LIGHT SHAPES SPACE

HOW LIGHT INFLUENCES OUR PERCEPTION OF SPACE

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RYERSON UNIVERSITY
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LIGHT SHAPES SPACE

HOW LIGHT INFLUENCES OUR
PERCEPTION OF SPACE

by

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B.Arch Sci, Ryerson University, 2010

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*Light Shapes Space:
How light influences our perception of space
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ABSTRACT

The role light that plays in architecture is not simply to brighten a room to enable people to see, but also to create atmospheres and define spaces. The quality of light affects our perception of space. Light has the power to enhance our experience of spaces by increasing pleasure and comfort. Conversely, light can make spaces uncomfortable for users. This thesis demonstrates how light with materiality and tectonic qualities can create different tactical and atmospheric conditions to strategically enhance the relationships of user to space and user to nature. By considering light in design, architects can turn light into a design feature and use it to create a variety of spatial perceptions. Light can define a room's characteristics and create atmosphere so that people feel connected to that space through association with natural lighting phenomena. Consequently, lighting can be used as a tool to enhance the user's experience with architecture.

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How light influences our perception of space

LIGHT SHAPES SPACE

INTRODUCTION

1

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1

INTRODUCTION

What is the role that light plays in architecture? Brightening a room? To serve human needs? To let people, see clearly and comfortably? Light does not simply enable people to see; on the contrary, it stimulates, informs and sometime even excites us. The presence or absence of light influences our perception not only of spaces, but of the world itself, and also has an effect on how we feel. Different light sources with different properties influence human behavior and emotions, and allow us to see and respond in different ways to our surroundings. (Flagge, 2002) (Major, Speirs, & Tischhauser)

Daylight is constantly changing. The patterns of light or shadow and the presence or absence of light influence our impressions of spaciousness. Light reveals the shape, form, colour, surface and function of a built environment. In a comparable manner, the built environment enables the experience of light. Whatever we do in our lives, light plays an important role and is a fundamental tool for communication. (Descottes & Ramos, 2011) (Karcher, 2009) Light is an important element of architecture. It impacts how an individual understands and perceives an environment. This thesis approaches the topic of light by exploring how light manipulates space to impact our perceptions of it. It also considers the relationship between light and architecture.

Light is like the ink of a pen: without it, nothing can be written. Without light, architecture and design cannot be revealed. Understanding the role that light plays in architecture demonstrates that light has a strong relationship to how we perceive spaces. (Johnson, 2011) Different atmospheres and experiences of space can be created within a physical environment by changing its lighting conditions. Natural light becomes a significant means of revealing the elements and qualities of

architecture. Both sunlight and daylight within a space are considered assets that add significant value to that space. Natural light is a powerful element that bonds architecture with nature.

The perception of space is influenced by the way the light is integrated. Light affects how we perceive and experience a space's essence and its constituent elements, such as quality of space. All aspects of architecture, including colour, form, volume, function and program, are associated with objects and viewers through the lighting situation. (Michel, 1995) The changing qualities of natural light and of fully controlled artificial light enable architects to evoke and demonstrate different atmospheres and experiences within the physical environment.

Many architectural theories, philosophies and languages of light incorporate insights from other disciplines, including principles of environmental psychology. The study of the psychology of visual perception allows architects to gain a greater awareness and understanding of their discipline, and to make optimal use of light within their designs. Architecture can become more robust through

Figure 4: Sunset image taken at Templo de Debod, Madrid during Summer 2015. By author

an understanding of the relationship between various environmental conditions, and of how various types of lighting can affect how people interact with the surroundings. (Shojazadeh, Karzemi, & Shafizadeh, 2014)

In both modern and current practice, architects have developed their own insights regarding light. Famous architects including Le Corbusier, Louis Kahn, Tadao Ando, Peter Zumthor and Steven Holl have incorporated aspects of environmental psychology and behavioral science into their use of lighting. They are not simply innovators of knowledge regarding light, but actually implement theoretical concepts in their work. Their current practice adapts and changes according to developments in environmental psychology. Insights into how light shapes architectural space involves an understanding of environmental psychology, and of research into it.

Environmental psychology expands knowledge by establishing principles and through its ongoing exploration of cognition, human perception and behavior. Architects make use of their research in the field of behavioral sciences as they develop concepts and design models that aim to provide a better built environment. (Shojazadeh, Karzemi, & Shafizadeh, 2014) A good understanding of the psychology of visual perception in the field of sensory design provides a powerful basic framework for architects as they design environments suitable for different purposes. In this thesis, knowledge gained from research into the psychology of light and perception is applied to the exploration of manipulation of light in architecture. This thesis builds upon existing hypotheses about perception, emotional states and behavior, and uses these hypotheses to inform architectural design.

This thesis intends to explore how the utilization of lighting conditions affects the spatial qualities of the built environment even as it enhances appearance and engenders emotional impact. Its investigation will propose a new framework for enclosed spaces. It will demonstrate that light is fundamental to the manipulation and shaping of the environment, not only as regards visibility, but also as a means of creating emotional responses to, and perception of, spaces in our built environment.

Definition (Oxford English Dictionary)

light¹ [laɪt]

noun

1. The natural agent of influence which (emanating from the sun, bodies intensely heated or burning, and various other sources) evokes the functional activity of the organ of sight.
- a. Viewed as the medium of visual perception generally. Also, the condition of space in which light is present, and in which therefore vision is possible. Opposed to darkness.

Figure 5: West Lake in Hangzhou, China. By author

1.1 | Intent and Position

This topic of this thesis -- *Light Shapes Space: How light influences our perception of space* -- is explored through a consideration of light design within architecture. A University Women's Club (UWC) was designed as a vehicle to demonstrate how light combined with materiality and tectonics can create tactical and atmospheric conditions that enhance the relationships of the user to space, and of the user to nature. The site under consideration is an urban one; in it, light intervention strives to connect the architecture with aspects of the natural world. Just as materials, program, structure, proportion, circulation and volume are primary considerations in architecture, so is light a primary consideration in the design of this thesis. The University Women's Club is a collective gallery of ideas, techniques, arrangements and visions of light in architecture that bonds architecture to nature. Nature is understood as the framework within which light exists in its pure and natural state, unspoiled by human intervention. This space permits visitors to gain a broad understanding of how light influences our perception of space. This thesis will present a variety of lighting conditions as it considers landscape, water, vegetation, rock and as it simulates cave or forest and other conditions. It will demonstrate that manipulation of both natural and artificial light can provide an immersive and emotional experience that can define space. It will show how reflections and shades of light create relationships to nature and engender and tap into emotional responses. It will argue that the essence of architecture is to retain a feeling of the space and to convey this feeling to people, thereby providing an interaction between humans and nature.

Figure 6: Lighting Consideration Variables. By author

1.2 | Problem Statement

Architecture often neglects light as a basic premise in design. However, just as materials, program, structure, proportion, circulation and volume are primary considerations, so should light be important in design, not just an afterthought. Why does light matter? Light is not only an essential to our lives, but it is also can function as a creative tool in architecture. Light has the ability to enrich physical objects and the environment by giving them emotional depth; at the same time, different lighting conditions can create various sensual experiences. Light (daylight and artificial light), awakens and brings life to the world around us. My interest in this thesis is to present nature as an oppositional framework in which we can see natural light in its pure state, unspoiled by human intervention. This thesis demonstrates that lighting can enhance the built form. The design takes its cues from natural lighting phenomena by having artificial light echo particular natural lighting conditions, and by demonstrating the uses and control of natural lighting.

1.3 | Methodology

A literature review of daylight and artificial lighting involved a study of the literature of perception research and architectural precedents. In addition, types of architectural lighting were experienced personally. An understanding of the relationship between light and architecture, and of lighting terminology and techniques, was helpful in the creation of dialogue and of a design language for this thesis. Elements of the research will be adapted and manipulated to create a design tool that can communicate effectively to allow designers to proceed in a positive and productive manner.

Literature Review

The theory of light is not a new topic within the architectural field. The following literature review will introduce the theory of light in architecture and will show that it has always been considered from different perspectives, and with different interpretations and ways of understanding. This section will explore the theory of light in architecture through considering its historical development, its methods and terminology, and finally, will address the importance of environmental psychology to architectural design studies.

Figure 7: Book (Unsplash, 2014)

How light influences our perception of space

LIGHT SHAPES SPACE

LITERATURE REVIEW

2

2.1 | Historical Development

Article Title: Lume di Lume: A Theory of Light and Its Effects

Author: Ann Marie Borys

Source: Journal of Architectural Education (1984-), Vol. 57, No. 4 (May2004), pp.3-9

Publisher(s): Taylor & Francis, Ltd. On behalf of the Association of Collegiate Schools of Architecture, Inc.

URL: <http://www.jstor.org/stable/40480505>

SUMMARY

Ann Marie Borys' article, "*Lume di Lume: A Theory of Light and Its Effects*" explores the theory of light and its effects on the architectural field during the Renaissance period. It uses diagrammatic drawings and companion text to introduce the history of light. The article presents information from research to demonstrate how architectural practices developed the idea of light as a tool for perception of spaces. The theory of light and its effects were articulated from the perspective of painters, mathematicians, scientists and architects. It shows that light in architecture can exist as illumination, but also as a penumbral zone between darkness and light. Light in architecture does not exist solely as illumination that affects perception, but it also links architecture to the sun in an invisible line. It is also an essential element.

Figure 8: Umbra and Penumbra is two different parts of a shadow casted on an object. Umbra is the dark shadow where light is completely obstructed. (Behind the object's shadow) Penumbra is the gray tone shadow where light is partially obstructed. (Outer shadow part of the object). By author.

HISTORICAL DEVELOPMENT OF LIGHT THEORY

The article articulates the historical development of the use and understanding of light. It considers how this development can aid in understanding the behavior of light and the mechanics of our perception. Much of the research contributes to our understanding of the metaphysics of light in an environment, showing how light in architecture creates meaningful forms and spaces.

This article further explains the historical background of light theory in

regards to developments in optical theory, art theory and architectural theory during the Renaissance period.

In art theory, many drawings and paintings from the Renaissance clearly depict the effects of light on objects. The presence of light in these paintings creates drama within the scene. An advance in optical theory was made through Newton's experimentation with prisms that revealed the relationship between colour and light. During the Baroque period, the use of light was representative, and techniques for its use were limited. (Borys, 2004)

FINDINGS:

This article is important to this research project because it reminds us that light can come to life only in the penumbral zone of shadows. Light is not solely about brightness and the presence of illumination; on the contrary, it is important to consider the absence of light in architecture. Today, light is often merely used for clarity, and can be uniform and relatively static. The comfort zone of an interior space is maintained by the use of diffused light. During the Renaissance, however, much attention was paid to glaring light, rather than to diffuse light. In order to control light in architecture, it is important for us to make architectural spaces meaningful through the creation and use of a variety of lighting conditions created through an understanding of light's properties.

Shadows can never be black; in fact, they consist of a variety of shades of gray. The effect of shadows is important within an architectural space.

In the dark, shadows create a sense of emotion. If light is the soul of architectural design, then shadow is what animates it.

Figure 9: Types of light and shadow on a rendered volume (By author)

2.2 | Method and Terminology

Journal Title: The Lume Materiale in the Architecture of Venice

Author: Marco Frascari

Source: Perspecta, Vol. 24 (1988), pp 136-145

Publisher(s): The MIT Press on behalf of Perspecta

URL: <http://www.jstor.org/stable/1567130>

SUMMARY:

Frascari's article introduces the methods and defined theories-- the *lume materiale*-- that Venetian architects used. Architecture exists because of light. Light is a *lume materiale*. Light as a material is free to express itself through construction materials, through material resolution of elements and through details of construction. In other words, *lume materiale* is a "touchup paint" on architecture. The presence or absence of light molds and affects how architecture tells a meaningful story. Meanwhile, the colour of elements collaborates with natural and artificial light to give a constant texture. The presence and absence of light enriches architectural elements through materials, details and ornamentation.

FINDINGS:

The article is relevant because it provides the fundamental knowledge and information about how light works within architecture. Shadow plays an important role in architecture because it reveals its details, forms and shapes. Today, people assume shadows are black and lights are white. This is not true, however, since, according to Frascari, shadows are blue and lights are yellow. Light is a giver of all presences; as Louis Kahn said, "*Light cast shadow and shadow belongs to light.*"

Light and shadow are interrelated. Light is a maker of materials the purpose of which is to cast a shadow. Architects today tend to forget their faith in natural light and people have become satisfied with static light. The changing qualities of natural light are interesting and dynamic design tools that can be utilized in architecture. The changing quality

of light can be expressed through the *lume materiale*, the light and shadow found in architecture.

2.3 | Sensory Design

Book Title: Sensory Design
 Author: Joy Monice Malnar and Frank Vodvarka
 Source: Book
 Publisher(s): University of Minnesota Press

SUMMARY:

This book Sensory Design is beneficial to this research project on atmospheric design and sensory perception because of its focus on sensory design and environmental psychology. Sensory design proposes useful tools based on collective data for the exploration of sensory experiences in existing buildings. It measures the visual, olfactory, acoustical and tactile qualities of an interior environment. These elements can constitute sensory design tools that can provide a conceptual context for the evaluation of physical environments, and for the assessment of emotional factors that affect user satisfaction.

Environmental psychology as applied to architectural design studies users' reaction to the characteristics of spaces. The principles of environmental psychology are relevant to design and to the management of the physical environment. The emotional response of humans to a physical environment will influence their desire to spend time there. We may want to analyze why we feel the way we do within a certain space. Reactions to sensory design, as well as the overall sensory experience and perception of spaces are dependent upon the cultural background of the visitor.

This book introduces the three theories of "Visual perception in architecture" described by Julian Hochberg, an expert in experimental psychology. These theories are empirical (known as classical theory), and also involve Gestalt psychology and Direct theories. The theory of

Empiricism arose during the 19th century and describes how the primary perception of space comes from sensory experience and is influenced by previous knowledge. Gestalt psychology is a 20th century theory that describes the perception of space as coming from the wholeness of a visual pattern. In other words, the perception of objects and scenes as a whole is more important than would be an individual perception of each element for the formation of order, unity and chaos. Lastly, direct theory derived from the American psychologist James J. Gibson, refers to stimulus-response phenomena. According to this theory, visual perceptions arise from stimuli based on present information and are not dependent on perceivers' personal experience and background. The theory of visual perception in architecture, based on the three theories in psychology, is summarized by Hochberg. He asserts that visual perception arises from the arrangement of objects that provide sensory stimulation, and that it provides cultural connection within architectural spaces.

FINDINGS:

I am interested in using environmental psychology to investigate how people perceive spaces. My goal is to design a highly personalized space that will respond to human emotional behavior. Monice Malnar's research gives directions for advancing the understanding of sensory perception. She describes it as the key determinant of users' satisfaction within carefully designed environments and spaces. There is a great opportunity to explore an architectural lighting design that focuses on the pleasure and comfort of the users. For example, a mall's layout and décor greatly impacts users' desire to stay there. Even hotels, restaurants, and retailers adopt environmental psychological principles in their architecture: they create spaces designed to attract consumers and maximize business profits. Design strategies and psychological tactics employed here include atmospherics (light, theme, finishes, décor, colours), cleanliness, and acoustic and odor sensory encouragement. These design strategies are now widely used in hospitals, hotels, retails and theme parks. This lies into my interest, if light is possible

to become the driver of architecture. I believe sensory design can be well developed through the theme of light shapes space – how light influences our perception of space.

From the perspective of natural science, knowledge is chiefly a result of experience. (González, p. 64) The three theories of visual perception in architecture as described by Hochberg are significant for this thesis. Light can only be revealed with respect to the existence and response of an object. Objects may be associated and arranged within a scene based on cultural connections. Light within architecture can have meaning and can play a role in the sensory experience of the user. These theories can be adapted for this thesis. It will be demonstrated that the visual perception of architectural spaces can differ according to the lighting conditions applied.

Figure 10: The interior of the Pantheon in the 18th Century, painted by Giovanni Paolo Panini. (Panini, 1734)

2.4 | Psychology of Light

Most of us collect a substantial amount of information about our world from our eyes. Light is a necessary prerequisite for this information gathering as it allows us to see. Light does not simply provide the basis for visual information gathering but it also impacts our psychological state. In addition, different lighting conditions and intensities of brightness can have direct impact on emotions. Designing architecture with light is a means of constructing our visual environment, and of affecting our emotional state. (Bernstein, Penner, Clarke-Stewart, & Roy, 2007) Good lighting design may eliminate many social and psychological issues and produce an effective environment conducive to our well-being. (Monice, 2004)

Light is an important component of the aesthetic qualities of places, and creates area atmosphere. From a scientific and medical perspective, light induces three important hormones that impact our internal clock and mood states: cortisol, serotonin and melatonin. These hormones are needed in order for our bodies to maintain their proper equilibrium. An example of the importance of light to our bodies is the effects of the hormone serotonin. Low levels of serotonin, known as the daylight hormone, may cause depression. Today, light therapy is used as an effective tool to cure depression. (Bernstein, Penner, Clarke-Stewart, & Roy, 2007)

Light becomes the emotional driver when the perceiver understands and interprets the lit environment. Light can create emotional states and can respond to them as well. Light as a response to emotional states involves the perceiver's behavioral response to light, as when light stimulates our perception. Light as a stimulus can guide, direct, excite, inform, and communicate with us. On the other hand, using light to create emotional states involves the manipulation of light through techniques. Light is manipulated in an attempt to affect the perceiver's mood. Light can create and increase visual satisfaction within a given environment through changes in its colour, brightness, contrast and intensity. (Tomassoni, Galetta, & Treglia, 2015)

Figure 11: Light and Psychology Diagram. By author.

Understanding the relationship between light and human emotional behavior is necessary for the understanding of the effect of light on architecture. Tadao Ando's The Church of Light is a prime example of how lighting effects can create emotional states in architecture. (refer to page 31) The contrast of the darkness of the corridor and concrete wall with the intense light from outside that enters through the cross on the wall creates a powerful effect of spiritual light and spirit of space. (Ando, *Tadao Ando: light and water*, 2003) The architectural design delivers the message, "God is watching us" and "Light is holy and warm". (Jodidio, 2004)

Stage lighting demonstrates how light and its effects can create emotional responses. The stage presents a fully controlled space that uses artificial light to affect the audience's behavioral responses. In addition to traditional lighting, the innovative use of LEDs and lasers creates special effects on the stage to involve the audience and incite people's emotions. (Major, Speirs, & Tischhauser)

Stage lighting design strategies may be adapted into architectural design for different situations. For example, in quiet spaces, the design may calm the environment by using yellow ambient and diffused/indirect light to relax the retina of human eyes, thereby creating comfortable visual perception. Recessed lighting on the ceiling or walls can be strategically positioned in order to absorb extra light and to create a crisp architectural appearance. (Birkhäuser, 1993) (Karcher, 2009)

Today, it is not only religious spaces that are designed to respond to the emotional behavior of human. Many social places, such as malls, casinos and health spas, are designed to influence users to experience changes in emotions and behavior through dramatic use of light. Research from psychologists and behaviorists indicates that even minor changes in light can have emotional impacts on humans. (Bernstein, Penner, Clarke-Stewart, & Roy, 2007)

Effective of Lights

Good lighting can encourage human excitement and alertness while poor lighting can cause dullness and boredom and can be stressful,

even causing the level of cortisol to drop significantly. The presence or absence of light can have pronounced positive or negative effects. For instance, the quality of light can actually affect a person's ability to make reasonable decisions. (Monice, 2004) (Tomassoni, Galetta, & Treglia, 2015)

Research conducted by environmental psychologists Rachel and Stephen Kaplan suggests that our senses are the stimuli when we enter a space. Light is an element that offers clarity. Distribution of light across a space may affect the overall impression of that space. Low light levels and uneven distribution of light can be used to create intimate atmospheres. Bright light levels and evenly distributed lighting conditions attract attention and create the feeling of spaciousness. For example, daylight exposure in offices improves work performance since lighting quality affects moods. (Tomassoni, Galetta, & Treglia, 2015) People tend to perform better while working in good light quality.

Much research today focuses on the effects of natural and artificial light on human moods. Artificial light has static properties. Daylight is a difficult area to study through experimentation because it is dynamic, that is, constantly changing. The changing quality of daylight makes it a unique lighting source with distinctive characteristics. (Boubekri, 2008) There is a consensus that people tend to prefer daylight over artificial light. (Gibson, 1966) The spectrum of daylight is generally a natural preference for humans, as the properties of the spectrum contribute to our good mood. The spectrum of daylight consists of white daylight with the combination of 7 colours called a rainbow spectrum. This spectrum activates hormonal and physiological growth in humans and contributes to our well-being. (Monice, 2004) (Tomassoni, Galetta, & Treglia, 2015) Our psychological preference for daylight has led many artificial lighting manufacturers to produce full-spectrum electric light despite the fact that its overall cost is higher than that of standard artificial light. The properties of full-spectrum electric lighting are similar to those of the dynamic spectrum found in daylight. (Boubekri, 2008)

Subjective Impressions on Lighting

Light may be communicative when its patterns suggest or emphasize forms that are shared by people and understood by people from similar cultural background. For example, commercial trademarks and traffic signals incorporate visual patterns and types of light that communicate information that is easily understandable by people from the same culture. These visual patterns are information sources used to guide individual and group behavior. Their visual forms have symbolic meanings, for instance, the Christian cross with its evocation of cultural and social rituals. (Monice, 2004) There is a complex system in place that influences our emotional responses and sense of place and that arises from information received through vision. (Gibson, 1966)

Light is one of the most influential aspects of visual communication. The varieties of light, referred to as lighting modes, include patterns of light and shade, as well as colours. The psychology of light involves a comprehensive study of perception, luminance, contrast, and subjective impressions of our physical environment. Subjective impressions of lighting involve an individual's response to light within a spatial dimension, and to the effect of light on his or her behavior. Design with light may function to provide intervention in human visual experiences, and can provide direction, guide movements, and affect concentration and focus. During the 1970s, an important research study was conducted by John Flynn. Called the *IERI (Illuminating Engineering Research Institute) Project 92* provided standardized measurements of subjective impressions of lighting. The two issues that Flynn's research focused on were (1) the effect of light on subjective impressions and attitudes, and (2) the effect of light on performance and overt behavior. The purpose of this study was to offer guidance on the application of light in space and to determine the most suitable types of lighting in every situation. (Flynn, Hendrick, Spencer, & Martyniuk, 1979)

This research measurement proposed a framework to understand the effect of light on how individuals perceive light sources, and how the changes in light effect our subjective impression.

Perceptual Categories	Impressions of visual clarity Impressions of spaciousness Impressions of spatial complexity Impressions of color tone Impressions of glare
Behavior Setting	Impressions of public vs private space Impressions of relaxing vs. tense space
Overall Preference	Impressions of preference (like-dislike) Impressions of pleasantness

Figure 12: Table of The Categories of Impression (Flynn, Hendrick, Spencer, & Martyniuk, 1979)

Semantic differential (SD) rating is one of research method that identifies different categories of impressions within a lighting environment. There are three classified areas of impressions within a lighting environment: perceptual, behavior setting and overall preference. These areas are crucial in developing lighting solutions for different type of spaces. (Flynn, Hendrick, Spencer, & Martyniuk, 1979)

Although there is no fixed scale that can identify subjective reactions to lighting, many of these studies emphasize and articulate the necessity for architects and engineers to be aware that lighting functions for more than reading, writing and working. It is also used and manipulated to provide visual sensations and experiences that will impress users. (Flynn, Hendrick, Spencer, & Martyniuk, 1979) (Gibson, 1966)

Figure 13: (left to Right) Low Contrast - everything in the scene is the same weight. Mid Contrast - some furniture stands out and it has a combination of emphasis. High Contrast – high bright and dark area. By author

Figure 14: Variation of colors at the same scene. By author

Brightness and Contrast

The degrees of brightness and contrast affect the perception of materials and forms present in architectural spaces. Similar to sound sensations, brightness and contrast of light create conditions that affect emotions and determine how people behave. (Monice, 2004) Figure 13 shows a series of experiments that investigate the degree of brightness and contrast on the same space. The brightness and contrast tend to affect how people perceive the space, which could in turn influence how the space affects people.

Color and Tone

The perception of colour comes from light. Colour can reveal an object's dimension and depth. It also has the ability to affect the temperature, emotions, size and shapes of a space. The visible spectrum of light is categorized into two colours groups: warm light and cool light. The visible spectrum classifies warm light as low colour temperature, and cool light as high colour temperature. Warm colour tends to advance (bring objects forward) and cool colours tend to draw back (make objects recede). Colour and tone have significant psychological value. They can make the space induce an emotional response in the perceiver that can range from active to quiet, or from excitement to tranquility. Human moods are strongly influenced by the variation of colours produced by light, and colours also have an impact on performance. (Gibson, 1966) (Steffy, 2002)

Although the perceptions of colour can be subjective depending on the person's cultural background and past experience, there are nevertheless common findings regarding the psychological effect of colour. For example, the colours red, yellow and orange evoke emotional and behavioral responses to be cheerful, active and exciting. Blue evokes a relaxed, calm and peaceful state. Green is considered to be a comfortable colour for our eyes, and to represent a combination of emotions: refreshing, cheerful, calm and tranquil. Lastly, black, grey, white and brown are considered to be neutrals, which act as accent that can heighten or cool down the feeling of an environment. (Steffy, 2002) Figure 14 shows results of an experiment that investigated visual aspects of a variety of colours. According to Gibson and Steffy the different colours lighting the same space have different emotional impacts on our visual perception on space. The variation of colours creates different atmospheres. (Steffy, 2002) The space tends to be more welcoming and comfortable with warmer colours (top row of Figure 14), while cooler light produces a lonelier atmosphere (bottom row of Figure 14). The investigation of colour and light gives important information about colour and its potential to affect mood.

Theory & Practice

This chapter, “Theory and Practice” includes a series of research, case studies, and precedents to construct a picture of how architects and their works demonstrate expertise through the introduction of light into architecture. A range of different types and sizes of buildings are studied to find out and understand ways in which architects express, achieve, carry out, and apply their theories in their work. Inspiration from architects and buildings offers important insights into technology and design strategies, while the knowledge of light within architecture that is provides enables this thesis to develop a distinctive position.

Figure 15: Warm Bath Perspective. By author

How light influences our perception of space

LIGHT
SHAPES
SPACE

THEORY & PRACTICE

3

3.1 | Inspired Architects and Buildings

The Beinecke Rare Book & Manuscript Library

ABOUT THE BUILDING

Architect: Gordan Bunshaft of Skidmore, Owings, & Merrill

Location: Yale University, New Haven, Connecticut

Opened: 1963

Figure 16: Interior of The Beinecke Rare Book & Manuscript Library, Yale University. (Beinecke Digital Studio, 2013)

RESEARCH:

The Beinecke Rare Book & Manuscript Library shows how light can be manipulated to affect a building’s exterior and interior appearance. Yale University’s library is a six-storeys windowless rectangular structure made of Vermont marble (1-1/4” thick), framed by granite and bronze, and elevated by a lower level of steel and glass. The exterior block walls give pedestrians an impression that the building is completely solid. In addition to avoiding direct sunlight, the interior is a fully open space with an enclosed glass temperature-controlled tower that houses 160,000 rare books for preservation. On the lower ground, a glass curtain wall provides an activity area that contains classrooms, reading spaces,

study spaces, office spaces and a garden courtyard. (Yale University Library, 2013)

The windowless facades – Vermont Montclair Danby Marble panels, are translucent marble walls that allow some light in the building even as they block the ultraviolet light that can damage the rare books. During the day, the light transmitted through the marble varies according to the intensity of the sun. At night, the marble glows from interior illumination and creates an interesting exterior façade that varies depending on the interior activity. During the day, the white marble causes the exterior to look cold and severe, but once you walk inside, the filtered daylight changes the mood to warm and rich. (Yale University Library, 2013)

FINDINGS:

This project is important to this thesis because it demonstrates how light influences architecture through the selection of material. Many architects like to amplify the use of natural light in their work because natural light creates harmony between the exterior and interior, between the natural and the man-made. Gordon Bunshaft worked with this idea – bringing natural light into the building – in a unique way. He investigated this concept with research and study of materials, asking *“how may light go into the building?”* (Plummer, 2003) What impresses me most is the precise and sensuous way Bunshaft uses the material. The semi-opaque marble walls transform the building into a translucent ornament, transmitting natural sunlight during the daytime and glowing luminous volumes at nighttime. By having a general understanding of the materials, such as its properties, the architect can generate a meaningful story of an architectural object.

Church of Light

ABOUT THE BUILDING

Architect: Tadao Ando

Location: Ibaraki, Osaka, Japan

Opened: 1989

RESEARCH:

The Church of Light has reinvented new ways light can be used in architecture. The overall layout of the building is based on the orientation of the church. The church is seen as a place of retreat where the outside world is forgotten and the natural world is emphasized through the control of light. The perception of light within the church evokes an emotion of nothingness and creates a feeling of spatial emptiness. The controlled natural light penetrates through the cross on the wall evokes a sensation of spiritual light which is purifying and clean. Light and shadow in this building makes the space dramatic, as the cross is perceived not merely as a sign, but as an integral part of Christianity. (Furuyama, 2006) (Jodidio, 2004)

The Church of Light has successfully connected with the senses and nature through the use of natural light. Ando further connected the architecture with nature by designing the church to coexist with light, and by providing for the growth of trees that would surround the building

Figure 17: (Above) Interior of Church of Light, Osaka, Japan. (tokyo wing2, 2011)

as time went on. The building is well known for its exemplary daylighting and for its dramatic interior space. The lighting design of this project is successful because of its ability to meet the needs of its users both in functional and spiritual terms. (Furuyama, 2006)

FINDINGS:

The use of natural light became an important element of this building because the light is not used to brighten up the room, but to create illusions and to influence the perception of space, material and sense of atmosphere. The effects of light provide an opportunity for architects to understand how light perceived through architecture can control or affect humans. Ando presents an example of how to transform light into a fundamental element of architectural design. (Ando, Tadao Ando: light and water, 2003)

Light and shadows may affect how people feel inside the building. The darker space can represent loneliness and the incoming light can symbolize God. This project studies how the appearance and disappearance of light creates the characteristic of a room and atmosphere of a space.

Figure 18: Exterior of Church of Light, Osaka, Japan. (Verena, 2011)

Mount Angel Abbey Library

ABOUT THE BUILDING

Architect: Alvar Aalto

Location: St. Benedict, Oregon

Opened: 1970

RESEARCH:

Mount Angel Abbey Library is an outstanding project for the study of control of light and energy conservation in architecture. Alvar Aalto was a master at utilizing light. Within the library where light is bent, borrowed and shielded, Aalto has manipulated light for utility and beauty. The spaces are shaped by light that corresponds to the function of the space. During the day, a crescent-shaped skylight over the multi-storey interior space penetrates from the light shelves and reading desk to the cantilevered floors in soft natural light. No matter where users sit or stand, the light is soft. (Good, 2002)

Aalto created the room's impression of warmth and serenity through the use of natural materials and muted colours. This applies to the whole library, except for the bottom level, where natural light is introduced to light-wash this area. In addition, most of the furnishing, such as light fixtures, chairs, desks, shelves and cabinets were designed by Aalto himself. The light fixture designed by Aalto provides a special character

Figure 19: (Above) Interior of Mount Angel Library, Oregon. (Swenson, 2012)

of light that differs from other standard light sources. Unlike standard artificial lighting that causes lighting issues such as glare, Aalto's light fixtures are designed to avoid glare and to mimic natural light. (Good, 2002)

This project points out how interior light both works successfully and fails with regards to those who use the library on a regular basis. The lighting techniques used in this building exemplify how the use of different kinds and qualities of light can create visual comfort by constructing a room that makes excellent use of all the different elements that architecture embraces. (Good, 2002) (Aalto's Second American Building, Mount Angel Library, St. Benedict Oregon', 1971)

The exterior facades, windows and openings are carefully designed to accommodate interior activities. For example, the long strip window at the auditorium is designed to begin at eye level and extends above the wood ceiling. A series of windows at the office level run from column to column and the windows of the children's library and the periodical room are located high on the wall. The variety of apertures demonstrate how light can shape spaces to accommodate different activities and circumstances. (Good, 2002) (Schaefer, 2006)

FINDINGS:

This project is relevant to my research because it demonstrates how control of daylight and artificial light through different types of opening or aperture sizes can optimize atmosphere and the experience of an architectural space. For example, conical skylights are located throughout different spaces in this building, such as the reception desk and interior corridor. The reception desk requires a brighter lighting environment for workplace performance than does the interior circulation corridor; therefore, the angle of the conical skylight above the reception desk is much bigger. The larger the cone angle is, the more daylight emits into the space. In order to accommodate different lighting requirements in relation to spatial functions, daylight composition and the arrangement of spaces are critical to designs that integrate daylight. Its relationship to form, materials, light and function is important to its

Figure 20: Daylight diagrams (Left), and photos (Right) of the interior of Mount Angel Library, Oregon. (Winkler, 1997)

effect on experience of the space.

Although it is unusual to experience direct sunlight in a library, this library surprisingly has a huge amount of natural light within its interior. (Good, 2002) Lighting here could be improved by the addition of artificial light, as the library would otherwise be dark at night; some areas like the periodical room have inadequate natural light. Daylight control, through the use of daylight sensors and dimmers, can be added to this project to improve the effectiveness of natural light and artificial light.

Aalto was skilled at incorporating skylights as an important architectural element. The location and shape of skylights affect the quality of light within a space. This project enhanced my understanding of how effectively skylights can define the shape and characteristic of a space. In addition, Aalto demonstrates the importance of particular spaces through his selection of materials, interior finishes, furniture and fixtures. The library is intended to be a highly personalized space that give users the feeling of warmth and serenity while reading and studying. Therefore, wood and muted colour are selected as the theme for all furniture and fixtures. Wood and muted colours demonstrate the design strategy of a controlled sensory experience. In the reading rooms, light is present only when it is reflected on a surface, that is, when the elements of finishes, theme, light, décor and colours come together in the physical environment. The light directly influences the characteristics of the spaces.

This project demonstrates a basic design principle, showing the relationship between light and material. It shows how light influences our perception of space through psychological tactics – atmospherics in architectural design. This project has enhanced my knowledge of light in architecture, as it has demonstrated that all objects matter in the creation of a unique character of a space. In this thesis, I will not limit my study of light and its influence on architecture to the selection of material, finishes of wall, floor and ceiling but will include décor, colours, furniture and fixtures, as they play an important role in revealing the characteristics of a space.

3.2 | Architects and the Light

What's architecture?

"The reality of building consisted not in the four walls and the roof but in the space within," from Lao Tze's 6th century philosophical insight. (McCown, Riera Ojeda, & Warchol, 2005, p. II)

Light within architecture depends on how the light is used, transformed and manipulated to highlight and enhance the space to a more suitable, comfortable and visible atmosphere. (Michel, 1995)

What happens when architects start to use light as a theme in their work? Who is the master of light within architecture? This section, "Architects and Light" is an introduction to architects who have influenced attitudes about light that have been innovative. I started to wonder whether it is possible to combine one's own theory with another's design philosophy to create a research topic. How can Ando's theory conflate with Aalto's lighting design strategies to make users feel comfortable and be able to concentrate for longer periods of time when working in a naturally illuminated environment? I believe the psychological effects of daylight and artificial light have a valuable architectural potential for further development and study. Instead of considering questions about the uniqueness of the architect's work, this thesis will address architects' thoughts on the language of light. Analysis of their ideas, theories and philosophies through study of significant projects has been crucial in the development of this thesis position.

The following architects have heavily influenced this thesis and their theories are manipulated and applied in the design investigation. The overall architecture thesis design (See the Design Outcomes in Chapter 6) is used as a vehicle to explore this thesis topic. Selected designed spaces in the building reflect significant applications of the theories and philosophies of light by Le Corbusier, Louis Kahn, Steven Holl, Tadao Ando, Peter Zumthor and Alvar Aalto.

Figure 21: Louis Kahn Looking at His Tetrahedral Ceiling in the Yale University Art Gallery, 1953. Gelatin silver print. (Freedman, 1953)

Figure 26: Ronchamp interior photographs, Le Corbusier. (Hyde, 2016)

The Poem of the Right Angle (Le poeme de l'Angle Droit), a major piece written by Le Corbusier, includes a series of poems with paintings created between 1947 to 1953. The beginning of *The Poem of the Right Angle (Le poeme de l'Angle Droit)*, under the section, *A.1 Environment*, relating to the cyclical nature of the sun, describes his vision and thoughts regarding the movement of the sun (translated into English by Kenneth Hylton, June 1989):

“... *The sun master of our lives
far off indifferent
He is the visitor – an overlord
he enters our house.
In setting good evening he says
to this mossy earth (oh trees)
to these puddles everywhere
(oh seas) and to our lofty
wrinkles (Andes, Alps and
Himalayas). And the lamps
are lit up.
Punctual machine turning
since time immemorial
engenders every instant of the
twenty-four cycle the gradation
the nuance the imperceptible
almost providing
a rhythm. Yet brutally
he breaks it twice –
morning and evening. Continuity
Is he but he
Imposes an alternate –
night and day – these two phases
rule our destiny:
A sun rises
a sun sets
a sun rises anew”*

(Merin & Samuel, 2003, p. 74)

The paintings convey his observations regarding the relationship between the sun path's and the horizon in a simple coloured diagram. Conversely, the paintings can be read as graphs to indicate heat gain and loss throughout the day from a scientific point of view. A further explanation of this idea was published in Le Corbusier's *La Maison des Hommes* in a set of three sketches. This series of sketches illustrates the

progression of the sun during winter and summer, where late afternoon is identified as the time of maximum solar heat gain throughout the day. Le Corbusier expressed his philosophies and desired building characteristic through his designs for illuminated space. These illuminated spaces are to be experiential. They avoid direct or harsh sunlight in order to establish a visual connection and air movement that is responsive to the existing context and environment. (Samuel, 2007, pp. 73-75) In others words, throughout Le Corbusier's architecture, the effect of light and shadows appears dramatic, like cinematic atmosphere. This effect changes and creates different atmospheres by influencing the observer's angle of vision in accordance with the cosmic rhythm of sunlight and season. A combination of space, light and order allow Le Corbusier's work to manipulate architecture in relation to sun, space and greenery. (Le Corbusier & Pierrefeu, 1948)

The Chapelle Notre-dame du Haut, Ronchamp, is a significant work that expresses Le Corbusier's language of light through architecture. In the Notre-Dame Du Haut, Ronchamp light strikes into the small openings with high intensity and causes the interior walls to appear dark. Contrarily, soft filtered light enters the space from the private chapel above, creating a sense of disturbance that is caused by the intensity of light that intrudes through the openings in the sanctuary. (Pauly, *Le Corbusier: the Chapel at Ronchamp*, 1997)

Structure assembly plays a major role in Le Corbusier's architecture, such as the Villa Savoye in Poissy, near Paris, France. In the Villa Savoye, the raised pilotis of the structure create a sense that the architectural spaces are floating while the combined effects of light and shadow define the space on the lower level. By using columns as the structure instead of bearing walls, the architecture becomes an open floor plan without barriers, which allows natural daylight to flow into the interior spaces. Daylight enters through the roof terrace and ribbon windows of the free façade. Many of Le Corbusier's work showcase these structural aspects. (Etlin, 1994)

Many were critical of Le Corbusier's approach in regards to over exposure of sunlight for projects such as the Villa Savoye in Poissy,

France for his barrier-free and ribbon windows. (Merin & Samuel, 2003) The Notre-Dame Du Haut, Ronchamp, however, clarifies his understanding, philosophy and language of light in another aspect, known as the play of light within architecture.

FINDINGS AND APPLICATIONS:

Constantly changing natural daylight can create different lighting conditions in different geographic locations. The major intention of this thesis is to expand our understanding of light within architecture. As experimentation and exploration in this area expands, the findings of architects can be used as a common reference point when designing with space and light. Because this thesis focuses on user experiences, perception, and emotional responses to light and space, acknowledging the way daylight is distributed is essential. This thesis explores the opportunity to connect space with light by means of different lighting situations and conditions, since daylight is constantly changing and current technology allows us to change artificial light with ease as well. Le Corbusier's scientific and poetic concerns about the movement of the sun and the progression of light throughout the course of the day and season of the year inspired this thesis to create architecture that is sun and climatic responsive, but at the same time also emotionally responsive to user's experience and interpretations.

Within design practice and the modern living tradition, artificial lighting is a fundamental lighting requirement for all architecture. I am interested in the manipulation and control of both daylight and artificial light, to change the perception of space throughout different times of the day. I believe the difference in light sources and lighting conditions during the day and nighttime throughout the year can create totally different atmospheres and experiences for users within the same architectural space. (Refer to Chapter 6, section Room character, L2 warm bath page 187 to 192, for elaboration of Le Corbusier's theory in the design development and details of the Light study within the same space, where distribution of different lighting situations and conditions produces a spectrum of atmospheric impressions.)

Louis Kahn

Louis Kahn was one of the most influential and visionary architects in his use of light and shadow to reveal architecture. Light is the central element of Kahn's designs. Not only does Kahn deploy light to reveal lighting effects on surfaces, but he also uses it to shape spaces. Light is treated as just another constructive material. (Goldhagen, 2001) Kahn states that light is the maker of material: material casts a shadow but the shadow belongs to the light. Many of Khan's works incorporate natural light in effective ways. He believes that light should not be an afterthought or secondary element in design. Instead, he suggests that floor plans should be read not solely for functional usage, but in regards to lighting consideration and pattern of light – the absence and presence of light. (Lobell, 2008)

Kahn's interest lies in manipulating light within spaces to create meaningful atmosphere. In his works, he attempts to reveal light in

Figure 27: Assembly Building of Bangladesh in Dhaka. (Flickr abrinsky, 2010)

its pure and natural state based on the level of darkness in shadow, creating dramatic atmospheres and meaningful spaces. There are two aspects to consider with Kahn when designing with light – geometric forms and division of spaces. (Goldhagen, 2001)

The National Assembly Building of Bangladesh in Dhaka designed by Louis Kahn is a unique and extraordinary example of integrating light through forms and spaces. This building contains eight halls surrounding the central core – the Parliament Chamber. The building is constructed of concrete and decorated with white marble; its location on an artificial lake both reduces heat absorption and insulates from heat. The light and shadows cast onto heavy materials – concrete and masonry -- create subtle variations in different spaces. The water feature reflects and refracts light onto the architecture to create intended spatial and light conditions. (Goldhagen, 2001)

Light is used as an accent for the National Assembly Building of Bangladesh building to enhance the overall visual perception through the use of divisions of spaces and geometric forms. Kahn states,

“In the plan of assembly I have introduced a light giving element to the interior of the plan. If you see a series of columns you can say that the choice of columns is a choice in light. The columns as solids frame the spaces of light. Now think of it just in reverse and think that the columns are hollow and much bigger and that their walls can themselves give light, then the voids are rooms, and the column is the maker of light and can take on complex shapes and be the supporter of spaces and give light to spaces’. In study models these ‘hollow columns’ were given clear geometric definitions; as realized, they were shaped by the columns they adjoined [...]”
(Brownlee & De Long, 2007, p. 126)

Figure 28: Assembly Building of Bangladesh Interior.
(pzarch14, 2012)

As described by Kahn, the 'hollow columns' function like light wells and are introduced to bring natural light into the interior spaces. The visual appearance of the structural columns merged in with the structure, space and light, give the overall massive structure an impression of weightlessness. (Goldhagen, 2001) The overall geometric form and shape of the building functions as a system to control the light that passes through to the interior spaces. In this building, light is not solely used to illuminate a space, but also to conceptualize it as an architectural space. (Brownlee & De Long, 2007)

The Parliament Chamber building as part of the central main plaza was carefully designed to allow daylight in from the roof into the building. The natural light shines onto the walls and the enclosed octagonal central core to create dramatic and atmospheric scenery. (Goldhagen, 2001) Many of his works demonstrate Louis Kahn's philosophy of using light aesthetically and efficiency. Light is a "giver of all presences" in his work. He believed that all materials are made of light. Light is a maker of materials and the purpose of a material is to cast a shadow.

FINDINGS AND APPLICATIONS:

Influenced by Kahn's theory, this thesis considers light as the basic premise in design. The fundamental elements of architectural design, including program, circulation, volume, function, materials, and structure are all arranged to respond to all lighting requirements. The objective of this thesis is to consider lighting requirements, such as functional usage of space, in order to design efficient architectural space.

Kahn's philosophy and insights in regards to light within architecture enhanced my knowledge with this thesis topic. In order to shape space with light, the presence and absence of light plays a very important role, according to Kahn's philosophies and theories. I am interested in exploring the effects of light and design spaces that allow observers to perceive the space as I want it to be perceived. How does light become a fundamental element within architecture, just like the structural, circulation and programming elements of a building? Kahn's philosophy and theories provide opportunity and insights for this thesis regarding

expanding architectural design thinking with light.

As cities become denser and taller every day, it is more difficult for architecture to access natural daylight in the seemingly endless vertical spaces within the urban centers. Designs of these vertical skyscraper form units are built up with stepped arrangements of stacked blocks to conserve access to daylight and views. Rather than sacrificing the quality of life, I am interested in exploring solutions for inhabitants to increase their quality of life through the accessing of daylight and views. Inspired by Louis Kahn, who uses shadow to reveal light in its pure and natural state based on level of darkness and shadow, I believe connection to the exterior and interior for greenery and landscape with the use of light may increase the level of feeling associated to the space. At the same time, such a connection would create possibilities for meeting the needs of dense modern cities by preserving living standards within skyscraper form units at the urban scale.

This thesis will use natural effects of light such as the interesting diffuse dappled light of trees and vegetation and the reflected and refracted light from water to create a design that can successfully relate to human emotional responses towards desire behavior. The quality (through filtering, dappling, colour, etc.) and brightness of light manipulates and associates with the environment to create connections and associations to the exterior and other portions of the interior. In this thesis, I used shadows of natural elements, such as vegetation, trees, water, and cave-like effects in architecture itself, to reveal natural light effects that create interesting patterns of shadows and light. Details and development of the design are featured in Chapter 6, page 171 to page 176, page 183 to page 189 and page 195 o page 194.

For example, Level 2 Tea Room is a design based on the elaboration of my theory of light; it connects the interior and exterior through side windows that increase the feeling associated to the space. This space makes use of the diffused shadows and filtered light created by the existing deciduous trees to reveal light in its pure and natural state. The constant changing patterns of light and shadows from the trees deploy different feelings associated with the space, but at the same time they maintain

a sensation of decent quality of life through the access of daylight and views to the landscape within urban centers. The experiment with this space provides opportunity for this thesis to explore light in its pure and natural state through the shadows of natural elements, such as vegetation. Other spaces of this design thesis enhance the elaboration of Kahn's concept and theory of light with my findings as well, such as the Level 2 massage room with diffuse dappled light of vegetation and view to green wall.

Steven Holl

Steven Holl is recognized for his capability to blend space and light to create concept-driven designs through stimulating the atmosphere, and for the qualities of his work. (Steven Holl Architects, 2016) Holl brings the theory of phenomenology into the realm of architecture. His philosophy emphasizes visual perception in architecture through the manipulation of light, shadow, space and material to create sensory stimulations that are based on cultural connection within the architectural space. The perception of space comes from the sensory experience that is created by the arrangement and setting of the physical environment. Human Experience is an important aspect of Holl's designs. Holl's theory of light is based on sensory perception. The arrangement of all architectural elements, including space, volume, light, form, shapes, circulation and program, depend on human sensation. (Fisher, 2002) In Holl's work, light acts as the engine of a machine that powers all the other architectural elements within an architectural space.

For this thesis, I am interested in the effect of light on human perceptions of space. Holl's theory and philosophy is beneficial to this thesis because it demonstrates the relationship of human sensation to the uses of light and other architectural elements. There is great opportunity for this thesis to explore shaping space with light through the theory of phenomenology within architecture.

Influenced by Le Corbusier, Holl's architecture is responsive to the behavior of light – sunlight, daylight and artificial light. Many of his works contain interesting curved, formed ceiling spaces, such as the Nelson Atkins Museum of Art. The designed ceiling collects natural light for

Figure 29: (Left) Steven Holl.
(Heithoff, 2014)

Figure 30: (Right) The Chapel of
St. Ignatius. (The Chapel of St.
Ignatius, 2011)

different lighting conditions. During daytime, the curved formed ceiling reflects and refracts different brightness of natural light into the interior space. The brightness of the space differs depending on the existing natural lighting conditions. For instance, if the sky condition is partly cloudy, the space becomes darker because the clouds offer shadow. The strong relationship of natural light to artificial light was taken into account in the design. At night, the architecture itself becomes a glowing box, a light feature that gathers attention exteriorly from a distance. (Descottes & Ramos, 2011, pp. 121-123) Different perceptions and experiences of the space are provided throughout day and night by the use of different types of light. Natural light is experienced throughout the day interiorly, while artificial light is experienced both exteriorly and interiorly at night.

Simmons Hall and the Chapel of St. Ignatius are some of his significant projects that express phenomenology through the usage of light as the driver of his design. The Simmons Hall allows light and air to flow spontaneously into the building since the façade functions as a sponge with the openings. Meanwhile, the Chapel of St. Ignatius is expressive with its use of coloured light that blends the physical and spiritual program spaces of the building. The lights reflect from the painted surfaces and enter the interior spaces with colour lights to affect our visual perception of space and emotional behavior through day and time. (Fisher, 2002) More discussion and analysis of Steven Holl's works will follow later in this chapter.

FINDINGS AND APPLICATIONS:

Sensory experience is all about attacking our senses, including smell, touch, taste, sight and sound. (Monice, 2004) It is well known that Holl's design appeals to the sense of vision. Light increases awareness and strengthens our impression of spaces. With sensory design, psychology of light as background, and Holl's theory as references, perception of space is based on cultural connections that stimulate the perceivers' personal experiences and backgrounds.

Different people have different backgrounds. The cultural role derives

from visual connection. I am interested in stimulating a sensory experience with light to arrange, create, and design physical environment. I believe light has the ability to invoke memories and stimulate user feelings. (Monice, 2004) Although light does not appear as a tangible element, it is a cheap and very effective source that can be used to appeal to human senses. It has powerful effects on the environment and can influence spatial perception. Inspired by Holl, I believe manipulation and association of the environment may reflect cultural connection; for example, white and glowing light within a white furnished space evokes the quality of purity, and bright light within a dark physical environment, similar to the effects shown in Tadao Ando's Church of Light, evokes a spiritual quality. Through the arrangement of physical settings, the effect of light develops interesting sensory responses that can stimulate user experiences. In this thesis, I adapted this awareness into theory and design guides to explore this thesis topic of, how light influences our perception of space. Refer to Chapter 6, page 193 for investigative experiments.

In order to connect light with space, I defined each functional space based on its desired lighting quality. Referenced projects are based on lighting conditions and are used as guides to define desired lighting quality for the functional usage of a space. For example, I would like to achieve a warm welcome lighting quality of space for the Spa Floor Level 2 Lobby and Foyer. Therefore, bright and warm lights are the desired lighting conditions. (Refer to page 181) The application of materials and physical settings are taken into account when designing the space. Design elements such as wood finishes, white painted surfaces, skylight planter, wood furniture, and big openings to access daylight are carefully considered to connect the space with light. Since wood and vegetation are elements derived from nature, the lighting effects on these materials can express a cultural connection for people from various backgrounds. I believe natural elements, such as trees, woods, leaves, greenery, rocks, sands and water, play a prominent role and have deep meaning in many mythologies and religions. Therefore, the most suitable element to reveal light in its natural and pure states is nature itself.

Tadao Ando

Tadao Ando is a Japanese self-taught architect who uses natural light to create spiritual spaces. Ando's expertise lies within emotional architecture: his architecture offers visitors a poetic experience as they journey through a sequence of spaces. (Ando, *Tadao Ando: light and water*, 2003) In Ando's work, the intangible element of light is expressed as a key to people's mind. The way he expressed light can be related to the elements that are well known as Zen aesthetic of Japanese architecture. He enables users to fall into his emotional design trap, as being calm, poetic, tranquil and quiet. (Veal, 2002) His philosophy of design reveals the soul of architecture and understands the architecture through the connection of natural elements, including light, water, and air. (Ando, *Tadao Ando: light and water*, 2003)

Ando relates the themes of his architecture to the natural elements, as can be seen in his works such as the Church of Light, the Church on the Water, and Water Temple. One of the most common design approaches that he uses to connect his architecture with nature is to provide views to the natural landscape in his architecture. Similar

Figure 31: (Above) Tadao Ando, Architect at the Modern Museum of Art, Fort Worth. in 2012 (Masker, 2012)

to the Chinese Gardens examined in Chapter 4 page 106, Ando also uses water ponds to beautify the scene as they reflect the sky and natural landscape like a mirror off the water's surface. The space within the scene instantly becomes more interesting with the presence of the water reflection. The view to the natural landscape itself becomes a part of a beautiful architectural scene. The presence of natural elements, including light, water, and air, illustrate his design language in emotional architecture and enables people to experience the concept of place spirit. (Jodidio, 2004)

Light is manipulated and shaped to create space with intentional atmosphere. I find it astonishing to experience place spirit within Ando's architecture, because his architectural spaces resemble industrial factory-like buildings with their use of concrete and the purposefully empty environment. The reason Ando likes to use simple and neutral cement surfaces such as fine concrete is to emphasize light and reflection. In his designs. Natural light is used to highlight spaces as independent design elements. (Murray, 1991, pp. 52-

Figure 32: Provide Views to Natural Landscape at The Church on the Water, by Tadao Ando. (Hoshino Resorts Tomamu, 2016)

61) For instance, the cross of light within the Church of Light entering through the walls into the dark interior does not only create contrast, but also gives the impression of an infinite beyond as well. The emotional design situation does not only allow the light to brighten a space, but also to reveal a state of awareness, as being holy and warm. Light requires space to demonstrate its beauty and function. The Church of Light demonstrates the senses of the natural element of light. The cross of light floats within the darkness and creates the feeling that God is watching. (Ando, *Tadao Ando: light and water*, 2003). (Jodidio, 2004)

FINDINGS AND APPLICATIONS:

Many chaotic cities today, such as New York, Tokyo, Hong Kong and London, desensitize and dehumanize individuals through an overload of sights and sounds. They are swept away in the wave of commotion, smells and glamour. I am interested in deconstructing these urban tensions through the creation of a peaceful space created with the use of light. I am inspired by Ando's architectural connection with nature, and aim to focus on the achievement of tranquility through natural elements like light. I believe tranquility can be achieved through the controlled presence and absence of light by control.

In contrast to Kahn's theory of light, where shadow exists/is used to view light in its pure and natural state, this thesis would like to bring in nature as an oppositional framework that allows us to perceive light in its pure and natural state. Inspired by Ando, I believe the soul of light can be understood through its connection of nature, such as vegetation, trees, wood, water and cave (refer to page 187). The design of this thesis associates daylight with nature by providing views to the natural landscape in order to achieve the desired atmosphere through the connection to light. The overall setting of a space within this design thesis, Level 2 warm bath, is influenced by Ando's philosophy of design. The warm bath includes a water pond, corrugated wall surface, and a green wall partition, which is applied to retain and associate a feeling of the space with light through the view of nature. During the day, the water reflects the sky and the green wall acts like a mirror, creating

an illusion to the inhabitant as if they are swimming inside a cave and experiencing a peaceful and calm atmosphere. Meanwhile, within the same space at night, the wall glows and the bright moon hung in the sky is reflected on the surface of the water, displaying a completely different type of peaceful atmosphere where the inhabitant travel in the galaxy of the universe. I believe nature, just like water, vegetation and caves, can be used to emphasize light as an oppositional framework to highlight spaces and give the user a unique spatial perception. Light within nature signifies the exclusive characteristic of a space. Light associated to nature can demonstrate a sense of depth and tranquility to an environment, as well as enhance the depth of field and spatial levels of the view.

Peter Zumthor

Peter Zumthor is acknowledged for his ability to create emotional spaces to enhance sensory experiences with light. He believes that light, materials, and atmosphere play an important role in architecture. Zumthor's design approach for emotional space is beyond tangible built form; instead, light, shadow, material, and space are manipulated so that the user can experience the architecture. (Wagner M.-C. , *Peter Zumthor: Different Kinds of Silence*, 2015) Zumthor's philosophy of light is all about experience and creating atmosphere by constructing presence in architecture. His personal and emotional approach to architecture is revealed through the pure presence of the users' first impression. (The David Azrieli School of Architecture T. A., 2013) Pure presence in Zumthor's design philosophy refers to no background, no meaning and no history, similar to the direct theory of Visual Perception in architecture. Visual perception directly derives from stimuli based on present information, with no reference to previous knowledge and experience. (Monice, 2004) Light is one of the most powerful elements within his work to constitute presence in architecture.

Many of Zumthor's projects, such as Thermal Vals and Bruder

Figure 33: Image of Peter Zumthor. (Cabral, 2014)

Klaus Field Chapel, represent his interest in designing material-led projects. (Zumthor P. , 2014) Articulation of light, shadow, materials and atmosphere allow Zumthor to intensify emotion through a series of sensory details into a larger setting and provoke human perception. Human experience is prioritized in his design with the use of light.

The Bruder Klaus Chapel is a significant project where he uses light to enhance experience and create emotion. What is interesting about this project is the way that light enters a 12 meters-high space through the tapered triangular opening, manipulated to resemble a cave-like environment. (Zumthor P. , 2014) The rough texture of the concrete surface imitates a cave atmosphere in the way that it controls light. Sunlight and skylight can only penetrate through the opening, creating a unique emotional space to experience during different times of the day. The sensual feeling that God is above and watching is manipulated through light, shadow, and materials that control and seduce visitors when they pray inside the chapel. In this chapel, intensification of emotion with the feeling of sanctuary is expressed through design features such as the reflection of light off the materials and the benefit of using natural light over artificial light.

In Zumthor's book, *Thinking Architecture*, he expounds his belief that the arrangement of space leads and seduces users to follow the intended sequence of space designed by Zumthor. These sequences and arrangements of space intensify emotions to create sensual experiences. Light is commonly used in his work to magnify human

Figure 34: Interior of The Bruder Klaus Chapel. (Ludwig, 2011)

perception of spaces through the expression of texture and material. The presence of light articulates materiality and brings cultural connection and knowledge, which he calls memories. (Zumthor P. , 2010) Zumthor's expresses his philosophy of light as a design feature for creating emotional space through human experience.

In his other book, *Atmosphere*, the emotional response from music is used as a metaphor to express the senses experienced through architecture. The book describes the manipulation of temperature, surrounding objects, sound, level of intimacy, tension between interior and exterior, organization of space and, most importantly, the light on things, as relevant design aspects to construct an effective and suitable atmosphere. (Zumthor P. , 2006) Zumthor elaborates the important aspects from sensory design and visual perception into a detailed exploration based on his research, studies, and experiments. The atmosphere theory and philosophy that he states in this book comes from his many years of practical experiences and architectural works. (Wagner M.-C. , *Peter Zumthor: Different Kinds of Silence*, 2015)

FINDINGS AND APPLICATIONS:

I find Zumthor's philosophy of light a very interesting approach. His work presents a deep understanding of the theory of sensory design and visual perception expression through the use of light, shadow and materials. In this thesis, I would like to express light as a design and strategy tool to motivate and control users' perception of a space or place to build up good design knowledge in thinking and planning. Zumthor's insights about atmosphere do not simply offer knowledge about light. They also support this thesis' goal to define philosophy and to consider light as one of the important factors that make up an effective emotional space. The physical and psychological measurement of environments with the use of light may greatly impact the emotional behavior of a user. Not unlike casino and shopping mall designs, which incorporate expensive designs to trap and convince gamblers and shoppers stay in the casino or malls as

long as possible, even at the cost of physical and economic exhaustion, I want to use light to make the space comfortable and inviting. (Mayer & Johnson) Daylight is a source free of charge provided from nature; the expression of light as a design and strategy tool may allow architects to create highly personalized spaces for the user to experience the design's intent. Zumthor's insights inspired my thinking in creating an environment that can attract and persuade users to stay, similar to what the casino and shopping mall designs are successful in doing. I believe the quality of architectural industry can be enhanced by the use of light as a fundamental design criterion.

Refer to Chapter 6, page 193 to 198, articulation of light, shadow, materials and atmosphere intensify emotion through a sensory experience. The glowing concave vestibule that is located at the entrance of the spa massage room creates a unique emotional experience that seduces users into walk in the room since people are attracted to move toward light. The change with light, materials, direction, and height enrich the user's experience as they transition from one space to another. Once the user enters the massage room, the interesting diffuse dappled light caused by the vegetation, filtered a soft lighting conditions, along with the wooden furnishes and finishes of the space, evoke the feeling of being under a tree. The changes in lighting conditions from the spa corridor to the massage room intensify emotion through the transition of spaces. The atmosphere within the massage room convinces user to stay in the space because of the emotional impressions caused by the lighting condition. Similar to casino and shopping mall designs, the massage room is a highly personalized space that is intended for the user to experience the design's intent function, to receive a massage. The sensory experience created by the light attracts and persuades users to stay. Light has the ability to greatly affect the users' total experience. Zumthor's philosophy and theory of light inspired my desire to explore how to intensify emotion through different lighting situations and conditions. Materiality become a supportive element in the deployment of light as the texture of a material that has the ability to intensify a unique and memorable architectural experience.

3.3 | Architects and Light Techniques

Different architecture requires different lighting techniques to fulfill its design intention. What lighting techniques can be used in architecture to highlight and enhance the space in order to fulfill the architect's language of light? With this knowledge at hand, the light techniques can formulate an exceptional knowledge that can be applied to other designs. This section will look into the architectural and lighting techniques used by architects and the effectiveness of each technique so that this knowledge can benefit other architectural design. Lighting techniques can be used as valuable tools to achieve desired lighting situations when designing spaces with light.

Le Corbusier + Thick Embrasures

Le Corbusier designed the Chapel of Notre Dame Du Haut located facing East in Ronchamp at France. The morning sun enters the building from the east wall and creates a contrast and glare effect interiorly. The glare does not create discomfort to human eyes, but instead, the sunlight scatters across the small windows to create an illusion of the morning star. Meanwhile, the south wall is composed of thick embrasures in various sizes. The thick, narrow and shaped openings control the light penetration inwardly similar to lighting containers. This architectural technique's purpose is to reduce the high summer-angled sun and low-angled winter sun penetrating through openings. (Pauly, 1997, pp. 70-76)

The small towers of the Chapels are oriented to different directions to capture the south and north light in order to penetrate down to the altar space below. One tower facing east is painted red to capture warm light from raising the sun. Another two towers facing west are painted in violet to catch the afternoon sun. The facing north façade of the Chapel has a large opening to capture constant light during the day. There is no artificial light used in this chapel and rarely any usage of candles during the day. The lighting design and effect allow for a sufficient amount of light for people to read. (Pauly, 1997, pp. 70-76)

Figure 35: Diagram of Thick Embrasures. (sunjongsong01, 2013)

Steven Holl + Lungs and Painted Surfaces

The Simmons Hall is a dormitory for the Massachusetts Institute of Technology designed by Steven Holl. The design concept of the building was to function as a sponge where light soaks up through the series of large openings and filters through the spaces. Steven Holl's original concept was to create these building lungs that would light up the spaces with daylight while air ventilates through the lung spaces. (Gannon & Denison, 2004)

Due to regulation of fire safety issues, the concept of lung was not acceptable in the built form, but the main idea remained. Instead of a large lung, the lungs are sized smaller throughout the building; gridded openings were created on the exterior facades. (Fisher, 2002) (Gannon & Denison, 2004)

Another technique that Steven Holl often used in his architecture is painting brilliant colours on side surfaces, such as walls, openings, floors, etc. The colourful painted surfaces will not only create a dynamic aesthetic effect exterior, but also create a mood when the colour and reflection of materials on a wall or floor integrate with light. (Gannon & Denison, 2004)

Figure 36: The Simmons Hall.
(Harting, n.d.)

Alvar Aalto + Skylights

Daylight and skylight play a major role in Alvar Aalto's architecture. Skylight is one of the major techniques that Alvar Aalto uses to manipulate daylight in his architecture. He developed techniques to provide daylight in an indoor environment which were constantly refined and reused in his works, such as roof lighting, clerestories, screened windows and lighting scoops. (Paranandi, 1991)

Most of Alvar Aalto's architecture works are located in Finland. The climatic condition there is overcast with diffuse lighting; the sun at its zenith is three times as bright as on the horizon. Therefore, the roof windows are able to observe brighter portions of the sky dome. (Paranandi, 1991) Aalto's architecture allows him to develop skylight types to be used in different lighting situations.

Figure 37: National Pensions Building by Alvar Aalto in Helsinki, Finland.(Barnes,2012)

3.4 | Precedents and Light Study

Different programs and functions require different lighting conditions; the following precedents are analyzed to define architecture from a lighting perspective. Light study refers to the thoughtful examination of architecture based on light-related aspects such as orientations, climatic conditions, selection of materials, function and program, lighting conditions, and light techniques. It is important to conduct in-depth analysis of light-related aspects in order to understand precedent uses of light and compile this valuable information into architectural design and strategies tools. The analysis and study of light is very informative and can provide the knowledge necessary for a decisive design approach. light

LIGHT STUDY ASPECTS:

- + Understand the geographic location, weather conditions (latitude / daylight, etc...)
 - + How light hits/emits the surfaces (materials, etc...)
- 1** **ORIENTATION** of Building & Surface respect to Light
 - 2** What **TYPE OF LIGHT** enter into the space? (diffuse, indirect, direct, reflected, etc.)
 - 3** **SIZES** of the space(s)
 - 4** **MATERIAL** used (construction / built methods)

Figure 38: Sundial (Strauß, 2016)

Nariwa Art Museum

ABOUT THE BUILDING

Architect: Tadao Ando
 Location: Nariwa, Okayama, Japan
 Opened: 1994
 Building Type: Art Museum

Figure 39: Site Plan. By author and Steven Geoeman. (Goeman, 2012)

CONTROLLING LIGHT

The Nariwa Art Museum designed by Tadao Ando was constructed to serve as an exhibition, art and cultural space for Okayama, western Japan. Nariwa Art Museum is located on an old residential site that is surrounded by a stone wall and limited on the south by a steep hill. There is a concrete wall wrapping around the concrete building. Inside the building, there are many

different museum spaces. The concrete wall acts as a barrier to avoid sunlight as well as to create a private space for users inside. A large artificial rainwater collection pond of water is situated between the slanted plane and the building itself. (Jodidio, 2004)

Nariwa Art Museum has a separate entrance and exit. Ando created a forced journey to experience

Figure 40: South East Perspective. (Fujimoto, 2014)

ORIENTATION

Figure 43: Sun Path Diagram. By author.

Figure 42: South facade receive sunlight all the time. By author.

light at different spaces through the transition of spaces and the act of entering in and out of gallery spaces. Visitors enter the building through an old stone wall that reminds them of the site's past, then enter a long ramp pathway that wraps around the building to separate visitor from the street and its occupants. Once the visitor enters the museum, there are other paths that will lead him or her outdoors to observe different museum functional spaces. (Jodidio, 2004)

The overall material selection of the building is composed of vertical concrete slabs with large-scale glass cladding. The design, orientation, material and program arrangement fills the museum with diffuse light and offers magnificent views of the surrounding landscape.

(1) Entrance	(7) Lecture Room
(2) Tea room	(8) Cashier
(3) Exhibition	(9) Outdoor Roof Path
(4) Outdoor Patio/
Seating Area	(10) Water Feature
(5) Book / Gift Shop	
(6) Lobby	

Figure 41: Floor Plans. By author and Steven Geoman. (Goeman, 2012)

CLIMATIC STUDY

Okayama, Japan has a mild climate in comparison to most of Japan. The city is ranked as the second driest and the fourth sunniest city in the Chugoku region. The overall climate is warm with low rainfall. Okayama is, therefore, often called “The Sunny Country”. (Weather Spark, 2016)

Figure 44: Climatic Study Data at Okayama, Japan. (Weather Spark, 2016).

BARRIER

Solid concrete barrier walls are designed to avoid direct sunlight and glare from east, south, west.

SECTION A-A

SECTION B-B

Figure 47: Building Sections. By author and Steven Geoman.

Figure 45: Sun Path Site Plan.
By author and Steven Geoman.
(Goeman, 2012)

Figure 46: Sun movement Diagram of the Outdoor Patio/ Seating Area. By author.

TYPE OF LIGHT & SIZES

- (1) OUTDOOR PATIO
- (2) EXHIBITION SPACE

Figure 48: Enlarged Floor Plans. By author and Steven Geoeman.

Figure 49: Exhibition space and outdoor patio photographs. By author.

Figure 50: Analytical Sketches of Lighting Conditions. By author.

MATERIAL

SURFACES (MATERIALS)

LIGHT COLOR = BRIGHTER SPACE + REFLECT
 DARK COLOR = DARKER SPACE + ABSORB

Figure 52: Light and Material Relations. By author.

Figure 51: Series of interior views. By author.

CONCRETE

Ando employs concrete as the fundamental material for his architecture. Ando's intention of using concrete is quite different from others, as he does not consider concrete's solidity and weight. Instead, he treats concrete as a cool and inorganic material with an obscured background of strength. The smooth surface and sharp edges of concrete reflect light with its homogeneous surfaces. Ando employs concrete to establish the single intent of the space, which is not to express the nature of the material itself. When light is emitted onto concrete, a cool and peaceful space enclosed by a clearly finished architectural element is liberated, becoming a soft and transparent area transcending materials instead.

(Murray, 1991, pp. 52-61)

Within his designs, Ando aims to minimize the use of materials. His simple expression of materials is intended to eliminate all nonessentials and to preserve the space so that visitors can concentrate on activities and view the artwork without distraction. The limitation of style to the utmost can produce a maximum effect of balance. (Murray, 1991, pp. 52-61) In order to achieve this effect, the simple expression allows the interplay of light and dark to reveal forms. Ando brings richness back into architectural space with concrete and light.

Nelson Atkins Museum of Art

ABOUT THE BUILDING

Architect: Steven Holl
 Location: Kansas City, MO. USA,
 Opened: 2007
 Building Type: Art Museum

Figure 54: Site Plan. By author.

MOLDS ARCHITECTURE THROUGH LIGHT

The Bloch Building is a new expansion of the Nelson Atkins Museum of Art, designed by Steven Holl. The addition fuses architecture with landscape by crafting an interesting experience for visitors through each individual's movement through space and time. The Bloch Building extends along the eastern edge of the site with the five glass "lenses" acting as the new formation of spaces and angles of vision through the adjacent sculpture park. (Kipnis & Holl, 2007)

As visitors move through the lenses, they will experience a flow between light, art, architecture

and landscape. Visitors observe different views and moods while transiting from one level to another and from inside to outside. There is a dynamic flow of movement connecting the lenses together with a collection of different lightings. (Kipnis & Holl, 2007)

The addition did not create obstructions, but instead developed an interesting relationship to the existing context. The primary façade system of the building is constructed with channel glass. During the day, indirect sunlight enters the building, providing the perfect museum quality of

Figure 53: South East Perspective (Front Entrance Night View). (Emesi, n.d.)

ORIENTATION

Figure 55: Summer Sun and Winter Sun. By author.

Figure 56: Sun Path Diagram. By author.

filtered light. At night time, interior light illuminates the exterior façade of the building into glowing blocks. The glowing blocks offer a new paradigm to attract visitors to the activities and events hosted in the museum. Steven Holl created a dynamic expression that molds architecture through light. (Kipnis & Holl, 2007)

WEST ELEVATION

EAST ELEVATION

0 50 100 200

- (1) Entry Plaza
- (2) Reflecting Pool
- (3) Lens 1 Lobby
- (4) Lens 2
- (5) Lens 3
- (6) Lens 4
- (7) Lens 5
- (8) Original Museum
- (9) Sculpture Park Lawn
- (10) Garage Below
- (11) Garage Entrance

SITE PLAN

Figure 57: Elevations and Site plan. (ArchDaily, 2008)

CLIMATIC STUDY

Kinsas City, MO has a humid continental climate with hot summer and no dry season. The average temperature is 11.9°C. The average annual rainfall is 867mm. (Weather Spark, 2016)

Figure 58: Climatic Study Data at Kansas City, MO, USA. (Weather Spark, 2016)

(1) Library	(7) Photography	(13) Multipurpose Room
(2) Upper Lobby	(8) African Art	(14) Executive Offices
(3) Event Room	(9) Featured Exhibitions	(15) Auditorium
(4) Museum Store	(10) Noguchi Court	(16) Cafe
(5) Lower Lobby	(11) Art Service Level	
(6) Contemporary Art	(12) Parking	

SECOND FLOOR PLAN

FIRST FLOOR PLAN

GROUND FLOOR PLAN

Figure 59: Building Plans and Building Sections. (ArchDaily, 2008)

TYPE OF LIGHT & SIZES

3 Types of light gathering

- (1) Reflect indirect
- (2) Direct
- (3) Through water lense

Figure 62: The T-Shaped thick walls in galleries contains mechanical, electrical and structural elements. (Griffin, 2008)

Figure 60: Analytical sketch - types of light. By author.

Figure 61: Wall Section. (ArchDaily, 2008)

MATERIAL

Glass + White Finish

Figure 63: Series of exterior and interior views during day and night. (Ryan, 2012)

CHANNEL GLASS

Steven Holl employs channel glass on the exterior façade for the newly added Bloch Building of the Nelson Atkin Museum of Art. Because Holl intended to keep the windows seamless, channel glass was chosen. Channel Glass is a translucent u-shaped cast glass that is used to create frameless glass wall systems. It is an ideal daylighting material for the gallery spaces because direct sunlight can be transmitted into the space as diffused light. A fluorescent tube system is also mounted in the cavity of the channel glass

to transform the building into glowing blocks at night. (Kipnis & Holl, 2007)

There is a dramatic interplay of light on the channel glass wall as visitors move between lenses from the exterior to the interior of the building. At different times of the day, the channel glass wall will have different effects. In addition to this, the channel glass emits an opalescent sheen when sunlight is emitted on the glass surface.

Honpuku-ji Water Temple

ABOUT THE BUILDING

Architect: Tadao Ando
Location: Ninnaji Shingon, Japan
Opened: 1991
Building Type: Buddhist Temple

Figure 65: Site Plan. By author.

FILTERING LIGHT

The Honpuku-ji Water Temple was designed by Tadao Ando. The building is situated on a slope. The entrance is located at the top of the hill among bamboo forest, mountains and fields of rice. The Honpuku-ji Water Temple is a Buddhist temple constructed with concrete and wood. Ando designed a sensory journey to represent the transformation in the tradition of building temples in Japan. Visitors must pass through a sequence of space before arriving to the stairway leading

to the underground temple beneath the large oval shape lotus pond. The concrete stairway intersects at the oval pond into two symmetrical halves, transiting with the lighting condition of daylight to darkness. (Jodidio, 2004) Surprisingly, the overall underground interior spaces are filled with colour. The red-orange light created by the reflection of the material fills the interior circular space with colour. Ando invites daylight onto a platform – a garden located at

Figure 64: Honpuku-ji Water Temple. (Sierra, 2015)

ORIENTATION

Figure 68: Summer Sun and Winter Sun. By author.

Figure 66: Sun Path Diagram. By author.

the bottom of the slope to reflect and filter light horizontally through a layer of lattice screen. (Jodidio, 2004)

ELEVATION

SITE PLAN

Figure 67: Sections (Kenchikuu, 2008) and Site plan (Sierra, 2015)

CLIMATIC STUDY

Awaji, Izumisano, Japan has a warm humid temperate climate with hot summer and no dry season. The average temperature is 29°C. It occasionally snows in winter. (Weather Spark, 2016)

Figure 69: Climatic Study Data at Ninnaji Shingon, Japan. (Weather Spark, 2016)

TYPE OF LIGHT & SIZES

3 Types of light gathering

- (1) Direct
- (2) Diffused
- (3) Moderate
- (4) Dimmed

Figure 72: Analytical sketch - types of light. By author.

- (1) Light Court
- (2) Inner Sanctum
- (3) Outer Chamber
- (4) Entrance
- (5) Corridor
- (6) Storage
- (7) Sutras Chamber
- (8) Meeting Room

Figure 70: Building Plans and Building Sections (Kenchikuu, 2008)

Figure 71: Progression of Light Diagram for Water Temple. By author.

Therme Vals

ABOUT THE BUILDING

Architect: Peter Zumthor
 Location: Vals, Switzerland
 Opened: 1996
 Building Type: Spa

Figure 74: Site Plan. By author

ENHANCE A SENSORY EXPERIENCE

The Therme Val is a spa that is situated on the slope of a valley that overlooks the only thermal springs in the Graubünden canton in Switzerland. Designed by Peter Zumthor, the spa building is surrounded by five hotels and a traditional small village. The building lies below a grass roof structure that is buried into the hillside of the site, forming a cave design structure. There is also an underground passage that connects the spa to all the hotels. (Wagner M.-C. , *Peter Zumthor:*

Different Kinds of Silence, 2015)

Even though the indoor baths are enclosed in dark spaces, Zumthor created a unique lighting treatment on the walls, ceiling and underwater which makes the space surprisingly bright. Zumthor invited natural light into the underground space between the stone roof. He did this with the use of thin lines of openings called fissure skylights. Natural light enters through the fissure skylights into the private space and fills it with

PETER ZUMTHOR
Therme Vals

Figure 73: Therme Vals (doronhu, 2015)

ORIENTATION

Figure 77: Summer Sun and Winter Sun. By author

Figure 75: Sun Path Diagram. By author

lighting that makes it reminiscent of a sanctuary. The building design intent is to work with darkness, light, and the light's reflection on the water. Thermal Vals Spa exemplifies how light can give a space character by enhancing the sensory experience for users. (Wagner M.-C. , *Peter Zumthor: Different Kinds of Silence*, 2015)

PERSPECTIVE SECTION

SITE PLAN

Figure 76: Site plan and Perspective section (Du, Qian, & Ng, 2012-2013)

CLIMATIC STUDY

Vals, Switzerland has a cool temperate climate with extremely dry warm summer. It tends to be colder than neighbor countries. Vals is located in the Penninicum zone of the Alps. The temperature will not exceed 30°C during summer time and it receives heavy snowfall in winter. (Weather Spark, 2016)

Figure 78: Climatic Study Data at Vals, Switzerland (Weather Spark, 2016)

(1) Point of access/ exit	(7) Washrooms	(13) Sound Bath	(19) Flower bath
(2) Cleaner's storeroom	(8) Turkish showers	(14) Fire Bath	(20) Rest Space
(3) Make-up room	(9) Indoor bath	(15) Cold Bath	(21) Outdoor shower stone
(4) Drinking fountains	(10) Outdoor baths	(16) Shower stone	(22) Massage
(5) Change room	(11) Stone island	(17) Drinking stone	(23) Disable facilities
(6) Showers	(12) Rock terrace	(18) Sounding stone	(24) Bath attendants

Figure 79: Building Plans and Building Sections. (Du, Qian, & Ng, 2012-2013)

TYPE OF LIGHT & SIZES

3 Types of light gathering

- (1) Direct
- (2) Diffused
- (3) Reflected on water
- (4) Artificial

LIGHT SLITS: The light slits from the fissures created a sense of fluidity to the enclosed indoor space. The contrast between the darkness of the wall and the wall washed by top light generates an interesting light path effect. (Du, Qian, & Ng, 2012-2013)

ARTIFICIAL LIGHT: Sixteen spotlights are situated above the indoor pool area. The skylights for the spotlights are a blue colour to invite natural sunlight during the day in the indoor pool area. The blue-coloured skylight also softens sunlight to create an interesting atmosphere. (Du, Qian, & Ng, 2012-2013)

Figure 80: Analytical sketches - type of light . By author.

Figure 81: Effects of Skylight and Fissures Diagram. By author.

MATERIAL

Figure 82: Stone Strata Interior Finishes Diagram. By author.

STONE STRATA

The main building of Therme Vals Spa was built with natural stone strata - Valser Quarzite slabs. The stone is layered throughout the building, giving texture to the floors, stairs and walls. It is in a deep and graphite colour. Peter Zumthor employed stone as the main material because of its thermal capacity. The thermal capacity of the stone is much lower than the water. When the stone faces the sun, its temperature rises quickly, and the heat gained will transfer to the water. (Du, Qian, & Ng, 2012-2013)

Switzerland is a country located at the higher geographic latitude. During winter, the solar altitude angle is extremely low which lead to difficulties with warming the water. Therefore, it

is a necessity to maximize the exposed surface area in order to receive more direct sun light to generate heating with the advantage of solar latitude.

Zumthor interpreted bathing with the used of stone and water. Stone and water interact with each other, creating an unexpected atmosphere.

Figure 83: Reflective Pool Day Perspective. By author

How light influences our perception of space

LIGHT SHAPES SPACE

4

LIGHT & ITS EFFECTS

4.1 | Background and Relations

All light sources have their own qualities. Some of these are dependent on the light source itself, while others are influenced by external factors, such as geographic location, weather, and existing environment.

What is Daylight?

Daylight is the combination of direct and indirect light beams from the sun during the daytime. (Pedersen, 2009)

Direct Sunlight Light beams from the sun that are strongly directional and will cast a sharp shadow. (Pedersen, 2009)

Diffuse Sunlight Indirect light from the sun which is constantly changing, depending on the time of day, the time of year, the weather conditions, etc. (Pedersen, 2009)

The three measurable basic lighting terms are:

Luminous Intensity brightness of a source and lighting conditions (Pedersen, 2009)

Luminous Flux light is emitted from a source and strikes the surface (e.g. Materials), it's the light output from the source (Pedersen, 2009)

Illumination application of light to achieve aesthetic and practical effect, also known as light level (Pedersen, 2009)

The natural lighting or artificial lighting quality can be defined in...

Tone Tone is defined by the colour temperature of a light source. It is interpreted by how light and dark a colour is, instead of by just interpreting its actual colour or hue. Every colour generates a variation of tones. The colour of natural light is a part of an electromagnetic spectrum of visible light. The colour's temperature varies from cool (bluish white) to warm (yellowish white through red). The "white" light perceived by human eyes is generated from the mixture of spectrum colours made up by light, but all light sources vary in colour. (Christman , 1971)

Intensity is the brightness of light that can be adjusted to comply with the quality of

the atmosphere in a space. Extremely bright light is not recommended for application on design; however, if it is used, it should be controllable. A space becomes interesting when the light there is adapted and adjusted to create an atmospheric environment. (Christman , 1971)

Natural Effects of light

Outdoor atmosphere is produced by natural conditions such as weather conditions, sun angle, sun path, climatic conditions, etc. The quality of sunlight at noon in the northern hemisphere is harsh and bright with sharp shadows. Contrarily, on a rainy day in the same geographic location, the light becomes muted and soft with dim shadows. The whole atmosphere at the same location can feel very different, diffused and vague as a result of differing weather conditions. Human emotional behavior is strongly influenced by these conditions. The feeling of presences and absences of light is dependent on the quality of light about the place or scene.

Our fundamental knowledge and study of light and mood is derived from the impressionist painters of the Renaissance period. Light was represented with pigment, by capturing atmosphere through colour. Many painters during the Renaissance used light and shadows in their paintings to create drama, perspective and timing in their art. Important information about colour and mood can be gained through observing their paintings. (Varriano, 2010)

Figure 84: The Calling of St Matthew. Caravaggio used light and shadow to create drama. (Caravaggio, 1599-1600)

Daylight Concepts

Daylight does not equal sunlight. Daylighting in design is about bringing natural light into a space. However, many day-lit spaces do not want or require direct sunlight and daylight concepts often favor diffused and/or indirect lighting. In order for all exposures of the building to receive diffused light rather than direct sunlight, appropriate use of shading devices is required to block direct sun penetration. Daylighting is environmentally advantageous because it reduces the use of artificial

lighting. Additionally, heat is generated from light, reducing both the energy needed to power artificial lights and the heating needed for the space at the same time. Daylight is also advantageous because it improves worker productivity and is associated with higher achievement in students. (Pedersen, CDID550 Lecture 2 [Powerpoint Presentation Slides], 2009) (Guzows, 1999)

The Relationship between Architecture “FORM” and “LIGHT”

Light plays a significant role in the design of a visual setting. Lighting visualizes architecture, objects and people. Light influences our perception and behavioral responses to a space. The origin of light is natural light called “daylight”. Light is an important architectural material and tool because it is able to bring architecture to life by revealing its forms, spaces and meanings. (Pedersen, CDID550 Lecture 2 [Powerpoint Presentation Slides], 2009) (Guzows, 1999)

Important principles of light include...

- Light is sharp and diffuse
- Light reflects and refracts
- Light creates shadows
- Light changes

4.2 | Light and Climate

Designing for climate involves taking advantage of that climate and making use of light to create a comfortable environment. In order to obtain an energy-efficient heating and cooling system, it is important to design a building that allows the user to remain thermally comfortable with minimal heating and cooling support. Statistics indicate that 40% of the energy expended by households is used to attain thermal comfort through heating and cooling. This percentage of energy consumption can be reduced through passive design for climate. As energy costs are increasing rapidly each year, designing for climate is a valuable payback for reducing this cost. (Reardon, *Design for Climate*, 2016)

The key design objective for this thesis is to create thermally comfort environments with light while also taking design consideration for climate into account. In order to design for light and climate, the following must be considered: orientation, windows and shadings, insulation, climatic conditions and construction techniques.

Orientation

The orientation of a building affects its energy efficiency and thermal comfort. The sun path varies according to season, time and day. The optimal orientation for a building is one that takes into account the effects of sunlight and winds and reduces the need for heating and cooling. (McGee C. , 2016) Considering the effects of the sun is important with relation to passive heating and cooling is important to building orientation. By keeping direct summer sun out of a space and inviting winter sun in, orientation becomes the fundamental principle when designing with light. The sun is a source of cost-free heat and making the best use of it is essential to efficient design with light. (U.S. DOC, 2011) Figure 83 shows the ideal site orientation for good passive sun control and to better capture cooling breezes in most climates. (Reardon, Mosher, & Clarke, Orientation, 2013)

For example, in hot humid climates and hot dry climates, a basic

Figure 85: The ideal and good site orientations based on passive design principle for most climates. (Reardon, Mosher, & Clarke, 2013)

consideration in design is the exclusion of direct sunlight. This can be achieved through the use of neighboring trees and shadows as no heat is needed for the winter in these areas. However, in climatic conditions that require heating and cooling, there is a need to achieve a balance between solar access and cooling breezes. (Reardon, Mosher, & Clarke, Orientation, 2013) (U.S. DOC, 2011)

Figure 84 illustrates an experiment that investigates how the sun movement changes the atmosphere of a space based on its geographical location, season and time. The images indicate changes of light within the interior space during different seasons of year and time of day in the northern hemisphere. The orientation of scene is west-facing and there is a large side window on the left of the scene for daylight to enter the space. The overall experiment indicates the differences in light over time – morning sun, noon sun, evening sun, winter sun and summer sun.

Sun movement in summer is angled high while that of winter is angled low. North orientation is the ideal location to gain free heat during winter because a low sun angle allows more solar radiation to enter the north facades during winter as compared to the summer. The high angle of the summer sun generates shades on the north facades and the ground, which may minimize heat gain. Optimizing northern exposure and maximizing southern exposure allows for the most daylight access and for the best control of heat gain in summer. Good exposure to the sun and wind are a desirable design feature for climate and light. Unlike sunlight, breezes can be diverted. Plants, windows and fences may be used to deflect breezes within the environment. Consideration of sunlight and breeze orientation is important to my study of light as I seek ways to use them to their greatest advantage in architecture. (McGee C., 2013) (Ander, 2003)

Figure 86: Experimental renderings of sun movement during different seasons of year and time of day in the northern hemisphere. (By author)

Sky Conditions

Sky conditions cause variation in the nature and quantity of light entering a building. There are three types of sky conditions to consider when evaluating illumination levels within a space. (Pedersen, CDID550_Lecture1 [Power Point Slides], 2009) (Ander, 2003)

Overcast

An overcast sky is the most uniform type of sky condition. When the sky is overcast, almost 80% of its dome is obscured by clouds. Compared to other sky conditions, overcast has a general luminance distribution which is approximately three times brighter at the zenith than at the horizon. It provides diffused light from the clouds and reflected light from the ground. (Pedersen, CDID550_Lecture1 [Power Point Slides], 2009) (Ander, 2003)

Clear

A clear sky is less bright than an overcast sky and is brighter at the horizon than at the zenith.

Approximately 30% of the sky dome is obscured by clouds. The overall luminance distribution is constant apart from the zone near the sun due to the movement of the sun. The direct sun under clear sky conditions is 8-10 times brighter than diffuse blue sky. A clear sky is 3 times as bright at the horizon because it is directly above and offers direct sunlight as well as diffuse sky light, as well as reflected light from ground. (Pedersen, CDID550_Lecture1 [Power Point Slides], 2009) (Ander, 2003)

Cloudy

A cloudy sky has a cloud cover that may range from fairly dense to very light. About 30%-80% of the sky dome is obscured by clouds. The luminance distribution varies from one district to another as the sky tends to transform quickly. (Pedersen, CDID550_Lecture1 [Power Point Slides], 2009) (Ander, 2003)

Figure 87: Sky Conditions. By author.

Partly Cloudy

A partly cloudy sky condition is a mixture of cloudy and clear skies. Other than light, in this sky condition, clouds are very bright secondary sources. A partly cloudy sky offers diffuse light from the ground and direct light from the sun. (Pedersen, CDID550_Lecture1 [Power Point Slides], 2009) (Ander, 2003)

Figure 88: Light as Material Diagram. By author.

4.3 | Light as Material

Different materials render different qualities in architecture. Light is an influential and valuable architectural element. Lighting fixtures are important tools for lighting design. According to the architect's intention, each fixture is placed and selected based on their function. For example, lamps, spotlights or chandeliers are lighting fixtures that identify a space. One goal of lighting is to allow the right amount of light to float within a space comfortably. The intended activity and function of a space should be the basis of any light design. (Major, Speirs, & Tischhauser) It is important to define all programs and activities that may happen within the space.

Light should be considered as a material and not solely as a function, although it is necessary to perform a function. Construction materials such as glass, bricks and steel should be sculpted with light into a building with the same thoughtfulness that went into choosing materials.

Light Creates Shadows

Light can be sharp and diffused. During a bright sunny day, light is sharp. When clouds flow into the sky, however, light is diffused. Light does not always reveal the refraction and reflection of the existing environment. (Gherri B. , 2015)

Diffused leaf shadow is an interesting medium when designing light as material. When direct sunlight strikes the leaf and casts shadows onto the ground and planes, these shadows are sharper for leaves that are closer to the ground and more diffuse when they are further from the ground. The shadows cast by the leaves suggest depth as light reflects and refracts. (Gherri B. , 2015)

Light reflects and refracts on the surface of water in a way that is similar to how diffused shadows are cast by leaves: light bounds off and is absorbed on the surface. The reflection and refraction cast on the ground or plane suggests depth as well as a different atmosphere. (Gherri B. , 2015)

Figure 89: Diffuse Leaf Shadows at Lisbon World Exposition '98 in Summer 2015. By author.

Figure 90: Water refraction & reflection at Lisbon World Exposition '98 in Summer 2015. By author.

Shading

Figure 92: Deciduous Trees as Shading Devices Diagram. By author.

Figure 91: Density of trees. Intensity of light and shadows. Illustration by Rodica Prato. (Prato, n.d.)

Shading techniques can be adapted from such shading devices as trees and vegetation. Shading openings of a building is the best way to reduce unwanted heat and glare into the space. Other than built shading devices, plants are interesting shading methods. Plants may be used to shade different environments. For instance, deciduous trees and vines are used to shade buildings during the summer with their leaves while bare branches invite sunlight during winter. (McGee C. , 2013) (Gherri B. , 2015)

The amount of light and shade that enters a space is dependent on the density of trees. Shade is not simply shade but involves different shading conditions. These vary from full sun to light shade, partial shade, full shade and deep shade. Plants are shaded based on the day, time, season, age of trees, density of leafs and canopy configuration. (McGee C. , 2013) (Gherri B. , 2015)

Figure 93: LiTraCon (Thomas, 2011)

Light and Building Materials

LiTraCon

LiTraCon is a light-transmitting material that contains a combination of optical fibre and fine concrete. LiTraCon can be prefabricated as building blocks and panels. The benefit of LiTraCon is that whereas it is

stronger than glass and translucent, it functions as concrete. LitraCon is an extremely expensive building material. (LiTraCon, 2014)

i.light

i.light is a precast light-transmitting concrete panel made by the Italcementi Group. Compared to LiTraCon, i.light is cost effective because the translucent concrete (i.light) is filled with multi-coloured resin rather than glass fiber. The manufacture production time is much faster than other translucent concrete materials— LiTraCon. i.light was used for the Italian Pavilion designed by architect Giampaolo Imbrighi at the Expo 2010 Shanghai, China. During Expo 2010, the contractor produced more than 200 panels per day. The project indicates that 20% natural light transmits through the panel, and significantly reduces the cost of artificial lighting. (Italcementi Group, 2014)

Figure 94: Italian Pavilion, Expo 2010 Shanghai, China. (ArcVision, 2010)

Opal Stones

Opal is a gemstone that was commonly used in expressways to diffract light at night. There is a variety of colours ranging from colourless, white, yellow, red, orange, green, brown, black and black. However, due to the glare that it produces, many countries have abandoned its use on expressways. (Tilley, 2010)

StarPath

StarPath, a spray-on coating that makes paths glow in the dark, is manufactured by Pro-teq. The coating may be applied to a wide range of materials. The aggregate material in StarPath absorbs and stores energy from UV light during the day; it releases it at night as it glows a soft blue in the dark. The material glows up to 16 hours after being charged with UV sunlight. It's been suggested that the material will last for a minimum of 20 years. It is recommended for use on driveways and playgrounds. (Pro-teq, 2014)

Figure 95:: StarPath. Night release energy and glow, Morning absorb UV energy. (Nelson, 2014)

4.4 | Illumination at Night

Humans are diurnal species with a multitude of five senses: sight, hearing, taste, smell, and touch. Out of these five senses, eyesight is the only sense that is restricted by the low lighting level at night. For more than 10 thousand years, humans had to limit their performance activities between evening and dawn. Light was introduced and used during nighttime about 1.5 million years ago. Fire was one of the important sources of light for humans in enclosed and outdoor spaces. Fire kept nocturnal animals away and allowed humans to continue their activities in the absence of natural light. Other than fire, moonlight was another outdoor light source that was habitually used to perform activities at night. (Rich & Longcore, 2006) Today, outdoor lighting conditions at night are mainly derived from streetlights. The misuse of artificial light at night leads to lighting pollution, especially in metropolitan cities such as Toronto, New York City, Tokyo, Shanghai and Hong Kong. (Schreuder & Narisada, Light Pollution Handbook, Volume 322, 2004)

Figure 96: Visions Diagram. By author.

Moonlight

Moonlight is the reflected light from the sun that strikes on the surfaces of the moon and becomes visible on earth. Historical references illustrate that many parts of the world perform nocturnal activities by moonlight. The intensity of moonlight depends on the lunar cycle. Moonlight is never considered daylight, but was used to illuminate the landscape at the phase of the full moon, when the moon is at its brightest. Figure 95 indicates the lunar illumination level that was created by C.D. "Kit Courter. (Moyer, 2013) (Westfall, 2000)

The level of luminance of the landscape varies depending on sky and weather conditions, for instance, the presence or absence of clouds and the phases of the moon. However, two major variables that affect the luminance of the landscape are the phases of the moon and the moon's level in the sky. (Moyer, 2013) (Westfall, 2000)

Similar to traffic signs, the moon's surface is retro-reflective, which means that it reflects light directly back in the direction it came from. The moon is brightest in the sky when it is full. There are 30% changes in the levels of illumination. The brightest illumination of the moon is 0.03fc when it is directly overhead. However, nowadays, most outdoor illumination surpasses the illumination level of the full moon. As recommended by IESNA, the illumination level of expressway is 0.9fc, which is six times brighter than a bright full moon. (Rich & Longcore, 2006) (Moyer, 2013) (Westfall, 2000)

Figure 97: Earth Surface Lunar illumination (C.D., 2003)

Low Light Level Conditions

The human visual system observes a scene differently by comparing the luminance of the objects and the illumination that is lighting up the scene. There are three types of human and animal vision that are dependent on various lighting conditions: Photopic (daytime) vision, scotopic (nighttime) vision and mesopic (twilight) vision. (Schreuder & Narisada, *Light Pollution Handbook*, Volume 322, 2004) (Schreuder, *Outdoor Lighting: Physics, Vision and Perception*, 2008)

Photopic vision, also known as daytime vision, is typified by excellent colour judgment that renders sharp details and detects motion. Meanwhile, scotopic vision, or nighttime vision, which is very different from photopic and mesopic, is the vision of eye under low lighting conditions. Scotopic vision is characterized by monochromatic colour perception, by the lack of ability to see sharp details, and by reduced depth perception. So, scotopic vision is a condition marked by poor visibility and lack of sensitivity. (Schreuder & Narisada, *Light Pollution Handbook*, Volume 322, 2004) (Schreuder, *Outdoor Lighting: Physics, Vision and Perception*, 2008)

According to a scientific report of Lighting Research Center (LRC), an illumination level of 0.015fc is sufficient for the human eye to perceive an overall scene with mesopic vision, also known as twilight vision, by using the rod and cone cells of a retina. Most outdoor illumination at night, including traffic lights, is in the mesopic light level range. Mesopic vision is a combination of both scotopic and photopic vision, and is characterized by visual acuity and reduced colour perception. (Schreuder & Narisada, *Light Pollution Handbook*, Volume 322, 2004) (Schreuder, *Outdoor Lighting: Physics, Vision and Perception*, 2008)

Figure 98: Ipomoea alba, also known as moonflower (Online Plant guide, 2013)

Moonlight Garden

In Victorian times, moonlight gardens were introduced. Moonlight garden were designed to come to life at dusk when flowers with vivid colors of red, orange, blue and purple, begin to fade. During this time, all features within the garden stay cool. (Earle, 2014)

Sissinghurst Castle, England

The garden at Sissinghurst is among the most famous moonlight gardens in the world. It is filled with flower colours - white, silver, pink and pale lavender, which would glow at nighttime. The series of green colours – gray-green, variegated green and white/silver plantation reflect the dim light of the moon and becomes visible during the nighttime when the white and cream flowers blossom, such as *Ipomoea alba*. (National Trust, 2014) (Labreche, 2012)

Ipomoea alba also known as moonflower, is a signature flower used for moonlight gardens. It is trumpet-shaped and blooms at dusk and closes at dawn – a species of night-blooming morning glory during the summer. As moonlight reflects on the surface of *Ipomoea alba*, it creates dramatic effects on the pale-green to silvery-gray foliage. Without artificial light, a powerful radiance exists in the dense flowerbeds when there is a full moon. (Earle, 2014)

Mehtab Bagh (moonlight garden)

In the 17th century in India, the Taj Mahal complex's moonlight garden also known as Mehtab Bagh, was designed for use during the nighttime. The garden was created as “a moonlight pleasure garden”. It is constructed with white plaster walkways, airy pavilions, an octagonal pool, fountains and a river planted with continuous flowerbeds. The landscape context created a cooling effect at night when views and moonlight were reflected in the river and pools. It was a popular place to view sunset, sunrise and moonlight. (Moynihan, 2001)

Figure 99: Mehtab Bagh (moonlight garden) (Derek810121, 2012)

Figure 100: (1) moonlight garden, (2) Terrace area: tomb, Mosque and Jawab, (3) Charbagh (gardens), (4) Gateway, attendant accommodations and other tombs, (5) Taj Ganji (bazaar) (Mcgrinnly, 2007)

Artificial Light and Kelvin Temperature

The colour of artificial light is measured with a numerical scale called Kelvin temperature. The Kelvin temperature of lamps come in three categories, warm, cool, neutral. The scale refers to how the light source appears visually. Warm sources are low colour temperatures of 3500K or less with a red-yellow appearance. Neutral sources are colour temperatures between 3500K to 4100K with a yellow appearance. Cool sources are colour temperatures above 5000K with high colour rendering capabilities. Cool sources are usually used in retail and commercial applications to stimulate sales, one example being full-spectrum lights. Colour temperatures of 5000K are known as pure white light. The theory is that the higher the colour temperature, the bluer they are in colour temperatures. (Thornley & Fitt, 2002)

Based on the *IESNA Lighting Design Handbook*, cool sources are usually used in offices, retail and factories to stimulate productivity and reduce errors by enabling better vision. Warm sources are earth toned, and provide feelings of comfort and warmth. (Light Energy Source, 2005) (Thornley & Fitt, 2002)

Figure 101: Colour Temperature Chart (Lighting 101, 2015)

4.5 | Light and Nature

Chinese Garden

The characteristics of a typical Chinese garden are ponds, rocks, trees, flowers, pavilions, moon gates and bridges. The Chinese garden is an imitation of the natural landscape within a built environment. It's a representation of the Buddhist's concept of nature and illustrates the harmony between nature and human. (Rinaldi, 2011)

Ponds - reflection of water

The pond is the fundamental element of a Chinese garden. Water within Chinese gardens is incorporated to cool down the large open space in hot weather. At the same time, water is a symbolic element in Chinese culture, literature and philosophy. From an architectural perspective, the reflection of water beautifies a scene by providing a full, mirror-like reflection of the sky and garden. The garden becomes more interesting with the presence of the ponds. The water not only functions as a decorative pond but also can hold goldfishes or heat sinks. Light reflection from water also functions as an element of beauty in Chinese gardens. (Yu, 2010)

Moon Gate

A moon gate is a circular entry gate as the main passage in a Chinese Garden for pedestrian crossing. The moon gate's function is to display the garden scene partially to visitors without letting them see the whole garden scene all at once. This broken view attracts visitors and makes them want to explore further. Through these openings, visitors can move from scene to scene along winding pathway and through enclosed structure as the garden reveals its story. The sudden appearance of different scenes is reminiscent of wandering through a natural landscape. Visitors will be both concealed and surprised. (Kesich, Jencks, & Hardle, 2003)

Light Shapes Space

DESIGN PROPOSAL

Figure 102: Tea Room Day Perspective. By author

How light influences our perception of space

LIGHT SHAPES SPACE

DESIGN PROPOSAL

5

5.1 | Daylight in Canada

The geographic location chosen for the exploration of light within architecture is Toronto, Canada. Toronto has a humid continental climate (SUMMER – hot & humid, AUTUMN – damp, WINTER – cold with snow, SPRING – warm and dry). These conditions may aid in the further development and addressing of lighting issues – daylight and artificial light. (Weather Spark, 20160) (Environmental Canada, 2014)

The United States and Canada are located in the North America in the northern hemisphere. (Figure 101) The intensity of the sun is high from June through September and is stronger in the south than in the the north. The available daylight in Canada has an average illumination at 46°, 7500lux, 15 times more than the illumination required for everyday tasks. Toronto, Ontario is located at 43°40' North Latitude and 79°24' West Longitude. The summer solar angle is 70°, and the winter solar angle is 22.8°. (U.S. DOC, 2011) (Environmental Canada, 2014)

Figure 103: Sun Path of Toronto (SunEarthTools.com, 2016)

Figure 104: Northern Hemisphere highlighter in yellow. Southern hemisphere highlighter in white. By author.

TEMPERATURE	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Year
Daily Average (°C)	8	-3.2	1.3	7.6	14.2	19.2	22.2	21.3	17	10.6	4.8	-0.9	9.2
Standard Deviation	2.7	2.5	2	1.5	1.9	1.4	1.2	1.2	1.1	1.5	1.4	2.5	0.8
Daily Maximum (°C)	-1.1	-0.2	4.6	11.3	18.5	23.5	26.4	25.3	20.7	13.8	7.4	1.8	12.7
Daily Minimum (°C)	-7.3	-6.3	-2	3.8	9.9	14.8	17.9	17.3	13.2	7.3	2.2	-3.7	5.6
Extreme Maximum (°C)	16.1	14.4	26.7	32.2	34.4	36.7	40.6	38.9	37.8	30	23.9	19.9	
Date (yyyy/dd)	1967/25	1976/25	1946/28	1842/22	1962/18	1964/30	1936/08	1918/13	1953/02	1963/07	1950/01	1982/03	
Extreme Minimum (°C)	-32.8	-31.7	-26.7	-15	-3.9	-2.2	3.9	4.4	-2.2	-8.9	-20.6	-30	
Date (yyyy/dd)	1859/10	1855/05	1868/03	1923/01	1854/06	1842/10	1843/12	1855/18	1843/22	1844/31	1875/30	1933/29	
PRECIPITATION													
Rainfall (mm)	29.1	26.2	42	63.2	73.3	71.5	67.5	79.6	83.4	64.7	67.3	41.9	709.8
Snowfall (mm)	38.2	26.6	22	6	0	0	0	0	0	0.1	8.1	32.2	133.1
Precipitation (mm)	61.2	50.5	66.1	69.6	73.3	71.5	67.5	79.6	83.4	64.7	75.7	71	834
Average Snow Depth (cm)	7	7	3	0	0	0	0	0	0	0	0	3	2
Median Snow Depth (cm)	7	6	2	0	0	0	0	0	0	0	0	2	1
Snow Depth at Month-end (cm)	7	5	0	0	0	0	0	0	0	0	0	4	1
Extreme Daily Rainfall (mm)	63.5	43.4	43.7	59.7	68.6	63.5	98.6	93.5	87.9	86.9	79.5	49.5	
Date (yyyy/dd)	1843/31	1855/13	1881/19	1850/03	1894/21	1957/28	1897/27	1905/15	1843/14	1954/15	1861/02	1870/05	
Extreme Daily Snowfall (cm)	39.9	45.7	40.6	21.1	7.6	0	0	0	0	12.2	30.5	48.3	
Date (yyyy/dd)	1966/23	1846/20+	1870/27	1901/20	1875/01	1840/01+	1840/01+	1840/01+	1840/01+	1969/21	1950/24	1944/11	
Extreme Daily Precipitation (mm)	52.3	52.6	43.7	59.7	68.6	63.5	98.6	93.5	87.9	86.9	79.5	49.5	
Date (yyyy/dd)	1932/01	1965/25	1881/19	1850/03	1894/21	1957/28	1897/27	1905/15	1843/14	1954/15	1861/02	1870/05	
Extreme Snow Depth (cm)	65	37	29	19	3	0	0	0	0	13	20	41	
Date (yyyy/dd)	1999/15	1971/14+	2001/06	1979/09	1963/01	1995/01+	1955/01+	1955/01+	1955/01+	1969/21	1997/16	1977/12	

Figure 105: Yearly/Monthly/Daily Climate Data, Toronto, Canada. (Environmental Canada, 2014)

CLIMATIC STUDY

Figure 106: Climatic Study Data at Toronto, Canada. (Weather Spark, 2016)

TORONTO YEARLY WEATHER SUMMARY

SUMMER

June – August

Average high of 26°C

Rainfall - 11 days /month

Wind speed – LOW

WINTER

December – February

Average 2°C to -7 °C

Snow - 10 days /month, average 7cm of snow

AUTUMN

September – end of November

Average SEPT. 21°C, NOV. 7 °C

Rainfall - 11 days /month

Wind speed – 16kph (Nov.), 11 kph (AUG)

Shorter day start

SPRING

March – May

Warming up

Snow - average 3cm of snow (melting in March

- April)

Figure 107: Solar Path of Toronto (SunEarthTools.com, 2016)

5.2 | Design Approach

This thesis aims to explore the topic of “Light Shapes Spaces: How Lights influences our perception of space” within the proposed University Women’s Club (UWC) building type. The University Women’s Club offers a variety of services and activities that require different qualities of light. The fundamental program of the UWC is to provide all functions with light, thereby adding interest to their programming.

Charateristic of Light (Room & Space)

ROOM & SPACE REQUIRE RELATIONSHIP

characteristic of light is creating the type of room and spatial perception

TRANSITION FROM ONE SPACE TO ANOTHER

UNIVERSITY WOMEN'S CLUB UWC

University Women's Club program activities are in 4 categories:

- (A) GROUP MEETING & EVENT SPACE
- (B) LOUNGE (PRIVATE MEETING)
- (C) SPA SPACE
- (D) EXERCISE

Each space is arranged to flow seamlessly into each other with light.

Figure 108: Characteristic of Light Diagram. By author.

Spatial Relationships

Light Shapes Space

DESIGN PROPOSAL | DESIGN APPROACH

Figure 109: Spatial Relationship Diagram. By author.

Functional Relationship

Figure 110: Relationship Diagram. By author.

Figure 111: Target Users Diagram. By author.

Target Users

The UWC is not only open to women from the University of Toronto campus, but also to other women from the community who wish to become members. Club members include students, working women, retirees, community leaders, and professional and business women. The University Women's Club of Toronto is a paid membership club. All applications to the University Women's Club must be presented to the Board of Director for approval.

The purpose of the UWC is to be part of the

university while maintaining a connection between students and communities. Members may develop their leadership skills by joining the club committee. Students who join the club house are encouraged to play an active role in empowering and enhancing their experience within communities. It is a club house that aims to promote understanding and support for the operations and functions of the university.

Membership of the University Women's Club is listed below:

		Cost (per year)	Privilege of access to facilities	Population (%, total 100%)
1	Regular Membership	\$700	Unlimited access to most facilities, but additional charges may apply	20%
	Open to all female graduate of university worldwide (alumni who are working women)			
2	Associate Membership	\$800	Unlimited access to all facilities	30%
	Open to all professional women who share the interests and concerns of the University Women's Club			
3	Student Membership	\$350	limited # of access to the Spa, 3 times per month	40%
	Open to women enrolled in fulltime academic studies toward a degree			
4	Senior Membership	\$450	limited # of access to the Spa, 5 times per month	10%
	Open to 65 age or above retired women			

Schedule of User

	Professionals / Working women	Students	Seniors
Morning 8am-12 pm		X	X
Afternoon 12pm – 4pm		X	X
Evening 4pm – 6pm	X		
Night 6pm – 10pm	X		
Late Night 10pm – 12am		X	
Remarks	The professionals and working women occupies the building after they busy day of work.	The students occupies the building before, in between and after class, usually in the afternoon and late at night.	The senior occupies the building early in the morning and afternoon.

Figure 112: University Club House Charts. By author.

General Program Summary

The University Women's Club has a variety of programs and activities throughout the year. General Programs offered at UWC is as follow:

- (1) Speakers Meetings
- (2) Events and Celebrations
- (3) Spa Treatment and Massage
- (4) Exercise, Health and Fitness
- (5) Interest Groups (Book group, bridge group, etc.)

There are different motivations for members joining this club. Some join for networking, some join for sharing common interests while others join in order to unwind from their stressful lives. The club provides a balance between professional needs and personal enjoyment and growth.

SEMI - ACTIVE: BUSY AND SMALL GROUP EVENTS

Bar Open Lounge & Patio

All events and activities within the UWC respond to the various needs of members. Small group events are schedule at a weekly, bi-weekly or monthly basis; these include luncheons, dinners and other social events at the Bar Open Lounge Patio. Small group events include a monthly breakfast as well as networking events held for the UWC committee. Each session provides opportunities to bring ideas to the table and to organize volunteering and fundraising meetings.

When there are no events, the Bar Open Lounge Patio allows all members to enjoy relaxing lunches and dinners with other members and friends.

SEMI QUIET: GATHERING AND READING

Library

The library room, a semi-private room, hosts weekly classes and lectures; guest speakers include authors and researchers who share their experiences. The library is designed to accommodate 10-15 people per visit. There are special interest groups, such as the book group and writing group, who meet during the morning and afternoon

for conversation. Wine tastings is also available on a monthly basis for all members and their friends to promote friendship and networking. When no events are being held, the space is a quiet reading and studying space. The library should offer relaxation to users who want to concentrate in a quiet atmosphere.

ACTIVE: PARTY AND BIG EVENTS

Multipurpose Hall

The Multipurpose Hall facilitates big events such as annual meetings for all members. It is also available for rental to the public for celebrations such as birthdays, weddings, and bridal showers. Bi-weekly, there is a big gathering for the Movie Night Event for all members and friends to enjoy. The space should be a flexible environment. Artificial and natural sunlight light play a significant role in this space.

QUIET: SPA & THERAPY

The spa facilities are not solely for beauty and elegance. Rather, the spa is a place to de-stress after work or before exams. It is somewhere to release stress and tension and achieves this partially through the engagement of light with the program and architecture.

Massage and Treatment Room

The character of the massage and treatment room is relaxing and healing. It should feature a low-light environment while users enjoy massages for neck, shoulder, upper neck, lower back, calves and feet.

OVERALL: Light therapy

The overall spa atmosphere is a light therapy for visitors. At certain times of the year, usually during the winter or fall season, or in a limited natural-light environment, people tend to experience mood disturbances. These disturbances are associated with depression. (Bernstein, Penner, Clarke-Stewart, & Roy, 2007) The spa area is a space where users are exposed to bright natural sunlight or to bright light that imitate natural sunlight with the effect of healing negative emotional states.

Figure 113: Spa Procedure & Spatial Sequence Diagram. By author.

Spa Procedure & Sequence

- (1) ENTRY
- (2) CHANGE SHOES
- (3) COMMON TEA ROOM
 - Public, non-spa visitor
- (4) CHANGE CLOTHES
 - Change to robe, etc
- (5) FITNESS (YOGA)
- (6) PRIVATE TEA ROOM
 - Relax lounge for Spa visitor after treatment
- (7) BATH
 - Indoor pool (salt water bath etc.)
- (8) TREATMENT & MASSAGE
 - Spa treatment to relief stress, for beauty etc.

Figure 114: Activities & Users Relations Chart . By author.

User of the Space	Description and Activities of the Space
Multifunctional Room Events space – Movie Night, Dancing party, cocktail party, etc.	
Everybody	Held events and celebration Catering services available within the warm up kitchen
Lounge Area (Bar): Event and Interest Group meetings – breakfast, lunch and dinner, Monthly committees meeting, etc.	
Professional	Professional women may join the club for taking their clients, contacts to lunches and dinners or holding clients' events. However, after a day of hard work, the other programs are ideal for relaxing conversation with other members and friends. They may attend scheduled events during the evening.
Students	Quick lunch and dinner before or after class
Housewives	Afternoon tea with friends
Senior	Morning for breakfast with friends
Everyone	Events - Luncheons and dinners
Library: Reading, Book Group, guest Lecture, wine tasting	
Professional, housewives and Senior	Join book group for personal interest
Students	Study space for exam
Spa: Treatments, Massage, Baths, Therapy	
Professional	Massage recliners, mindful relaxation from busy schedule of work
Students	Reduce stress from school, boot moods, stress and wellness A place to de-stress before the exam
Housewives	for beauty and elegance to experience the joy of being
Senior	Enjoy the wellness and meditation of spa
Tea Room	
Everybody	A space to retrieve and relax themselves after Spa
Exercise Space: Yoga Studio (indoor and outdoor), Indoor exercise space	
Professional	Release stress and tension due to work
Students	Release stress and tension due to school work
Working Women	Build up essential skill and release stress and tension due to work
Senior	No intensive exercise
Kitchen: Accommodate catering for required spaces – lounges, multifunctional room	
Staff	Prep and storage
Office and Services:	
Staff	Administration and Management

IESNA Illum Guide

Design Issues with Light

This is a matrix of design issues from the *IESNA Lighting Design Guide*, ranging from very important to not important or not applicable for different location (indoor/ outdoor) and tasks. The object of the matrix is give guidance to lighting designers. (Illuminating Engineering Society of North America, 2000)

I. INTERIOR		Very Important		Important		Somewhat important																	
LOCATIONS AND TASKS		Blank = Not important or not applicable																					
	Design Issues																						
		Appearance of Space and Luminaires	Color Appearance (and Color Contrast)	Daylighting Integration and Control	Direct Glare	Flicker (and Strobe)	Light Distribution on Surfaces	Light Distribution on Task Plane (Uniformity)	Luminances of Room Surfaces	Modeling of Faces or Objects	Point(s) of Interest	Reflected Glare	Shadows	Source/Task/Eye Geometry	Sparkle/Desirable Reflected Highlights	Surface Characteristics	System Control and Flexibility	Special Considerations	Notes on Special Considerations	Illuminance (Horizontal)	Category or Value (lux)	Illuminance (Vertical)	Category or Value (lux)
Art Galleries																							
	Flat displays on vertical surfaces																		(7)				D
	Exhibit cases																		(7)		D		B
	3-dimensional objects																		(7)		D		B
	Realistic environments																		(7)		D		B
	Lobbies, general gallery areas, corridors																		(7)		C		A
Auditoriums																							
	Assembly																				C		
	Social activity																				B		A
Club and Lodge Rooms																							
	Lounge and reading																				D		
Educational Facilities																							
	Corridors																						C
	Classrooms																						
	General (see Reading)																						
	Art rooms																				E		D
	Drafting (see Drafting/Graphic Arts)																						
	Home economics (see Residences)																						
	Social events																				B		A
	Outdoor sports facilities (see Section IV, Sports)																						
	Cafeterias (see Food Service Facilities)																						
	Dormitories (see Residences)																						
Exhibition Halls																					C		A
Offices (13)																							
	Private office																				E		B
Service Spaces																							
	Stairways and corridors																				B		
Toilets and Washrooms																					B		A

Figure 115: IESNA Design Guide Matrix (IESNA, 2000)

III. OUTDOOR LOCATIONS AND TASKS		Very ImportantImportantSomewhat important Blank = Not important or not applicable																			
		Design Issues	Appearance of Space and Luminaires	Color Appearance (and Color Contrast)	Direct Glare	Light Distribution on Surfaces	Light Pollution/Trespass	Modeling of Faces or Objects	Peripheral Detection	Point(s) of Interest	Reflected Glare	Shadows	Source/Task/Eye Geometry	Sparkle/Desirable Reflected Highlights	Surface Characteristics	Special Considerations	Notes on Special Considerations	Illuminance (Horizontal)	Category or Value (lux) ^(a, b)	Illuminance (Vertical)	Category or Value (lux) ^(a, b)
Bikeways																					
Alongside roadways — commercial areas																			10		20
Distant from roadways																			5		5
Building Exteriors																					
Entrances																					
Active (pedestrian/conveyance)																			B		A
Inactive (normally locked, infrequent use)																			A		A
Prominent structures																			B		A
Buildings and Monuments, Floodlighted																					
Bright surrounding																					
Light surfaces																	(2)				A
Medium light surfaces																	(2)				B
Medium dark surfaces																	(2)				B
Dark surfaces																	(2)				C
Dark surroundings																					
Light surfaces																	(2)				A
Medium light surfaces																	(2)				A
Medium dark surfaces																	(2)				A
Dark surfaces																	(2)				A
Bulletin and Poster Boards																					
Bright surroundings																					
Light surfaces																	(2)		A		D
Dark surfaces																	(2)		A		E
Dark surroundings																					
Light surfaces																	(2)		A		C
Dark surfaces																	(2)		A		D
Gardens																					
General lighting																			5		2
Paths, away from building																			10		3
Steps or ramps away from building																	(3)		10		3
Backgrounds — fences, walls, trees, and shrubbery																			20		5
Flower beds, rock gardens																			A		A
Trees or shrubbery, emphasized																			A		A
Focal points, large																			B		A
Focal points, small																			C		A
Gazebos, trellises, decorative structures																			B		A
Terraces, patios, decks																	(3)		B		A
Holiday and Entertainment																					
Holiday and festival lighting																			C		A
Entertainment lighting																			D		B
Parks, Plazas, and Pedestrian Malls																	B		A		
Parking Areas																					
Roadways																					
Roadway Rest Areas																					
Signs																					
Advertising																	(2)		A		C
Externally lighted roadway																	(2)		A		C
Walkways																					
Water and Rock Features																					
Scotscape (natural water bodies)																			B		A
Fountains, waterfalls																			A		B
Decorative pools																	(3)		B		A
Large natural rock features																			A		B

Notes:

- (a) Low illuminances (less than 30 lux) are given in lux; values greater than 30 lux are given in letter categories.
- (b) When security is a concern, consult Chapter 29, Emergency, Safety, and Security Lighting, for additional illuminance recommendations.
- (1) Intersections and conflict zones may require higher illuminances.
- (2) Lighting must not interfere with visibility for pedestrians, motorists, or boaters.
- (3) Hazards such as stairs or areas adjacent to bodies of water should be clearly identified and lighted for safety.
- (4) Illuminances for parking areas listed in Chapter 22, Roadway Lighting.
- (5) Illuminances for Roadway listed in Chapter 22, Roadway Lighting.
- (6) Illuminances for Rest Areas listed in Chapter 22, Roadway Lighting.
- (7) Illuminances for Tunnels listed in Chapter 22, Roadway Lighting.
- (8) Illuminances for Walkways listed in Chapter 22, Roadway Lighting.

5.3 | Site Analysis

Figure 116: Site Selection Plan B&W. By author.

The Site

The new University Women's Club of Toronto is located within the University of Toronto's St. George campus at 90 Devonshire Pl. The selected site, 90 Devonshire Place, was formerly a tennis court for Trinity College, and has now been transformed into a temporary parking lot between the Goldring Centre for High Performance Sport and St. Hilda's College within the University of Toronto St. George Campus.

Due to financial issues, the original University Women's club of Toronto was taken over by the University of Toronto. It was originally located at the intersection of St. George St. and Bloor St. W, (162 St. George St.) and was moved to share its facilities with the Faculty Club of the University of Toronto. The purpose of the selected site is to reintroduce University Women's Club of

Toronto programming back to this area through collaboration between the university and the city. A seating corridor with vegetation was introduced to provide views of the box office located on the ground floor of the Goldring Centre. A potential underground connection has been proposed to collaborate UWC events and activities with the Goldring Centre. By connecting these buildings, the new Women's Club Center can enrich the neighbourhood with its existing site context, conditions, and relations.

There are fair amounts of sun exposure on the east, south, and west sides of the site. St. Hilda's College, situated on the south side of the site, possesses a front garden. This thesis will explore the relation of light to vegetation by examining the shading providing by existing trees.

Figure 117: Site Selection Plan. By author.

LOCATION

Downtown Toronto

located within the St. George Campus of University of Toronto, a rich and heterogeneous urban areas of Downtown Toronto.

The Site

Site Relations

Light Shapes Space

DESIGN PROPOSAL | SITE ANALYSIS

Figure 118: Site Relations Plans - University Campus, District & Neighbourhood, Accessibility, Traffic. By author.

Site Relations

Figure 119: Site Relations Plans - Site Entrances, Existing Activity within the Site, Heights Relations. By author.

Day Conditions at Site

As shown in the photographs, the site is well lit with natural light during the morning and afternoon.

Figure 120: Day Conditions of the Site. By author.

Night Conditions at Site

At night-time, the site is surprisingly bright due to the Varsity Centre Sports Stadium's flood-lights that shine from across the street on the north side. They are responsible for the overall good lighting conditions here.

Figure 121: Night Conditions of the Site. By author.

Site Relatives to Illuminating an Outdoor Space

The context of the proposed site is the St George Campus. Control of light at night is a challenge due to disturbances at the Varsity Center across the street on the east side. The control of light to enable the performance of night-time activities will be examined.

Lighting up the space with artificial light at night is a challenge. Not only will it create lighting pollution, but artificial light will also disturb nearby residents. The potential of moonlight to provide illumination to enable night-time activities will be explored, keeping in mind the need to avoid disturbing the neighborhood.

Objectives of high light levels at night

With reference to the moonlight garden, illumination of outdoor space and low lighting human visual system, I would like to develop an efficient architectural strategy to bring uniformity to the levels of night illumination. (Schreuder & Narisada, Light Pollution Handbook, Volume 322, 2004)

This thesis will explore how architecture can respond to different lighting conditions, not only daylight and sunlight, but also low levels of night-time light. It will discuss how to prioritize safety and how to reduce power consumption due to misuse of light.

We do not need to return to that primitive time when the performance of human activities was dependent on the illumination provided by the full moon. We now understand the concept of sensible lighting. This thesis explores how architecture can respond to low light conditions not only through use of artificial lighting, but also through utilization of luminescent objects which would include building materials, pavement and plantation.

Tree Study

The study of use of trees and vegetation as shading methods highlights the importance of gaining an intrinsic understanding of these natural forms, as well as of their potential applications as elements of architecture. The map and chart below give detailed information regarding the vegetation and trees on the site, including species, types, heights and seasonal colour variations.

Figure 122: Tree Study Plan. By author.

The characteristic of trees at the site:				
	1	2	3	4
Tree Species	Red / Green Ash	London Plane	Linden Tree	Norway Maple
Tree Type	Deciduous			
Height (m)	12 – 25	20 – 30	18 – 37	20 – 30
Leaves	Sharp, narrow	Irregular, wide	Irregular, round	Irregular, sharp
Color (Spring)	Green	Green	Green	Green
Color (Summer)	Green / Red	Green	Pale Green	Green
Color (Fall)	Golden-Yellow	Yellow	Pale Yellow	Red
Color (Winter)	-	-	-	-
Shade	Tolerate some shade	Tolerate some shade	Slightly shade tolerant	Tolerate some shade

Figure 123: The Characteristic of Tree at the Site Chart. By author.

The maps below indicate the percentage of time the wind blows from the indicated direction at different times of the year (Annual, Spring, Summer, Fall, Winter)

Figure 124: Wind Study Plan. By author.

Sun Study

Figure 125: (Top)
Summer and Winter
Sun Study Plan. By
author.

Figure 126: (Bottom)
Sun Path and Sun Ray
Study Plan. By author.

Shadow Study

Figure 127: Shadow Study Plan. By author.

Light Shapes Space

DESIGN PROPOSAL | SITE ANALYSIS

Figure 128: Warm Bath Night Perspective: By author

How light influences our perception of space

LIGHT SHAPES SPACE

DESIGN OUTCOMES

6

6.1 | Research Question

HOW CAN LIGHT BE MANIPULATED TO INFLUENCE PERCEPTIONS OF FORMS AND SPACE?

The characteristics and brightness of light can be manipulated to enable responses in the following two categories¹:

- 1 PHYSICAL & EMOTIONAL RESPONSES**
(How the body responds to lighting conditions)
- 2 ASSOCIATIONS TO EXPERIENCES & CULTURAL CONNECTIONS**
(How the mind responds to lighting conditions)

¹ Please note that such transformations may affect mood by creating particular emotional responses. While this thesis endeavors to transform space with light, the human responses to such transformations are beyond the scope of this work.

6.2 | Issues and Strategies

ISSUES

Architects often neglect light as a basic element of design. However, it should be a primary consideration just as are such elements as materials, program, structure, proportion, circulation and volume; it should never be just an afterthought.

STRATEGIES

Natural light should be seen in the framework of nature, in its pure state unspoiled by human intervention. This thesis demonstrates that built form can be enhanced by lighting. The design takes its cues from natural lighting phenomena and echoes natural lighting conditions with artificial light. It deals with the uses and control of natural light.

6.3 | Lighting Considerations

This thesis addresses five major considerations of light in design: **Distribution:** The first consideration is to define the characteristics of a room through the way light is spread, directed or focused. This strategy can be used to create an atmosphere that connects people with the space. **Enhancement:** The second consideration is to enhance the differences between spaces. Enhancement involves the creation of a distinct difference between the lighting in two spaces. **Connection to nature:** The third step consideration is to reveal light in its pure and natural state through its connection to nature; this includes daylight, moonlight, and starlight expressions. The presence of nature articulates light and brings cultural connection and knowledge, which influences the overall perception of the space. **Natural effects:** The fourth consideration is to understand the natural effects of light in order to manipulate environments in different spaces. This includes the use of daylight and artificial light that is informed by natural lighting phenomena. **Range of Lighting effects:** The fifth consideration is to explore the continuum of stimulation from lighting effects, ranging from energizing conditions at one extreme to tranquil or meditative conditions.

With these lighting considerations in mind, a

series of lighting explorations and studies was completed to develop and articulate how light shapes space. To investigate these lighting considerations, this design thesis studies how light shapes and influences our perception of space within the program of a University Women's Club (UWC). The program is divided into three areas: public, semi-private, and private. The lighting considerations respond to theories of psychology regarding the effects of visual perception on emotion and behaviour, the overall perception of the space, and the effects of light within a spatial dimension.

Chapter 6, "Design Outcomes", displays the thesis hypotheses and philosophies of how light shapes and influences our perception of space in a building design.

Results

These five considerations of light are design principles applied to address how light shapes space and influences our perception of space. The changing quality of light is responsible for changes in our perception of a space. The thesis concludes that design outcomes support my hypothesis that the perception of space is reliant on the way architects bring light into a space, and on architects' manipulation of space through emphasizing light as an architectural element.

LIGHTING CONSIDERATIONS

The following conditions are considered in the development of the design strategy:

- 1** ROOM CHARACTERS
- 2** TRANSFORMATION:
TRANSITION FROM ONE CHARACTER TO ANOTHER
- 3** CONNECTION TO NATURE
DAYLIGHT EXPRESSION & MOONLIGHT/ STARLIGHT
EXPRESSION
- 4** MANIPULATION OF THE ENVIRONMENT
- 5** THE CONTINUUM FROM STIMULATION / ENERGIZING
CONDITIONS TO TRANQUIL / MEDITATIVE CONDITIONS

Figure 129:Light, Effects and Outcomes Diagram. By author

6.4 | Themes and Strategies

Light defines physical and perceived spaces. By proposing ways to change the way light is distributed and perceived, this thesis focuses on user experiences, perceived spatial dimensions, and experienced spatial atmospheres. This thesis proposes to expand the knowledge base so that architects can more easily use light like a material in the design architectural space. It explores three distinctive ways in which light shapes and influences our perception of space: control and manipulation of daylight, association of daylight with nature, and stimulation to be controlled by variation of sensory conditions.

- 1 | Daylight Features
control & manipulate
- 2 | Association
daylight with nature
- 3 | Stimulation
controls for a variety of sensory conditions (the continuum)

Design Features

Control & Manipulate

VEGETATION

natural shadows

Summer sun and Winter sun

SHADING DEVICES

architectural interventions

Appropriate use of shading device

use of lightshelves/ Louvres

CONSTRUCTION MATERIALS

material selection

change of materials to achieve lighting conditions

frosted glass, wood, dark/light finishes

WATER

natural reflection

Water feature to reduce heat as well as to reflect and refract light

Daylight Features

Daylight is a valuable source that can reveal the existence of architecture and spaces. It provides visual comfort for inhabitants and allows for avoidance of artificial light. Despite the importance of daylight, however, direct light from the sun can be too bright at times and may create glare and visual discomfort. Daylight control and manipulation of daylight are critical to architectural designs that integrate daylight as the main source of lighting.

This thesis emphasizes daylight as the key element in design rather than the use of artificial light in darkness. It will develop theories and methods for ensuring that daylight is the main priority in the

design. Controlled use of daylight by architects can aid in the creation of flexible environments in which light affects perception. Using shading devices such as louvers or light shelves; construction materials such as frosted glass; light or dark finishes, and light filters like water and vegetation can improve visual and thermal comfort at the same time as energy consumption is reduced. The control and manipulation of daylighting can enhance the visual characteristic of a space and users' perception of it.

Figure 130: Daylight Features Diagram. By author.

Associate

Daylight with nature
views to natural landscape

VEGETATION

filtering
Light and shadows
reminiscent feeling of calm and relax
filtered light - warm white
soft & gentle light

WATER

reflection & refraction
above water / underwater
reminiscent feeling of comfort and calm
reflected light - white
ambient & indirect light

CAVE

focused and controlled
isolation from exterior (limited view to outside)
reminiscent feeling of quiet & calm
light and shadow - cool white
dimmed & gentle light

Associate Daylight with Nature

This thesis conducts its exploration through a consideration of the experience of light within architecture. Natural light is a powerful element that bonds architecture with nature. This thesis examines a variety of lighting conditions through the use of landscape, water, and the simulation of cave conditions. In addition, the manipulation of artificial light will provide an immersive and emotional experience to define space through light. In this thesis, reflections in water and leaf shading are just two of the elements used to create strong relationships to nature. The essence of architecture becomes consideration of a space as connector of humans to nature.

The design strategy that will be used to associate daylight with nature is to provide views to natural landscapes, and to use and simulate natural elements such as vegetation, water, rocks and caves. In this thesis, light is revealed and expressed through the presence of nature. Nature's presence within the scene has the effect of magnifying the user's experience with light. The view to nature becomes united with the connection of light to space. A person's feelings are important elements of communication, and much of human perception is visual. The way light is expressed within an environment affects the impression that a space gives a person.

Figure 131: Association Diagram. By author.

Stimulation

Controls for a variety of sensory conditions
the continuum

LED

variation of color, intensity, brightness

Daylight Sensor

energy savings

Lighting Control Panel

efficient lighting control

Stimulation - controls for variety of sensory conditions

Daylighting stabilizes our mind when we are indoors, however, daylight is not always readily available in some indoor spaces. An imitation of daylight can be created with artificial lighting. At the same time, artificial light can also provide light in the darkness of night-time. In this thesis, the role of artificial light is to stimulate environments that lack daylight. The technology of artificial lighting creates special effects for a space even as it controls and affects the emotions of the perceiver with its variety of effects, such as colours, tones, apertures, directions, tones, intensity and brightness. The range of effects that can be produced with artificial light can be

used to stimulate a space for the creation of an interesting environment. Artificial light has the power to stimulate the environment and to affect spatial perception in a way that is completely different from daylight. This thesis presents the use of daylight sensors and lighting control panels as an option for the control of a building's energy consumption. Such use would reduce lighting pollution and create sustainable, light-responsive architecture.

Figure 132: Stimulation Diagram. By author.

6.5 | Design Objectives

Users of this building are mainly busy women seeking to escape from the stress of their busy lives. The architecture of each individual space has been developed to interact with the users' perception. Those who experience the building should retain a feeling in their hearts from the impressions that were created by the appearance and disappearance of light.

The spa and activities spaces of the University Women's Club building type are focal points of my thesis. They allow for the study of how light affects different situations within individual and multiple spaces. The program sets up situations to amend lighting requirement. Light is used to enhance programs and enrich spaces because of its singular capacity to make a simple space dramatic and thereby to affect human perception of it.

For instance, the spa floor (level 2) has been organized and designed based on the lighting conditions of the space and its functional lighting requirements. The spa level sets up a sensory experience of light through a sequence of spaces: (1) foyer, (2) tearoom, (3) change room, (4) corridor, (5) warm bath, (6) massage and treatment room. According to *A Pattern of Language* by Christopher Alexander, Section 112 – Entrance Transition, Section 128 – Indoor Sunlight, Section 130 – Entrance Room, Section

135 – Tapestry of Light and Dark, light has the capacity to affect human feelings within a space. For example, people tend to move toward light rather than darkness. Since placement of light in a darker space attracts people towards it, the flow of movement within the spa spaces is controlled through the placement of light. Light may make a space quiet or active. The function of each spa space necessitates different lighting conditions and qualities. The mood characteristic of the room can be achieved by a psychological transition which could involve a change of light, change of direction, change of materials, or change of view. The characteristic of light can have physical effects as well as evoke associations that affect feelings and perceptions. Physical effects involve the body's response to light while association refers to how the human mind responds to light. The case studies and precedents make references to the characteristic of light and to its association to spaces. For example, the massage room references the lighting quality of the Naman Spa designed by MIA Design studio and located in Vietnam. The massage room associates with nature through the use of natural light and vegetation. The use of filtered light is intended to achieve a characteristic in the room of calmness and wellness.

SITE PLAN

(1) UNIVERSITY WOMEN'S CLUB UWC

Figure 133: Site Plan. By author.

Floor Plans

Light Shapes Space

DESIGN OUTCOMES | FLOOR PLANS

Figure 134: Floor Plans. By author.

Sections

Light Shapes Space

DESIGN OUTCOMES | BUILDING SECTIONS

1. Lobby

2. Offices

3. Reflective Pool

4. Bar Lounge

5.Cafe

6. Library

7. Warm-up Kitchen

8. Multi function Room
9. Foyer

10. Tea Room

11. Change Shoes

12. Change Room

13. Water Curtain

14. Warm Bath

15. Massage / Treatment Room
16. Outdoor Exercise

17. Indoor Yoga Studio

18. Female Washroom

19. Seating

20. Unisex Washroom / Change / Shower

21. Skylight Planter Seating
22. Green Corridor

23. Mechanical Room

24. Garbage

25. Underground Connection to Goldring Centre for High Performance Sport

Section A

Section B

Figure 135: Building Sections. By author.

6.6 | Arrangement of Space

In this project, the arrangement of space considers the lighting requirements that would promote or encourage movement through it. The desired lighting is used as a guide to determine the relationship between private and public programming for the University Women's Club building. The program of light in spaces is totally integral to the design of floor plans, sections, and elevations. When the combination of activities, building materials, fixtures, décor, colours, light and furniture come together in a physical environment, it creates a particular characteristic for the space. Each space is designed to be highly personalized and is intended to have users respond to it in a certain way.

Connection to light

Ground Floor

Bar Lounge
Indirect & Filtered Light
Relax Quality

Library
Filtered & Dim Light
Comfort Quality

Multifunctional Room
Variable Light (artificial + daylight)
Live and Active Quality

Cafe
Bright & Filtered Light
Energetic & Lively Quality

Lobby + Foyer
Very Bright Light
Warm & Vivid Quality

Reflective Pool
Reflective & Gentle Light
Calming Quality

LIGHTING CONDITIONS - REFERENCE PROJECTS

(1) Corallo House by PAZ
Arquitectura. Santa Rosalia,
Gutatemala

(4) Campus Restaurant and Event
Space by Barkow Leibinger
Architects. Stuttgart, Germany

(7) Starbucks Coffee by Kengo
Kuma. Dazaifu, Japan.

(2) Concept Rendering - Visual Arts
Building for University of Iowa
by Steven Holl.

(5) Gatwick Clubhouse by Pearson
Lloyd. Gatwick, London.

(8) Big Solar LED Art in China.

(3) Porsche Pavilion by HENN
Architects. Wolfsburg, Germany

(6) CHANNEL GLASS: Nelson
Atkins Museum by Steven Holl.

Figure 136: Connection to Light
Ground Floor Diagram. By
author.

Connection to light Second Floor

Light Shapes Space

DESIGN OUTCOMES | ARRANGEMENT OF SPACE

LIGHTING CONDITIONS - REFERENCE PROJECTS

(1) AGO's Italian Gallery by Frank Gehry. Toronto, Canada	(6) Carabanchel Social Housing by Foreign Office Architects, Madrid, Spain	(11) The MIXX Bar & Lounge by Gwenael Nicolas. Tokyo, Japan
(2) Moon Gate at Chinese Garden. China.	(7) Naman Spa by MIA Design Studio. Vietnam	(12) Kanebo Sensai Select Spa by Gwenael Nicolas
(3) Weekend House by Ryue Nishizawa. Tokyo, Japan.	(8) Yomogino Ryokan hot Spa by Sasaki Architecture. Fukushima, Japan.	(13) Kring Kumho Culture Complex by Unsangdong Architects. Seoul, Korea.
(4) Beijing Tea house by Arch Studio, Beijing, China	(9) Benesse House by Tadao Ando. Naoshima, Japan.	
(5) Hiroshi Senju Museum by Ryue Nishizawa. Karuizawa, Japan.	(10) Sensory Exhibition by DGT Architects. Paris, France.	

Figure 137: Connection to Light Second Floor Diagram. By author.

Connection to light Basement Floor

Unisex Change Facilities
Artificial Light

Indoor Yoga Studio
Refraction & Soft Light
Quiet and Calm Quality

Seating Area
Toplight (skylight planter)
Reminder of daylight underground

LIGHTING CONDITIONS - REFERENCE PROJECTS

(1) Semi Buried Home Rises from the Earth by Molos Group.	(3) Image of Light refraction under water
(2) The Blue Planet - Denmark's National Aquarium by 3XN. Copenhagen, Denmark.	(4) Casa de la Flora by VaSLab Architecture, Thailand.

Figure 138: Connection to Light
Basement Floor Diagram. By author.

Lighting Idea of the Space

Light Shapes Space

DESIGN OUTCOMES | ARRANGEMENT OF SPACE

	SPACE	WARM (3500K or less)	NEUTRAL (3500K - 4100K)	WHITE (5000K)	COOL (above 5000K)	Variable (control)	Color Temp. (K)
GF	GF Lobby	Warm White					3000K
	Reflective Pool				Reflected, diffused and filtered light	Daylight sensor, louvers, water	3500K – 5000K
	Bar Lounge	Indirect and reflected light					2000K
	Café	Filtered and indirect light				Vegetation	2700K
	GF Toilet	Artificial					2500K
	Multifunctional Room	flexible	flexible	flexible	flexible	Daylight sensor, louvers	3500K – 9000K
	Library	Artificial light					1500K
2F	2F Foyer		Bright, skylight				
	Tearoom	Soft white, Filtered Light				Vegetation	2700K
	Change Room		Filtered Light Cool White		Reflected light	Louvers	4100K
	Warm Bath	Reflected and diffuse light, Cool White				Baffles	2700K
	Spa corridor			Pure White Glowing light			5000K
	Massage room	Filtered Light Warm White				Vegetation	3000K
	Tearoom Corridor		Natural Illumination, Skylight			Vegetation, Louvers	3500K
	Outdoor Exercise space				Full Daylight		5000K
B1	Indoor Yoga Studio	Reflected and refracted light				Water	1000K
	Seating Lounge		Filtered skylight Warm White				3000K

Figure 139: Lighting Idea of the Space Chart. By author.

Lighting Quality of the Space

	SPACE	Lighting Conditions	Quality	Color Temp.	Lighting Expression
GF	GF Lobby	Filtered light	Warm and Vivid	Warm White	
	Reflective Pool	Reflected, diffused and filtered light	Energetic and lively	Cool	Above Water, Vegetation
	Bar Lounge	Indirect and reflected light	Relax	Warm White	Beside Water
	Café	Filtered and indirect light		Warm White	Vegetation
	Multifunctional Room	flexible	flexible	flexible	flexible
	Library	Artificial filter light, Dim and ambient	Pleasure and relax	Warm white	Vegetation
2F	2F Foyer	Bright filtered skylight			
	Tearoom	Filtered Light		Soft white	Vegetation with existing trees
	Change Room	Filtered Light, reflect and refract	Time	Cool White	Light in Time with water
	Warm Bath	Reflected and diffuse light, Cool White	Relax and coexist with Nature		Cave
	Spa corridor	Glowing light	Purification	Pure White	Heaven
	Massage room	Filtered Light	Warm Calm and Wellness	Warm White	Jungle / Vegetation
	Tearoom Corridor		Natural Illumination, Skylight	Soft and Warm White	
	Outdoor Exercise space	Full Daylight		Cool	Top of the hill
B1	Indoor Yoga Studio	Reflected and refracted light		Warm White	underwater
	Seating Lounge	Gentle Light with skylight		Warm White	Vegetation

Figure 140: Lighting Quality of the Space Chart. By author.

Layer of Lights: Atrium

ARRANGEMENT OF SPACE TO RESPONSE TO LIGHT
control of light

6.7 | Layer of Lights

The building is flooded with natural light through the atrium and large openings on the south side. The architecture is arranged around a central courtyard and reflective pool. The courtyard gives space for inward private and reflective times by means of its seamless connection to natural light. At night, the atrium is illuminated by a low lighting system. Level “A” (second floor) is illuminated by the stadium lights across the street on the north-south side. A dim, soft, warm, light falls onto the interior landscape of greenery that includes trees, bamboo and other plants, and green walls, making them glow in a pale green. On Level “B” (ground floor), reflections of water create a caustic¹ pattern. The intensity and color of the space change depending on the motion of the water and the integrated LED light at the bottom of the pool. Level “C” (basement floor) is illuminated by the refraction of water that produces a caustic pattern. The overall lighting condition of the atrium at night is the result of indirect light, which is very different from bright and direct daylight.

¹ **Caustic:** Physics Formed by the intersection of reflected or refracted parallel rays from a curved surface.
(Definition from Oxford EnglishDictionary)

Lighting Conditions - reference Projects

- (1) Beijing Tea house by Arch Studio. Beijing, China
- (2) Weekend House by Ryue Nishizawa. Tokyo, Japan.
- (3) Porsche Pavilion by HENN Architects. Wolfsburg, Germany
- (4) The Blue Planet - Denmark;s National Aquarium by 3XN. Copenhagen, Denmark.

Figure 141: Layer of Lights: Atrium Diagram. By author.

Design Process

Light Shapes Space

DESIGN OUTCOMES | LAYER OF LIGHTS

STUDY MODEL 1

Figure 142: Photos of Study Model 1. By author.

STUDY MODEL 2

Figure 143: Photos of Study Model 2. By author.

STUDY MODEL 3

Study Models

EXPERIMENTING THE ARRANGEMENT OF SPACE TO RESPONSE TO LIGHT through the study of physical models (in addition to models for a previous scheme)

MODEL 1

3 storey spatial and light study model

MODEL 2

3 storey spatial and light study model

MODEL 3

2 Storey study model

The study models were used to gain understanding of the connection between light and space in a three-dimensional way. The overall form, volume, structure, and layout are greatly influenced by lighting requirements and distribution of light. The series of study models help this thesis to explore, understand, and obtain light in the spatial dimension and also to communicate ideas throughout the design process.

Figure 144: Photos of Study Model 3. By author.

Relations of Space with Light

Figure 145: (Top) Atrium Lighting Relations of the Space Diagram. By author.

Figure 146: (Center) Atrium Colour Temperature Relations of the Space Diagram. By author.

Figure 147: (Bottom) Color Temperature Scale. By author.

Progression of Light

Figure 148: Atrium Progression of Light Diagram. By author.

Design Development

Sectional Model

EXPERIMENTING THE LAYER OF LIGHTS IN THE ATRIUM SPACE

Figure 149: Photo of Sectional Model Perspective. By author.

Figure 150: Photo of Sectional Model, Front Perspective. By author.

Figure 151: Photo of Sectional Model, view from West. By author.

Figure 152: Photo of Sectional Model, view from South. By author.

6.8 | Ground Floor

Balance with light

G/F | Meeting Floor

Lighting experience begins on the ground floor, which features spaces with little or no privacy. Public activities and semi-public activities occur here. People designate separate areas for different functions according to their atmosphere and to the characteristic of light required in each space. Light is the material that defines the shapes, forms, and function of the spaces.

GROUND FLOOR
MEETING FLOOR
Active | Public | Energize

Figure 153: Ground Floor Furniture Plan. By author.

Room Characteristic

Ground Floor Lobby & Foyer

Bright Light
Warm & Vivid Quality

DEFINING SPACE WITH LIGHT
Visual cues from light

MATERIAL SELECTION

White Finishes

Wood

Figure 154: Ground Foyer Perspective 1. By author.

Figure 155: Ground Foyer Perspective 2. By author.

Figure 157: (Top) Reference lighting Conditions Projects for Ground Foyer. By author.

Figure 156: (Bottom) Ground Floor Foyer Enlarged Plan. By author.

ACTIVE | PUBLIC | ENERGIZE

Multifunctional Room

Variable Flexible Lighting
Conditions (artificial + daylight)
Live and Active Quality

Bar Lounge

Indirect Light
Relaxing Quality

Stairs

Glowing Light
Channel Glass
Purify Quality

Reflective Pool

Reflective & Bright Light
Caustic Water Pattern
Calming Quality

GROUND FLOOR ENLARGED PLAN

Room Characteristic

Reflective Pool

Reflective & Gentle Light
Calming Quality

MATERIAL SELECTION

- Vegetation
- Wood
- Water

Attraction

In the center of the building, there is the body of water. Visitors walking through the building come from a room of light into a room of water. Next to the body of water stands a half-height solid wall – like a sculpture. The reflection and sound of the water is to propose a unique architectural experience as users pass by this space. The atrium requires that a large amount of energy be expended for heating and cooling. As a result

of this issue, a reflective pool was introduced to reduce heat gain and loss. The courtyard space on the ground floor of the atrium controls daylight penetration with glass louvers.

Experience the Pool

Depending on the light and weather conditions, the appearance and atmosphere of the reflective pool and surrounding space constantly changes. During the daytime, daylight penetrates through

DEFINING SPACE WITH LIGHT

Manipulate and associate environment to reflect connection to nature. (water refraction)

Figure 158: Reflective Pool at 12pm. By author.

Figure 159: (Top) Reference lighting Conditions Projects for reflective pool. By author.

Figure 160: (Left) Longitudinal Section Reflective Pool. By author.

Figure 161: (Right) Reflective Pool Enlarged Plan. By author.

(i) Porsche Pavilion by HENN Architects.
(ii) Visual Arts Building, University of Iowa by Steven Holl Architects.

ACTIVE | PUBLIC | ENERGIZE

the glass louver above, bringing diffused natural light into the reflective pool space. The serene sound of moving water calms the soul of users and isolates the area from both the city environment outside and public spaces within the building such as the café and lobby spaces.

At night, the space is illuminated as stadium lights across the street on the north-south side flood it with light. Daylight sensors and dimmers were installed in the atrium space to create a light-responsive architecture. The glowing water resulting from

LED installation under the water symbolizes the dynamism of light and stimulates the inhabitants' experience by giving life to this space. During the night time, the serene sound of moving water not only calms the soul of users but also creates an inviting ambience for passers-by.

LONGITUDINAL SECTION

GROUND FLOOR ENLARGED PLAN

Figure 162: (Top) Heat and Reduction Section. By author.

Figure 163: (Center) Reflective Pool at Night. By author.

Figure 164: (Bottom) Reflective Pool with electrochromic glazing on roof monitor during the day. By author.

Light Study of Atrium and Reflective Pool

Figure 165: Atrium & Reflective Pool Light Study. By author.

Room Characteristic

Bar Lounge & Library

Indirect & Reflected Light
Relax Quality

Filtered & Dimmed Light
Comfort Quality

MATERIAL SELECTION

- Wood
- Water
- White Finishes

DEFINING SPACE WITH LIGHT

Manipulate and associate environment to reflect connection to nature. (water refraction)

Quality and quantity of light affect a spacious impression.

GROUND FLOOR PLAN

- (i) Porsche Pavilion by HENN Architects.
- (ii) Starbucks Coffee by Kengo Kuma. Dazaifu, Japan.

Figure 166: (Right Top) Bar Lounge Perspective. By author.

Figure 167: (Right Bottom Left) Library Perspective. By author.

Figure 168: (Right Bottom Right) Reference Lighting Conditions Projects for Bar Lounge & Library. By author.

Figure 169: (Top) Sectional Diagram of Ground Floor. By author.

Figure 170: (Bottom) Enlarge Plan of Bar Lounge & Library By author.

Room Characteristic

Cafe

Bright & Filtered Light
Energetic & Lively Quality

Figure 171: Cafe Perspective Rendering. By author.
Figure 172: South East Perspectives. By author.

INTERIOR AND EXTERIOR CONNECTION

The lighting condition recieved inside creates a fluid movement between indoor and outdoor spaces.

Manipulate and associate environment to reflect connection to nature with vegetation.
It's bright and cheery place, where people can find an experience to immerse themselves during the day.

SOUTH EAST EXTERIOR PERSPECTIVE DURING THE DAY

Figure 175: (Top) Reference lighting Conditions Projects for Cafe. By author.

Figure 174: (Center) Cafe Sectional Diagram. By author.

Figure 173: (Bottom) Cafe Enlarged Plan. By author.

(i) Campus Restaurant and Event Space by Barkow Leibinger Architects. Stuttgart, Germany
(ii) Carabancel Housing by Foreign Office Architects. Madrid, Spain.

ACTIVE | PUBLIC | ENERGIZE

MATERIAL SELECTION

GROUND FLOOR PLAN

6.9 | **Second Floor**

L2 | Spa Floor

The experience of moving through light continues onto the spa floor (level 2). Light enables us to experience space and its distribution stimulates movement and activities. The psychological transition – the change of light, change of direction, change of material and change of view-- influences the way we experience the private and public space. The spa floor is a highly finished area that offers privacy, comfort and relaxation.

SECOND FLOOR
SPA FLOOR
Calm | Private | Tranquil

Figure 176: Second Floor Furniture Plan. By author.

Room Characteristic

L2 Lobby & Foyer

Warm Light (skylight - filtered light with vegetation)
Artificial Material with natural and light colour

Figure 177: (Top) L2 Lobby and Foyer Perspective Rendering. By author.
Figure 178: (Bottom) Reference lighting Conditions Projects for L2 Lobby and Foyer. By author.

DESIGNING WITH SPACE AND LIGHT

Manipulate and associate environment to reflect connection to nature with vegetation

MATERIAL SELECTION

Vegetation

Wood

White Finishes

REFERENCE LIGHTING CONDITIONS

(i) AGO's Italian Gallery by Frank Gehry. Toronto, Canada.
(ii) Japanese Restaurant Design.

Figure 180: (Top) Skylight planter Details. By author.

Figure 179: (Bottom) Second Floor Lobby & Foyer Enlarged Plan. By author.

CALM | PRIVATE | TRANQUIL

Room Characteristic

Tea Room

Filtered & Gentle Light
Peaceful Quality

MATERIAL SELECTION

INTERIOR AND EXTERIOR CONNECTION

The lighting condition recieved inside creates a fluid movement between indoor and outdoor spaces.

CONCEALMENT & SURPRISES

Multiple openings are laid out in the tearoom space to invite natural light in while minimizing harsh southern exposure. The views to the terraces and atrium present a connection to nature. The design is intended to evoke a peaceful quality that users can enjoy with a cup of tea while looking at the natural landscape.

At night, inhabitants may find it difficult to view to the exterior landscape while sipping their cup of tea. Their attention may focus instead on the landscape of greenery. The tea room is lit up at night like a dreamland as soft warm and dimmed light highlights details such as the table, stairs

and walkways to give a feeling of relaxation. The low-intensity lighting conditions of the interior greenery landscape highlight bamboos, trees and plants by casting a pale-green glow onto them. The interior landscape scenery at night is envisioned to simulate the lighting effects in a moonlight garden. The overall impression of the tearoom at night is that has an entirely different sense of place compared to the tea room during the day.

Figure 181: Sectional Diagram of Tea Room. By author.

Figure 182: (Bottom Left) South East Facade. By author.

Figure 183: (Top Right) Reference Lighting Conditions Projects for Tea Room. By author.

Figure 184: (Center) Tea Room Perspective. By author.

Figure 185: (Bottom Right) Enlarged Plan of Tea Room. By author.

(i) Weekend House by Ryue Nishizawa. Usui-gun, Japan.

(ii) Moongate in Chinese Garden.

CALM | PRIVATE | TRANQUIL

SOUTH EAST FACADE

SECOND FLOOR PLAN

Room Characteristic

Water Curtain in Change Room

Reflect Light
Light in Time

EXPERIENCE OF LIGHT

Light in Time with Water Curtains Corridor

How can we intensify the experience of light in time? Light is constantly changing and it is difficult to visualize the changes as they happen. The falling water curtains stimulate the constant changing light as it is illuminated first by daylight and during the night by artificial light (LED). This illumination makes water droplets look like falling diamonds. As users go through the water curtains, their experience intensifies. The falling water curtains do not function solely as a wet area that

precedes entering the warm bath. Rather, they create a space where light and water interact in harmony. The water curtains corridor offers a continual enigmatic atmosphere where users can experience light in time.

Figure 186: Enlarged Plan of Water Curtain in Change Room. By author.

Figure 189: (Top) Reference Lighting Conditions Project. By author.

Figure 187: (Center) Water Curtain Perspective 1. By author.

Figure 188: (Bottom) Water Curtain Perspective 2. By author.

REFERENCE LIGHTING CONDITIONS

(i) Sensory Exhibition by DGT Architects. Paris, France.

CALM | PRIVATE | TRANQUIL

Figure 190: Warm Bath (day)
Sectional Diagram. By author.

Room Characteristic

Warm Bath during the day

Reflect & Diffuse Light
Reference: Cave like. Connection to nature
(Green Wall)

ASSOCIATE TO NATURE THROUGH THE MANIPULATION OF LIGHT

inside a cave

DURIGN THE DAY

The warm bath facilitates the study of light and water. The design intention is to create the feeling of taking a nice warm bath while inside a cave. Light from the north bounces off the water and reflects the sky onto it. Beautiful scenery appears in the reflection of water through the skylight situated above it. The design is intended to evoke the enclosed feeling of being inside a cave. By using the rough texture of the wall and the smoothness of the water pond to emulate elements from the

natural world, the atmosphere of the space takes users back to nature for an appreciation of the harmony between man and the earth. The water reflection appears as an illusion of the natural landscape, making the users feel like they are bathing in nature rather than a cave. This bathing space is a unique paradise with an interplay of water, light, and vegetation.

Figure 193: (Top) Warm Bath during the day Perspective. By author.

Figure 192: (Bottom Left) Reference Lighting Conditions Projects for Warm Bath - day. By author.

Figure 191: (Bottom Right) Warm Bath Enlarged Plan. By author.

CALM | PRIVATE | TRANQUIL

- (i) Brother Klaus Field Chapel by Peter Zumthor. Eifel, Germany.
- (ii) Benesse House by Tadao Ando. Naoshima, Japan.
- (iii) Yomogino Ryokan hot Spa by Sasaki Architecture. Fukushima, Japan.

Figure 194: Warm Bath (night)
Sectional Diagram. By author.

Room Characteristic

Warm Bath at Night

Reflect & Glowing Light
Quiet Feeling to Water
Reference: Cave like starry night.
Connection to nature with water

ASSOCIATE TO NATURE THROUGH THE MANIPULATION OF LIGHT

Night Vision in a Cave

Sunlight helps to lighten the entire space of the cave. Without the presence of light, the space becomes virtually lifeless. In order to make the watercourses appear more attractive at night, artificial lighting is used to intensify the scene with reflections from the wall and water. On clear nights, visitors see the moon reflection as a shimmering spotlight on the surface of the water. Artificial lighting evokes a totally different atmosphere and presents a different room characteristic of the space during nighttime.

To further understand the Warm Bath lighting conditions over time see (next page)

Light Shapes Space

DESIGN OUTCOMES | SECOND FLOOR

Star Path is a spray on coating that make the space glow in a soft blue in the dark. The material will glow up to 16 hours after it was charged with UV sunlight.

Figure 197: (Top) Warm Bath at Night Perspective. By author.

Figure 196: (Bottom Left) Reference Lighting Conditions Projects for Warm Bath - night. By author.

Figure 195: (Bottom Right) Warm Bath Enlarged Plan. By author.

CALM | PRIVATE | TRANQUIL

(i) New Zealand Cave illuminated by glowing worms. North Island. New Zealand.

(ii) Wuzeng, Water Village at Hangzhou, Suzhou, China.

Room Characteristic

Warm Bath Light Study

DIFFERENT TIMES OF THE DAY AND SEASONS OF THE YEAR

A totally different ATMOSPHERE and ROOM CHARACTERISTIC of the space throughout times

SPRING MAR - MAY

SUMMER JUN - AUG

MORNING 9:00AM

NOON 1:00PM

AFTERNOON 3:00PM

EVENING 8:00PM

Figure 198: (Top) Warm Bath.
Section. By author.

Figure 199: Light Study of
Warm Bath. By author.

DAY: Spring & Summer - light is WARMER
Fall & Winter - light is COOLER
NIGHT: Spring & Summer - light is less bright (sky is brighter)
Fall & Winter - light is more intense and bright (sky is darker)

FALL SEP - NOV

WINTER DEC - FEB

MORNING 9:00AM

NOON 1:00PM

AFTERNOON 3:00PM

EVENING 8:00PM

Room Characteristic

Spa Corridor

Glowing and White Light
Transitional Space
Purifying Quality

Figure 200: Spa Corridor
Perspective. By author.

SENSORY EXPERIENCE

Intensify emotion through the transition of spaces

Instead of having a clearly delineated space for each room, the flow of light links each space together in a continuous flow. One approach is a transitional space / pathway within the spa.

PURIFICATION

The pathway serves as the preliminary entrance into the spa massage room and tearoom from the change room. The glowing concave vestibule that users encounter before entering the spa massage

rooms symbolizes purification. The glowing light source consists of artificial light (LED) that is installed behind a translucent frosted glass to evoke pure lighting. The glow varies from day to night, depending on lighting conditions. (LED can be used as a light sensor.) The spa corridor is crucial to the exploration of design as it enables the study of both daylight and artificial light.

CALM | PRIVATE | TRANQUIL

V | Spa Corridor View

Figure 204: (Top) Reference Lighting Conditions Projects for Spa Corridor. By author.

Figure 203: (Center) Spa Corridor Transition Diagram. By author.

Figure 201:(Bottom Left) Spa Corridor Sectional Diagram. By author.

Figure 202:(Bottom Right) Enlarged Plan of Spa Corridor. By author.

(i) Kanebo Sensai Select Spa by Gwenaél Nicolas
(ii) Sky Loft by KUBE architecture, Washington DC, USA.

TRANSITION FROM ONE SPACE TO ANOTHER BY...

change with light
change in material
change of direction
change of height

MATERIAL SELECTION

LED Light Panel

Wood

TRANSITION DIAGRAM

SECTION

SECOND FLOOR PLAN

Room Characteristic

Massage Room

Filtered & Soft Light
Warm Calm & Wellness Quality

Figure 205: Massage Room
Perspective. By author.

INTENSIFY EXPERIENCE THROUGH LIGHT

Calming

The massage room enables the study of light with filtering and reflection from vegetation. The green walls system allows natural light to penetrate through the vegetation gaps. This effect is intended to evoke the feeling of being in a forest while receiving a relaxing massage. The lighting condition of the massage room is meant to evoke the feeling of being under a tree or taking a nap in nature.

At night, the massage room is illuminated by a

pale-green colour and by low-intensity glowing light from the green walls system. Plants on the green wall reflect the dim lighting level from the atrium to evoke another sense of calmness, as if the user is sleeping in a garden surrounded by flowerbeds.

Figure 206: (Top) Reference Lighting Conditions Projects for Massage Room. By author.

Figure 208: (Center) Massage Room Sectional Diagram. By author.

Figure 207: (Bottom) Enlarged Plan of Massage Room. By author.

(i) Vietnam spa by MIA Design, Vietnam.
(ii) Carabanchel Housing by Foreign Office Architects. Madrid, Spain.

CALM | PRIVATE | TRANQUIL

MATERIAL SELECTION

- Vegetation
- Wood
- White Painted Concrete

Room Characteristic

Tea Room Corridor

Bright & Gentle Light
Winding Pathway

INTENSIFY EXPERIENCE THROUGH LIGHT

Interesting Places to Visit

The tearoom corridor enables the study of light with vegetation. The pathway serves as an inviting entrance into the spa massage space, spa treatment space, and into tea room. The green spaces, such as the green walls and bamboo terraces, are not meant to be seen all at once. Instead, they are laid out to present a series of scenes. The visitor can move from scene to scene within the enclosed galleries and the winding paths. The different scenes allow for the evocation of different feelings based on the

differing lighting conditions that may appear at the turn of a path, through a window or hidden behind a bamboo.

The pathway will bring the tranquility of nature to city dwellers by making them forget about the busy city just beyond its confines. After the spa experience, users can further relax by sipping tea in the tearoom, leaving them feeling rejuvenated before they venture outside again.

During night time, a contrast of light is found within the tearoom corridor. Light on winding paths

MATERIAL SELECTION

Vegetation

Wood

LED Panel

Figure 209: Tea Room Perspective. By author.

Figure 211: (Right) Reference Lighting Conditions Projects for Tea Room Corridor. By author.

Figure 210: (Left) Enlarge Plan of Tea Room Corridor. By author.

CALM | PRIVATE | TRANQUIL

invites and directs visitors to move from scene to scene. The glowing concave vestibule located at the entrance of the treatment room and the pale-green colour and low-intensity glowing lights from the interior vegetation and landscape stimulate a sense of anticipation. Visitors can proceed from one space to another and can choose their own path since there are many options available to them.

(i) Beijing Tea house by Arch Studio. Beijing, China.
(ii) Hiroshi Senju Museum by Ryue Nishizawa. Karuizawa, Japan.

All spaces are designed to relate light to the nature and directing user to an architectural journey with light.

SECOND FLOOR PLAN

6.10 | Basement Floor

B1 | EXERCISE FLOOR

Underground spaces can be dark and gloomy. The exercise floor (basement level) pushes the boundaries of access to daylight with its creation of a unique lighting experience there. Bringing daylight to the underground space is a reminder of the natural world. This thesis deals with reminders of nature such as skylights and underwater lights as they are distributed and perceived throughout spaces for the creation of an experiential journey of light. Imagine light penetrating through water and imagine further the beauty of the image as the light changes as it travels weightlessly across the surface of the water and enters beneath it.

BASEMENT FLOOR
EXERCISE FLOOR
Silence | Meditative | Peaceful

Figure 212: Basement Floor Plan. By author.

Room Characteristic

Underground Yoga Studio

Refraction & Soft Light
Mediation Quality

Figure 214: (Left) Indoor
Yoga Studio Sectional
Diagram. By author.

Figure 213: (Right)
Enlarged Plan of Indoor
Yoga Studio. By author.

REMINDER OF THE NATURAL WORLD WITH LIGHT

Pushes the boundaries of access to daylight within underground space

The intention is to create a space where people do yoga for meditation and stress recovery. The yoga studio space is a place to ponder one's own existence for emotional balance and peace in mind. The light filtered through water creates light refractions on the wall from the effects by water ripples. The yoga space is situated below the reflective pool. The water creates a connection to the light above. The light falls from above onto the interior space and onto users inside. Refraction

and lighting conditions allow users to deepen their body awareness, calm their mind and move deeply into a meditative state. It is an isolated place for contemplation (deep thinking).

SILENCE | MEDITATIVE | PEACEFUL

(i) The Blue Planet - Denmark;s National Aquarium by 3XN. Copenhagen, Denmark.

Figure 215: (Top Left) Indoor Yoga Studio Day Perspective1. By author.

Figure 216: (Top Right) Reference Lighting Condition Project for Indoor Yoga Studio. By author.

Figure 217: (Center) Indoor Yoga Studio Day Perspective2. By author.

Figure 218: (Bottom) Indoor Yoga Studio Night Perspective. By author.

GLASS FLOOR

ACRYLIC DOME

WHEN LIGHT ENTER WATER, IT SCATTERS

- (1) When the glass is flat, light refract in one direction.
- (2) Dome shaped glass allow light to refract in all direction.

DETAILS OF DOME & GLAZING FLOOR

Artificial light (LED) is installed along the circular skylight opening. During the day, the LED performs as light sensors to ensure sufficient penetration of the water by daylight. When the daylight lighting level becomes low due to weather conditions, the artificial light (LED) will illuminate the studio space with cool light. Cool light is used to mimic the visible spectrum of daylight conditions. At night, the space is illuminated by refracted light underneath the water and light is distributed from the installation of LED light sources. The LED light sources change in colours, intensity and brightness, depending on the preferred emotional states and activities of the space. For example, red, yellow and orange can be used for energizing activities such as aerobics, hot yoga and fitness classes. Green is suggested for activities like Pilate and Tai-chi classes. Blue is used for yoga to facilitate meditation and bring stress relief.

ACRYLIC DOME

LED STRIP

Figure 221: (Top) Material Indication Diagram. By author.

Figure 220: (Center) Light enter water diagram. By author.

Figure 219: (Bottom) Details of Dome and Glazing Floor Diagram. By author.

6.11 | FAÇADE DESIGN

Figure 222: Exterior Facing Devonshire Pl. Day Perspective. By author.
Figure 223: Exterior Facing Devonshire Pl. Night Perspective. By author.

Facing Devonshire Pl.

Rectangular white aluminum panels give a clean and pure appearance to the façade of University Women's Club (UWC). The exterior architecture of the building is designed to express the contemporary production culture through the use of aluminum cladding system. Three different sizes

of circular windows create an interesting pattern for the plain looking exterior. The circular window and alternating pattern offer a spatial experience for users from only one singular form.

Figure 224: Exterior Facing Devonshire Pl. Site Plan. By author.

Figure 225: Exterior South East Day Perspective. By author.

Figure 226: Exterior South East Night Perspective. By author.

Light Shapes Space

DESIGN OUTCOMES | **FAÇADE DESIGN**

South-East

Figure 227: South East
Perspective Site Plan. By
author.

Figure 228: Exterior Facing St. Hilda's College Day Perspective. By author.
Figure 229: Exterior Facing St. Hilda's College Night Perspective. By author.

Facing St. Hilda's College

Figure 230: Facing St. Hilda's College Perspective Site Plan.
By author.

Figure 231: Exterior St. George Entrance Day Perspective. By author.
Figure 232: Exterior St. George Entrance Night Perspective. By author.

St. George Entrance

Figure 233: St. George
Entrance Perspective Site Plan.
By author.

Figure 234: Elevations. By author.

Elevations

Light Shapes Space

DESIGN OUTCOMES | **FAÇADE DESIGN**

NORTH EAST ELEVATION 1

NORTH WEST ELEVATION 2

SOUTH WEST ELEVATION 3

SOUTH EAST ELEVATION 4

0 2m 4m 8m

Figure 235: Elevations Site Plan. By author.

6.12 | Lighting Management

Electronic Control System: an Open Loop System

ATRIUM COURTYARD | OPEN LOOP SYSTEM

The electronic control system, an artificial-and-daylight control system, will be integrated into the building. It is used to control the output level of electronic lights based on the detection of daylight in the lighting zone. An open-loop system will be selected as the photo sensor, and will be located at the Overall Atrium Space. This type of system is an appropriate and effective control system for daylighting and electric lighting that will satisfy both energy-conservation and occupant needs for an atrium space.

MATERIAL SELECTION

INTERIOR FINISHES: Light colored surfaces

GLAZING SELECTION: Triple-pane, low-e glazing with vinyl frames

Light-coloured surfaces are selected for the interior of the atrium because they are better for daylight performance (due to their reflective properties). They reduce cooling loads and the “urban heat island effect”.

Triple-pane glazing lets in high levels of daylight

while simultaneously minimizing solar cooling and winter thermal loss. The large area of the roof monitor enhances the building’s daylight usage. Clear visible glass and triple plane glazing with a properties of electrochromic glass are chosen for the roof monitor window to maximize lighting distribution in the atrium space. It is difficult to control light with clear visible windows so daylight penetration is controlled by a roof monitor with translucent glass louvers, and by a reflective pool for effective interior treatment.

LIGHTING SOLUTION

The atrium requires a large amount of energy if it is heated and cooled. As a result of this issue, a reflective pool was introduced to reduce the heat gain and heat loss of the space. The courtyard space on the ground floor of the atrium controls daylight penetration with glass louvers. The electrochromic glazing controlled shades on the atrium skylight – roof monitor is recommended for a flexible and sun- responsive architecture.

Figure 236: Daylight Photo-sensor Diagram. By author.

Daylighting Calculation

The large atrium space maximizes core daylight that approximates the full daylight of an outdoor space. A roof monitor is integrated into the design, top-lighting the space for optimal daylight distribution, control of glare, and noise attenuation.

The arrangement of the roof monitor allows daylight to enter the space from all directions and this may result in excessive heat gain. To counter this effect, light- filtering shades are installed on the monitor on summer days and on the bottom of the space a reflective pool is located in the atrium to reduce heat.

The following tables and chart show daylight calculation for the atrium space. The effectiveness of atrium lighting depends on the translucency and geometry of the atrium roof. The reflectance of the atrium wall and the geometry of the space area are taken into account for calculating the work plane illuminance.

ROOF MONITOR WITH GLASS LOUVER

The ideal illuminance for the Atrium is 2000 lx or 200fc. Referring to the calculation result, the average illuminance on workplane is 1302lx or 130fc. (Illuminating Engineering Society of North America, 2000) Due to the reflection of water, however, the illuminance of the atrium is estimated to increase to 700-800lx or 70-80fc.

Louvers are, therefore, introduced on the ground floor. The glass louvers filter light and control daylight distribution on the ground floor only. Distributed light is diffused and softened, so that it allows users to pass through and dine in a calm environment.

JUPITER SKYLIGHT TOOL

The Jupiter is a skylight calculation tool, a spreadsheet from the Lighting Research Center. Its output results are not guaranteed or imply a warranty or accuracy of its computed output. All calculations are performed with equations from the IESNA Handbook, Ninth Edition. The purpose of the Jupiter calculation tool is to determine the number of skylights and their sizes within the given geometry for the exploration of daylight calculations.

ERRORS WITH LUMEN METHOD

When calculating the CU value for such enormous room dimensions, the lumen method presents a problem. The CU Chart's room dimension does not exceed 40' in width and length, 14' in ceiling height. Thus, it is a challenge to calculate the project manually. As a result, the Jupiter Spreadsheet become a source to calculate the illuminance of the Atrium Space.

Figure 237: Recommended Illuminance Chart. By author.

Space	Recommended Illuminance	Ideal Illuminance
Atrium (Adequate for indoor plants to be incorporated in the atrium space)	1000-2000lx 100-200fc	2000lx 200fc
Warm Bath (Adequate for indoor pools)	150-300lx 15-30fc	300lx 30fc

Figure 238: Daylight calculation generated from Jupiter Skylight Spreadsheet. By author.

Jupiter: a skylight calculation tool

Enter information into white cells; calculated results are shown in yellow cells

To import weather data, macros must be enabled in Excel. See the instructions page for more information.			
Enter room characteristics below			Rule of Thumb Method
Room Dimensions			Results based on 1.5 x Ceiling Height
			Minimum number of skylights needed to meet minimum uniformity guidelines
Enter Length of room	41	Feet	1
Enter Width of room	20	Feet	Average Illuminance on workplane
Enter Ceiling Height of room	34	Feet	1302
Selected City Location	TORONTO, ONT.		Average Daylight Factor
Daylit Zone per skylight	2601	SF	52.4%
Maximum Spacing	51	SF	Skylight-to-Floor Ratio (SFR)
Room reflectances			100.0%
Ceiling Reflectance	80	%	Total skylight area
Wall Reflectance	70	%	820
Floor Reflectance	20	%	Total workplane area
			820
			# Skylights along room length
			1
			# Skylights along room width
			1
			Maximum spacing between skylights
			16 Ft. OC along room length x -6 Ft. OC along room width
			Feet
Skylight characteristics			Lumen Method
			Results based on Illuminance Criteria, room dimensions, reflectances and skylight characteristics
Visible transmittance	90	%	Minimum number of skylights needed to meet desired Illuminance on WP
Skylight Length	41	Feet	1
Skylight Width	20	Feet	Average Illuminance on workplane
Well Height	8	Feet	1302
Well reflectance	70	%	Average Daylight Factor
Skylight dirt depreciation	Clean - 70%	%	52.4%
			Skylight-to-Floor Ratio (SFR)
			100.0%
			Total skylight area
			126
			Total workplane area
			820
			# Skylights along room length
			1
			# Skylights along room width
			1
			Maximum spacing between skylights
			16 Ft. OC along room length x -6 Ft. OC along room width
			Feet
Illuminance Criteria			Skylight size is optimized
Average Daylight Contribution on WP	200	Fc	
Workplane Height	30	Feet	
Hours of interest	8:00	Start time (24 hr clock)	
Hours of interest	20:00	End time (24 hr clock)	

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Figure 239: Lumen method Graph generated from Jupiter Skylight Spreadsheet. By author.

Figure 240: Rule of Thumb Method Graph generated from Jupiter Skylight Spreadsheet. By author.

Lumen Method Calculations

	41'	Length	
	20'	Width	
	34'	Height	
	30'	Workplane Height	
	70%	wall reflectance	
	80%	ceiling reflectance	
	20%	floor reflectance	
	13%	RCR	
Total Skylight Area = Number of skylights x Area per skylight			
TOTAL SKYLIGHT AREA		126 sqft	
	0.95	CU,room	
	0.88	CU, well	
	0.7	Dirt depreciation factor, skylight	
	0.9	VT	
	0.0806	DF, predicted	
	820 ft2	WP Area	
	41'	Skylight length	
	20'	Skylight width	
NUMBER OF SKYLIGHTS, predicted		1	
	1 SFR,	actual	
	0.524477	DF, actual	
	4148 sqft	wall area	
	820 sqft	ceiling area	
	820 sqft	floor area	
	0.643331	average reflectance	
DF CALCULATIONS			
	200	desired fc level	
	25	average E from pivot table (at 1% DF)	
	4300	0.046512	
HOURS OF INTEREST			
	8:00:00 AM	AM start	
	8:00:00 PM	PM start	
ASPECT RATIO OF ROOM			
	2.05	L: W	
	0.487804878	W: L	
	1	Skylights per length	1
	1	Skylights per width	1
	41	Max spacing between sky-lights	
	1		
SPACING	L	16	16, W -6 -6
	16 Ft. OC along room length x -6 Ft. OC along room width		

Rule of Thumb method calculations

coverage 2601

row spacing = n/a

max spacing 51'

min skylights per length 1

min skylights per width 1

skylights recom-mended 1

skylights for mini-mum uniformity 1

spacing along length 16

spacing along width -6

16 Ft. OC along room length x -6 Ft. OC along room width

SFR, actual 1

DF, actual 0.524477

Simple equation for # skylights 0.315263

Parameters Data

ROOM PARAMETERS (FROM INTERFACE TAB)

41' Length

20' Width

34' Ceiling Height

30' Workplane Height

70 wall reflectance

80 ceiling reflectance

20 floor reflectance

2 RCR

CU CALCULATIONS - INTERMEDIATE

80 0.99 CU if ceiling = 80

50 0.737 CU if ceiling = 50

20 0.72 CU if ceiling = 20

0.95 CU, final

SKYLIGHT PARAMETERS

41 Skylight Length

20 Skylight Width

8 Well Height

70 Well reflectance

3 WCR, well cavity ratio

0.88 CU, well

Lighting Energy Saving Opportunities

Rensselaer Polytechnic Institute's software Energy Saving estimator, is used to calculate the lighting energy saving from daylight harvesting

Energy savings estimator			
	Inputs	Comments / Instructions	
Building length (East-West axis)	108	Feet	Enter data in green cells
Building width (North-South axis)	83.7	Feet	
Building area per floor	9039.6	SF	
Number of floors	2		
Lighting power density	0.8	Watts / square feet	
Building lighting load	14.46336	kW	
Operating hours per day	12	Hours	Assumes up to 12 hrs / day are during daytime hours
Operating days per week	7	Days	
Operating weeks per year	48	Weeks	
Sidelighting used?	Yes		Select from pull down list; if Yes, complete cells B27 and B37
Toplighting used?	Yes		Select from pull down list; if Yes, complete cells K27, K28 and K37
Utility Rates			
Demand Charges			
Summer Demand rate	\$17.16	per kW	
Winter Demand rate	\$17.16	per kW	
Number of months daylight harvesting can reduce demand charges	8	Months	Demand Profiles will provide information on potential savings
Energy Charges			
Summer energy rate	\$0.17	per kWh	
Winter energy rate	\$0.13	per kWh	
Total estimated annual savings	\$2,247		

Demand Savings from Daylight harvesting - Sidelighting		
Perimeter size	383	Linear Feet
% of sidelighting primary zone without fenestration	35	%
Primary daylighting zone on each floor	3153	SF Perimeter x 15 Ft primary Zone
Total primary daylighting zone	5676	SF Daylight zones for all floors
Energy use in primary daylight zone	4.5	kW
kW-Months	36.3	kW Months
Annual demand savings from sidelighting	\$416	

Energy Savings from Daylight harvesting - Sidelighting		
Yearly daytime lighting hours	4032	hours
Annual energy use	36615	kWh
% savings from daylight harvesting in primary zone	25	% User input energy savings data (default value - 25%)
Annual energy reduction in primary zone	4577	kWh
Annual energy savings from sidelighting	\$687	

Figure 241: Energy Saving Estimator Charts. By author.

Energy savings from daylight harvesting	
Annual demand savings from sidelighting	\$416
Annual energy savings from sidelighting	\$687
Annual demand savings from toplighting	\$314
Annual energy savings from toplighting	\$831

Demand Savings from Daylight harvesting - Toplighting			
Building area not in sidelighting primary zone (core)	4189	SF	
% of core building area to be toplit	75	%	
% of sidelighting primary zone that may be toplit instead	20	%	Only applicable if sidelighting is used
Primary daylighting zone for toplighting	4292	SF	Only top floor can be daylit with this method
Energy use in primary daylight zone	3.4	kW	
kW-Months	27.5	kW Months	
Annual demand savings from toplighting	\$314		

Energy Savings from Daylight harvesting - Toplighting			
Yearly daytime lighting hours	4032	hours	
Annual energy use	13843.1462	kWh	
% savings from daylight harvesting in primary zone	40	%	User input energy savings data (default - 40%)
Annual energy reduction in primary zone	5537	kWh	
Annual energy savings from toplighting	\$831		

Daylighting economic calculations should also account for potential reductions in internal heat gain, increased solar heat gain and increased winter heating requirements. Because of the reduction in internal heat gain, there are potential reductions in heating equipment, including compressors and distribution systems.

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Figure 242: Energy Saving Estimator Charts and Graph. By author.

Figure 243: Reflective Pool Night Perspective. By author

How light influences our perception of space

LIGHT SHAPES SPACE

APPENDIX

7

ARCHITECTURAL DRAWINGS

Site plan | Floor Plans | Building Sections

Site plan

Figure 244: Site Plan. By author.

(1) UNIVERSITY WOMEN'S CLUB UWC

Ground Floor Plan

ACTIVE | PUBLIC | ENERGIZE

Figure 245: Ground Floor Plan. By author.

Second Floor Plan

QUIET | PRIVATE | TRANQUIL

UNIVERSITY WOMEN'S CLUB UWC

L2 SPA FLOOR QUIET | PRIVATE | TRANQUIL

1. Foyer	6. Massage Room
2a. Change Shoes	7. Spa Seating area
2b. Common Tea Room	8. Tea Room Corridor
3. Outdoor Exercise	9. Treatment Room
4. Change Room	10. Private Tea Room
5. Warm Bath	11. Tea Room Terrace

Figure 246: Second Floor Plan. By author.

Basement Floor Plan

SILENCE | MEDITATIVE

Light Shapes Space

APPENDIX | ARCHITECTURAL DRAWINGS

B1 EXERCISE FLOOR SILENCE | MEDITATIVE

- 1. Foyer
- 2. Seating Area
- 3. Unisex Change / Shower / Washroom
- 4. Indoor Yoga Studio
- 5. Underground Connection to the Goldring Center for High Performance Sport
- 6. Staff Room
- 7. Service Space

Roof Plan

SKYLIGHT | BRIGHT |

RF ROOF PLAN
SKYLIGHT | BRIGHT |

Figure 248: Roof Plan. By author, 232

Section A

Figure 249: Building Section A. By author.

Section B

Figure 250: Building Section B. By author, 234

Section C

Figure 251: Building Section C. By author.

Section D

Figure 252: Building Section D. By author, 236

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