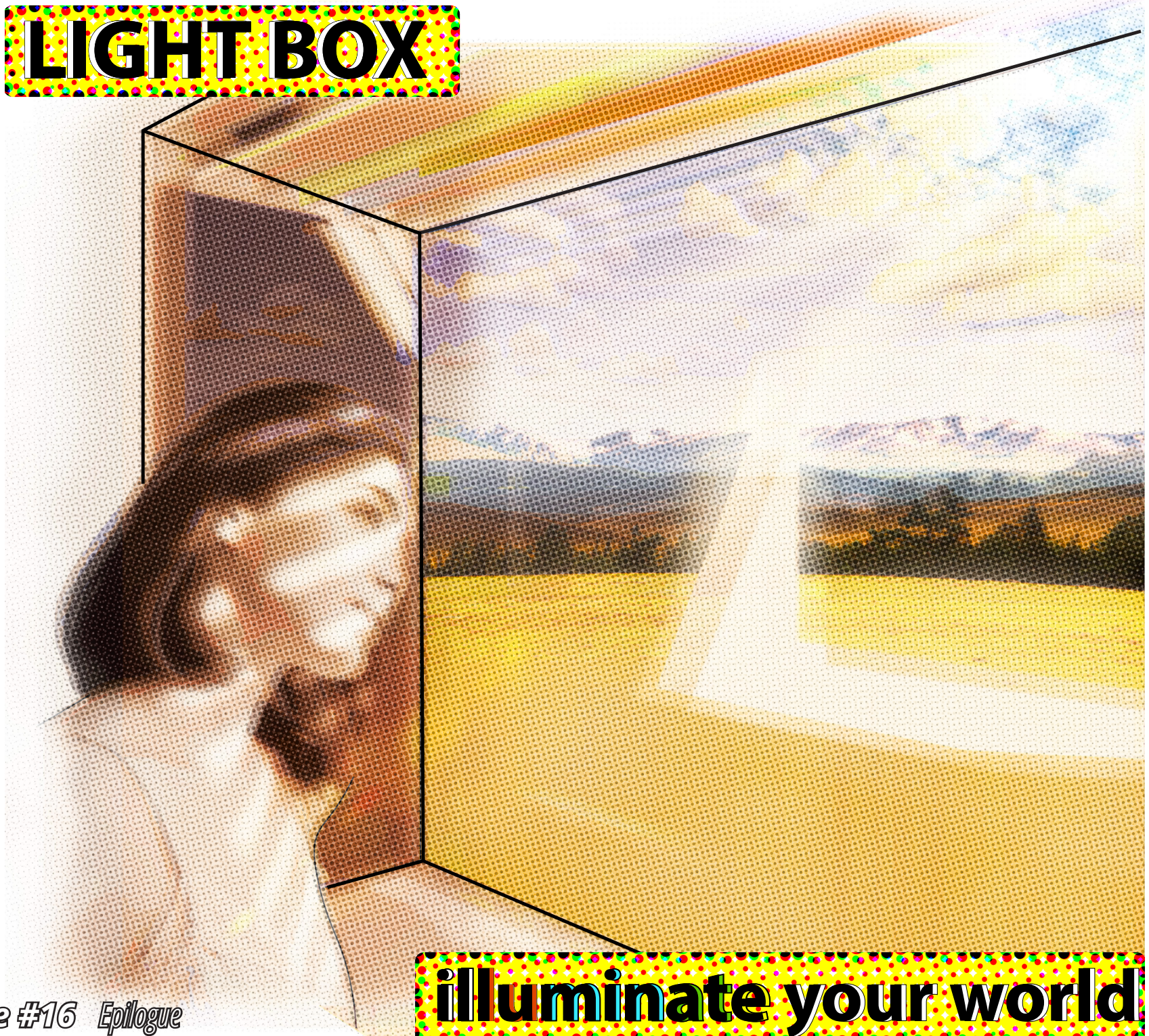


Figure #16 Epilogue

**illuminate your world**

# Epilogue

Sarah for years had struggled from Seasonal Affective Disorder. Every winter without fail, she began to feel those winter blues. The short lived sunrises and the quick days and long nights left him feeling exhausted and uninspired. One of her friends Rachel, had suggested she get a LightBox, they were like SAD lamps but with greater breadth of control, priced around \$300 with no technical installation required. Sarah being desperate to do anything to alleviate the winter blues gave in to at giving it a try. The Lightbox arrived in a long rectangular box and was sized to fit his standard apartment window. Cutting the edges of the box open revealed a 5' x 5' transparent LCD pane with snapping brackets along the edges. After placing the white brackets on his pre-existing window Sarah carefully lifted the pan up and snapped it into place with surprising ease. It seemed so indecipherable from her previous window that she scratched her head doubtfully if it would be worth the trouble. Next in the instruction was the installation of two smart lights in his studio overhead lights.

The new smart bulbs again looked indecipherable from her original but she swapped them out anyways. Grabbing her cell phone he opened the Lightbox app and scrolled carefully through the presets. "California afternoon?" she stated along and selected it. Watching the grayish light from the window slowly transform into a warmer hue of sun kissed light she smiled almost feeling an artificial rush of heat hit her cheeks. The room glowed the beautiful sun-kissed color that she so longed for and missed during the summer months. The overhead lights tangentially adjusting from their bluish hue to a warmer & calm light orange color. As the day pressed on the Lightbox pane shifted delicately in color giving him the feeling of a long and satisfying summer sunset. After a month of ownership, Sarah decide to try out tier three of the device which could allowed her to change the view of her window to the peaceful yet powerful mountains of Bozeman, Montana, favorite travel destination of hers. The long winter months become a little more bearable.

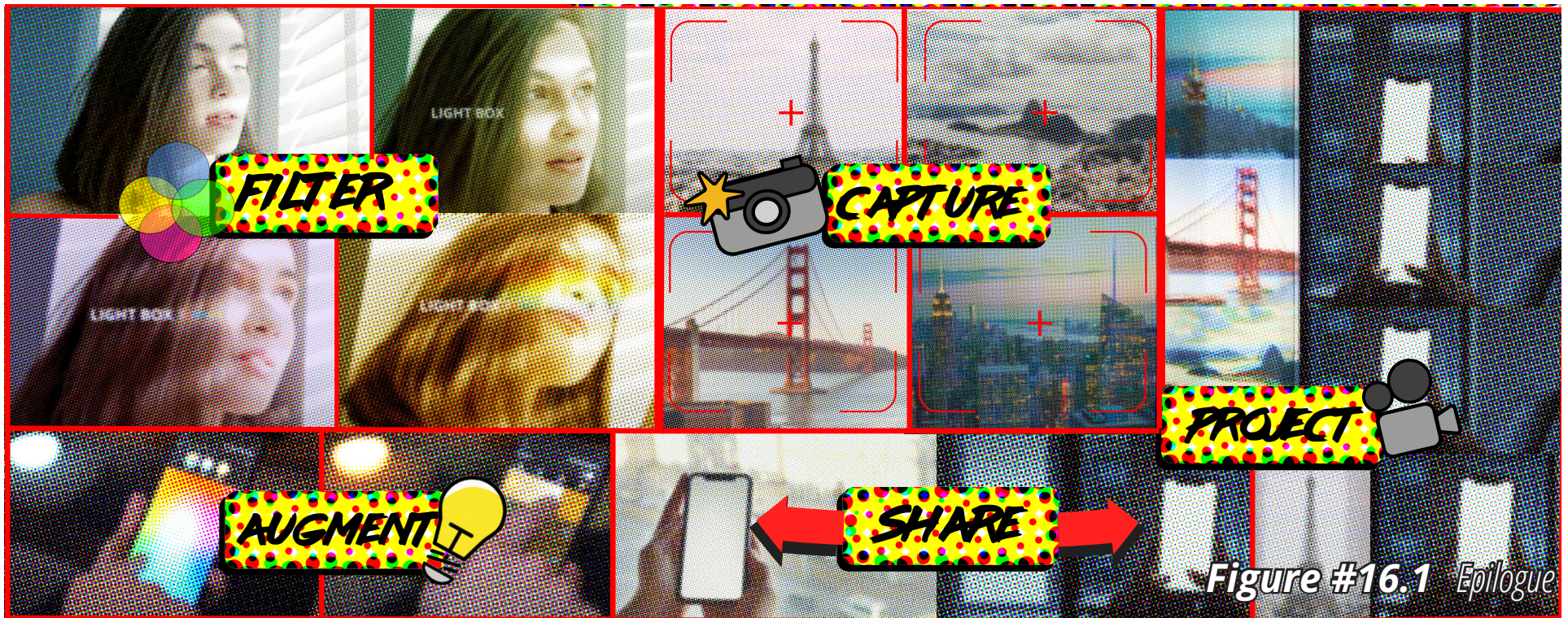


Figure #16.1 Epilogue

# Afterword

## Next Steps

If Lightbox were to be developed into a commercially viable product it would need to be easily accessible, with little to no technical knowledge required for assembly and have the main functionality divided into several tiers of entry.

In order to make LightBox highly accessible it would be ideally a product that could be integrated into a pre-existing window and interior lighting system. The following is a hypothetical first point of entry into the product.

Tier #1 would be the first point of entry. It could be a simple transparent LCD screen that could be installed onto the interior side of an exterior facing outdoor window. Light sensors would line the exterior facing side of the LCD and users could then use a phone application to control the color temperature of the natural light entering the room by altering the color of the transparent LCD screen.

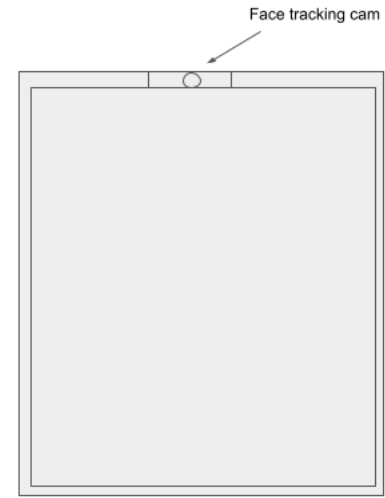
Tier #2 would be the second point of entry. In this tier users would have all of the functionality of tier #1 this time with the added functionality of being able to control the color temperature and brightness of interior artificial lighting via a phone application and smart lights. Users would need to replace all interior light bulbs with smart lights which would enable them to change the color temperature and brightness of the space. Allow users to alt

Light Box would contain a set of presets of different interior lighting settings that related to different seasons and geographic locations such as California Sunset, New York Fall etc., Additionally, during preferable exterior lighting conditions, Light Box could be automated to match the color temperature and supplement the exterior lighting accordingly to allow for maximum aesthetic value for the interior space.

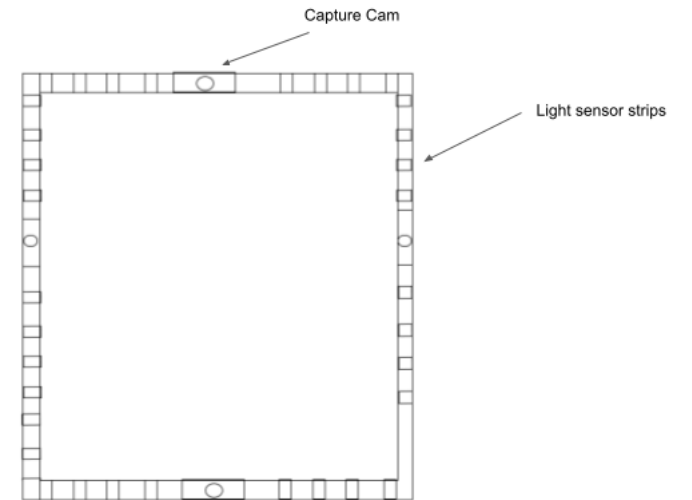
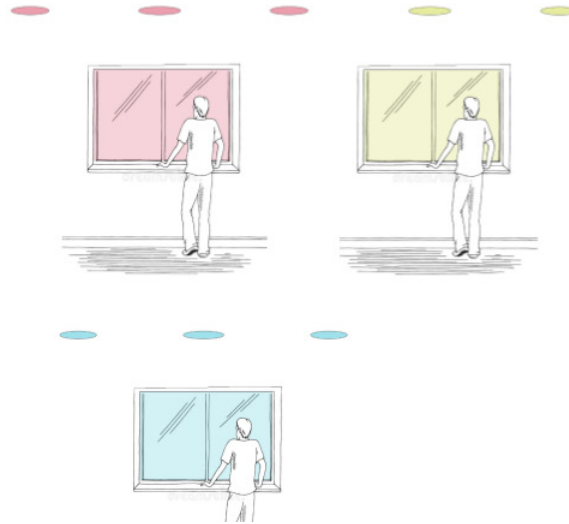
Tier #3 would be the final point of entry. In this tier users would have all of the functionality of Tier #1, and #2 with the added functionality of being able to capture and project AR views onto the window pane.

Users would need to install capture cams on the exterior facing side of the Lightbox and install a projector somewhere in the space to have AR augments of previous lighting conditions. Additionally users could make, view and share AR view and lighting presets so they could experience not only the view but also the lighting conditions of the desired place and time. This would allow for a much richer experience of memories, space, an place.

**TIER #1** → Filter the hue of Exterior light



**TIER #2** → Filter the hue of Exterior light & Augment with artificial smart lights



**TIER #3** → Filter the hue of Exterior light & Augment with artificial smart lights & change views with AR



Figure #17 Light Project Version 2

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# Appendix

Thesis Video Links

[Iridescent Light Filters Experiment Video](#)

[Light Box Promotional Video](#)

[Light Box, Filters Saturated Video](#)

[Light Box, Filters Natural Video](#)

[Holograms Night Video](#)

[Holograms Day Video](#)