DIMMING THE CITY

by

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CONTENTS

ABSTRACT

This thesis addresses light pollution, specifically overillumination, in cities. It examines the history of artificial lighting, the consequences of excessive light, and the motivations for its continued overuse: fear and normalization. My critique is aimed at urban design and architecture that does little to address the night, exacerbating our dependence on artificial light. The experiment investigates how the integration of minimal artificial light and architecture might alleviate our discomfort with the dark through the design of a city block. Drawing from the study of visual perception, principles were developed to assist in the design of nighttime environments in which we not only feel at ease, but that we embrace, thereby reducing both the need for and the amount of artificial light at night.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

> At the second match the wick caught flame. The light was both livid and shifting; but it cut me off from the universe, and doubled the darkness of the surrounding night.[1]

One rare, cloudless night on the west coast of British Columbia, I set out with a few friends in search of the Perseid meteor shower. To escape the orange glow of Vancouver's lights, we drove north along Highway 99 in search of darkness. It was a surprisingly arduous task to escape the bright sky. After an hour, we came upon an old logging road and began our ascent into the mountains. Eventually, we arrived at a clearing where we were awarded with a myriad of meteors shimmering across the sky. Nestled in my sleeping bag, looking up at that gorgeous display, I came to the realization that we were missing out on something quite wondrous and forgotten – the night.

Image 1.
Milky Way, photograph from pixabay.com

1 Robert Louis Stevenson, Andrew Lang, and Sidney Colvin, *The Works of Robert Louis Stevenson* (London: Chatto & Windus, 1911): 53.

One hundred and fifty-six years after incandescent light bulbs were first introduced to the world, our disconnect with night continues to grow as our surroundings become brighter. Artificial light encroaches into the remaining darkness as the cost of light falls, excessive brightness is normalized and our fear of the dark persists. We have designed our urban nights to be a continuation of the day, favoring uniform, diffuse lighting while failing to question what we lose when we banish the dark.

Image 2.
Collage: Between City and Night, 'Airplane'; base image from pexels.com.

By drawing upon an understanding of visual night adaptation processes it is the intention of this thesis to create nighttime environments in which we not only feel at ease, but that we embrace, thereby reducing both the need for and the amount of artificial light in our nighttime environment.

The ambition for the work is that this exploration into designing with minimal light will provide an alternative to the over-illumination that characterizes urban centers, and will serve as an alternative to a rapidly urbanizing and brightening world.

Image 3.
Collage: Night Obscured. 'City Highway;' base image from Pexels.

Thesis Question

How can the integration of artificial light and architecture reduce overillumination and reconnect urban dwellers with the night?

Definitions

Light pollution is simply the excessive or inappropriate use of artificial light. There are five components of light of pollution: sky glow, glare, light trespass, clutter and overillumination.

Sky glow

Sky glow is the brightening of the night sky over cities and other illuminated areas by excessive or misdirected light.

Glare

Glare is extreme brightness that causes visual discomfort such as the headlights of an oncoming vehicle.

Light Trespass

Light trespass occurs when light is cast where it not intended, needed or desired.

Clutter

Clutter refers to superfluous, confusing groupings of light.

Overillumination

Overillumination is the excessive use of light.

The components of light pollution are interrelated. For example, overillumination contributes to sky glow. While

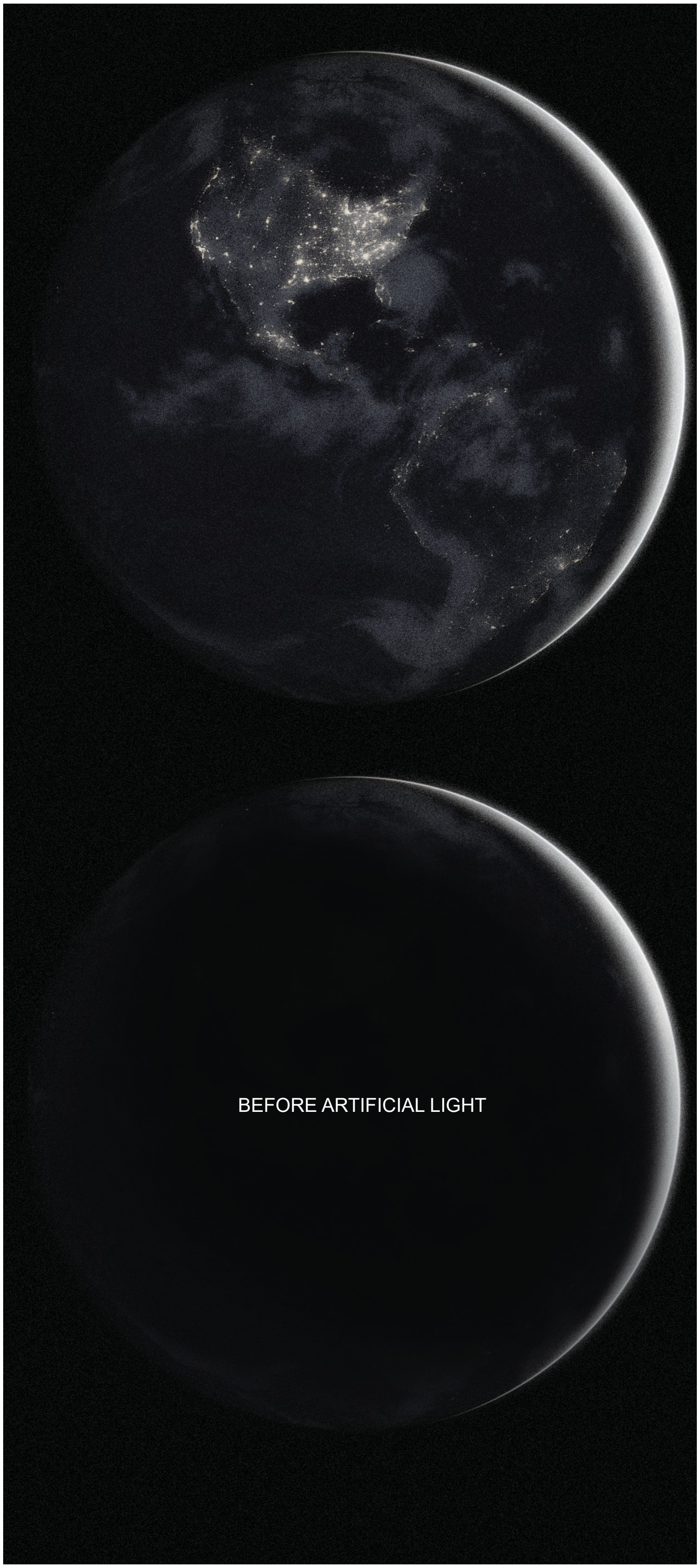

Image 4.
Adaptation of NASA Satellite; base image 'Earth at Night' by NASA.

this thesis primarily will focus on reducing overillumination in urban centres, it is important to recognize that reducing general overillumination has an impact on the other components of light pollution.

A Brief History of Artificial Light

Lighting technology evolved slowly in the beginning. While our ancestors first controlled fire at least half a million years ago, the earliest lamps, created by Ice Age humans, emerged only forty-thousand years ago.[2] These stone lamps were simply flat slabs of limestone with small, natural or carved depressions to hold a bit of tallow and moss. The next significant innovation occurred in roughly 500 BC, when Romans developed the wicked, beeswax candle, which gave "a fragrant, clear, steady flame."[3] Although improvements would be made to both the candle and oil lamp over the next two thousand years, no new breakthrough in lighting technology itself would transpire until the very end of the eighteenth century and fast-paced 'progress' would take off only in the nineteenth.

Following the Middle Ages, civic bodies made their first forays into urban lighting and required residents to place a candle on their windowsill or hang a lamp. In the world's largest, established cities, such as London and Paris, the first stationary oil lamps were installed and cared for by civic lamplighters.[4] Yet at this juncture, till the turn of the nineteenth century at the latest, the character of the light

2 Sophie A. De Beaune and Randall White, "Ice Age Lamps," *Scientific American* 266, no. 3 (1993): 108. doi:10.1038/scientificamerican0393-108.

3 Jane Brox, *Brilliant: The Evolution of Artificial Light* (London: Souvenir Press, 2012): 14.

4 Ibid., 28.

remained unchanged – the same faint, warm glow our ancient predecessors would have experienced.[5]

The Industrial Revolution ushered in a new era of lighting, beginning with the invention of the gaslight. Unrestricted by the size of its wick, the gas flame was much larger than that of an oil lamp.[6] Far brighter, cheaper and safer than oil and candlelight, gaslight was quickly adopted in factories and mines. It was not long before gaslight illuminated streets, shop windows, theatres, taverns and homes, changing the nightscape of the city dramatically and shifting its residents' comfort with the dark.

With the advent of electricity, the development of lighting technology gained momentum. Arc light, developed in the late nineteenth century, startled and overwhelmed city dwellers who "suddenly found themselves bathed in a flood of light as bright as the sun. One could have, in fact, believed that the sun had risen."[7] Far too bright to light interior space, the arc light was reserved for outside use and its intensity was such that it now required street lamps to grow taller, removing the source of light from the line of sight, fully blanketing the 'nightlife' below.

Edison's incandescent lightbulbs lit the first streets and neighborhoods in the early 1880s. The offices of the New York Times, which were among the first to be illuminated by incandescent, praised the consistency of the new light, "it seemed almost like writing by daylight to have a light without a particle of flicker."[8] It was the dawn of a new era.

5 Ibid., 58.
6 Ibid., 68.
7 Ibid., 104.
8 Ibid., 12.

Neon, fluorescent, halogen and LEDs were to follow in the 20th century. With each new, increasingly efficient lighting technology, our environment grew brighter.

The Need for Darkness

> Nighttime has remained a terra incognita of peripheral concern, the forgotten half of the human experience.[9]

By 1994, the residents of Los Angeles had become habituated to the near total erasure of the night sky to such an extent that the Northridge Quake Blackout prompted hundreds of residents to report a strange appearance in the sky to the Griffith Observatory and emergency services. Ed Krupp, director of the Observatory, recalled the event in an interview with the Los Angeles Times, "We finally realized what we were dealing with. The quake had knocked out most of the power, and people ran outside and they saw the stars. The stars were in fact so unfamiliar; they called us wondering what happened."[10] For the first time, the residents of Los Angeles were able to see the Milky Way.

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9 A. Roger Ekirch, *At Days Close: A History of Nighttime* (London: Phoenix, 2006), xxv.

10 Rong Gong Lin III, "A Desert Plea: Let There Be Darkness," *Los Angeles Time*s, January 04, 2011, http://articles.latimes.com/2011/jan/04/local/la-me-light-pollution-20110104/2.

Image 5.
Los Angeles at 'Night' or The View; photograph by Bryce David via Flickr

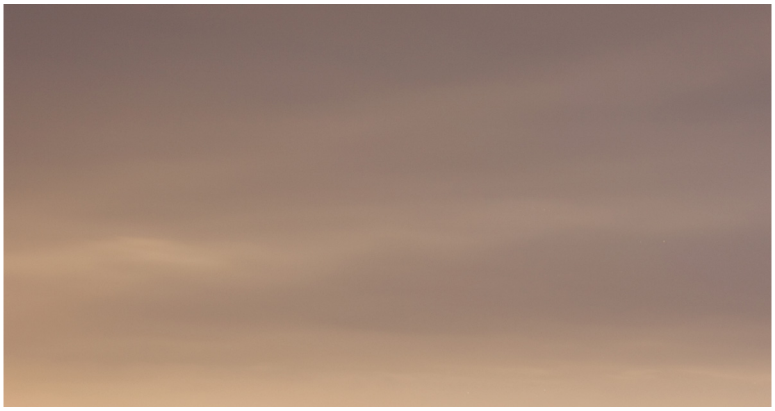

Image 6.
Inner City Sky; detail of photograph by Bryce David

Image 7.
Bright Suburban Sky; detail of photograph by Steve Hall.

Image 8.
Rural/Suburban Transition Sky; detail of photograph by Mike O.

Image 9.
Excellent Dark Sky; detail of photograph by James Faulkner.

Not long ago, the night sky was a universally available resource and, as a result, the stars and phenomena overhead shaped mythology and culture throughout the world.

The celestial motions have inspired writing, art, and architecture for millennia.

Perhaps, most importantly, the uninhibited night sky connected us to the wider universe and provided us with a glimmer into its vastness. The 'luminous fog,' as Falchi describes it, not only blocks our view of the show above, but in doing so diminishes our sense of scale.[11]

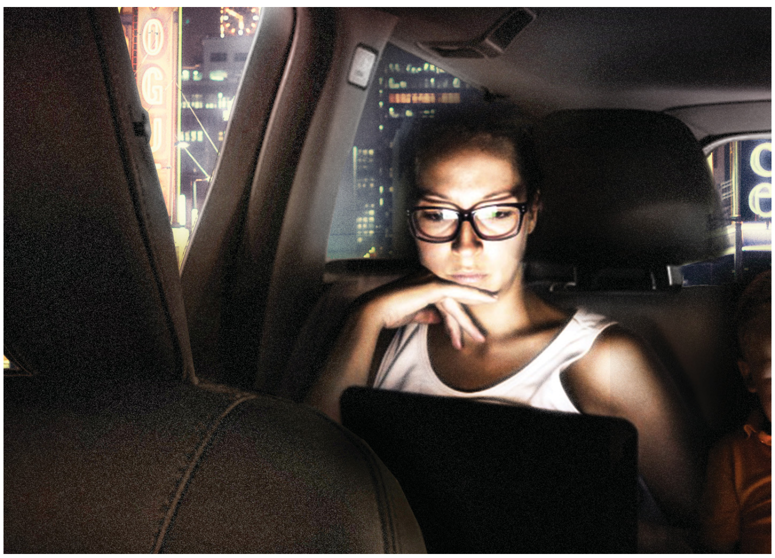

Image 10.
Collage: Looking Inward; woman from photograph by Andrés Nieto Porras.

> To be able to see the collective light from the stars making up our own galaxy gives a tantalising sense of the enormity of our universe and the structures within it. That so few people are not able to see now the Milky Way is a great loss. We are forcing ourselves to look inward and not outward...... If we don't [protect it], its inspirational value will be untapped and a site of scientific interest will be rendered accessible only using professional telescopes on mountains or on spacecraft.[12]

We are here on planet Earth but we live in a huge cosmos,

11 Fabio Falchi et al., "The New World Atlas of Artificial Night Sky Brightness," *Science Advances*, June 01, 2016, http://advances.sciencemag.org/content/2/6/e1600377.full.

12 Amanda Petrusich, "Fear of the Light: Why We Need Darkness," *The Guardian*, August 23, 2016, https://www.theguardian.com/environment/2016/aug/23/why-we-need-darkness-light-pollution-stars.

> and it's one of the things that links us to our position in the universe. And so it is wonderful to see it. I think by looking up at the stars we have endeavoured to do so many things, we've sent probes to Pluto and beyond, and if we lose contact with that I think we lose some of our ability to dream and to aspire. It starts with the Milky Way but where will it end?[13]

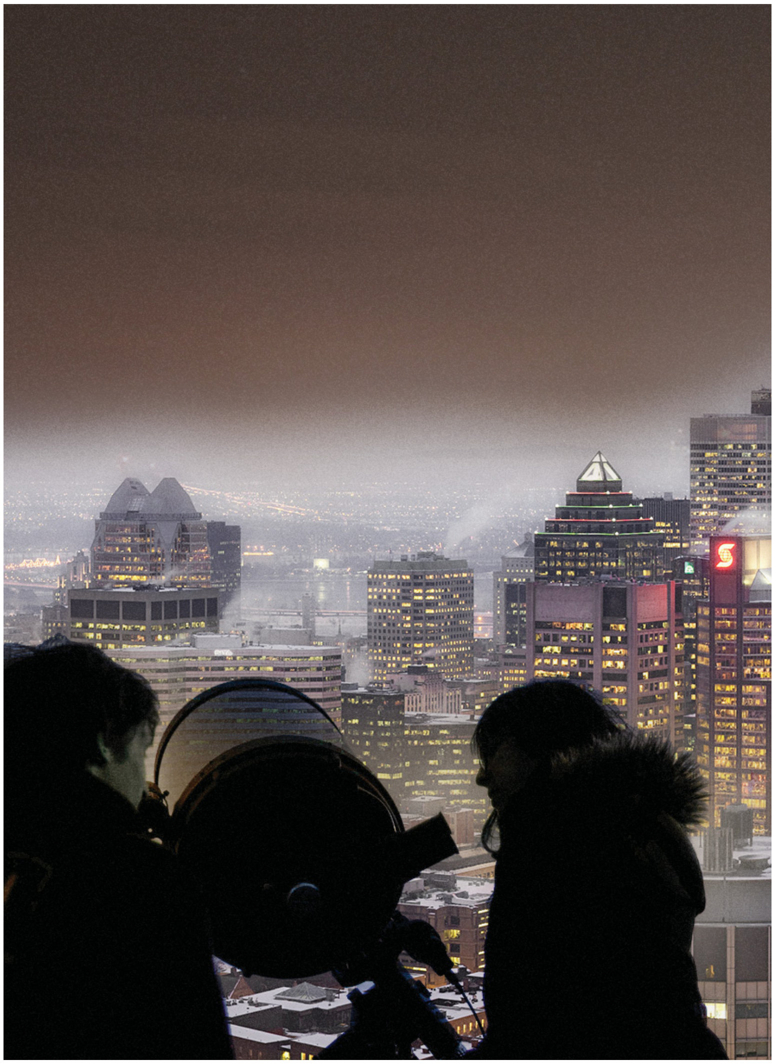

Image 11.
Collage: Urban Star Gazing; base photographs by Grand Canyon National Park and David Iliff.

Light pollution does not simply hinder our ability to view the night sky. Its reach extends to wildlife ecology, human health and climate.

Ecological Consequences

> What if we woke up one morning only to realize that all of the conservation planning of the last thirty years told only half

13 Ibid.

> the story—the daytime story? Our diurnal bias has allowed us to ignore the obvious, that the world is different at night and that natural patterns of darkness are as important as the light of day to the functioning of ecosystems.[14]

Life on Earth has evolved over the last 3.8 billion years to live in an environment that alternates between light and dark. In turn, many of the behavioral and physiological traits of the planet's inhabitants have been determined by this reliable cycle.[15] The disruption of the natural rhythm is widely thought to have a substantial and detrimental impact on the biology and ecology of numerous species. Confronted with artificial lighting at night, animals have been found to experience disorientation, attraction, or repulsion, which, in turn, affects behaviors such as foraging, reproduction, and communication. [16] The impact of lighting at night on wildlife is too great to discuss in entirety. Instead, I have chosen to briefly discuss select cases that have received wide scholarly attention.

Birds have long been studied in relation to light pollution and their attraction to lights is well documented. For example, it has been recorded that an off-shore platform accumulated roughly 200 birds within seven minutes of its lights being turned on. A further half hour resulted in the appearance of 4,000-5,000 birds. When the lights were shut off, the birds disappeared in 15 minutes.[17] Spheres of light, such as those produced by an off-shore platform or cityscapes, entrap birds leading to collision with the structure itself, predation

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14 Ibid.

15 Christopher C. M. Kyba et al., "Cloud Coverage Acts as an Amplifier for Ecological Light Pollution in Urban Ecosystems," *PLoS ONE 6*, no. 3 (2011): 1.

16 Travis Longcore and Catherine Rich, "Ecological Light Pollution," *Frontiers in Ecology and the Environment 2*, no. 4 (2004): 191.

17 J. Marquenie et al., "Bird-Friendly Light Sources: Adapting the Spectral Composition of Artificial Lighting," *IEEE Industry Applications Magazine* 19, no. 2 (2013): 57.

or collapse from exhaustion.

Sea turtle populations are catastrophically impacted by light pollution. While dark nesting sites are preferred and disappearing, artificial light most aggravates hatchling sea-finding. When sea turtles hatch, they instinctively crawl away from tall or dark objects toward the flat ocean horizon, lit by reflected light from the moon and stars.[18] It is widely thought that newly hatched turtles mistake artificial light for the ocean.

Fish and other marine species are also not immune to illumination at night. Lights along a migratory watercourse, for example, have been shown to increase predation of salmon fry by both fish and mammals. Increased lighting allows diurnal species to extend their foraging period. Along the Puntledge River in British Columbia, halogen lights assisted the foraging of harbor seals on outmigrating smolts.[19]

Numerous other species are affected by the brightening of our night. Bats congregate around street lamps in feeding frenzies.[20] Diminishing light is the trigger for the mating process of fireflies.[21] Zooplankton migrate vertically to feed on algal biomass only after the sun has set. [22] We have all witnessed the reaction of a moth to a flame.

18 Catherine Rich and Travis Longcore, *Ecological Consequences of Artificial Night Lighting* (Washington, DC: Island Press, 2006), 145.

19 Ibid.

20 Ibid., 43-46.

21 Ariel Firebaugh and Kyle J. Haynes, "Experimental tests of light-pollution impacts on nocturnal insect courtship and dispersal," *Oecologia* 182, no. 4 (September 19, 2016): , accessed April 21, 2017, doi:10.1007/s00442-016-3723-1, 1203-1211.

22 Christopher C. M. Kyba and Franz Hölker, "Do artificially illuminated skies affect biodiversity in nocturnal landscapes?," *Landscape Ecology* 28, no. 9 (2013): , doi:10.1007/s10980-013-9936-3.

The role of light in the physiology and ecology of plants is undeniable. Light is both a resource, in photosynthesis, and a source of information, used to determine the time of day and season of the year. Artificial light at night provokes physiological responses in plant life. It has been documented to cause the retention of leaves on deciduous trees as well as early budbursts (flowering). [23]

Climate

The release of carbon dioxide (CO_2) from the production and use of energy is a leading contributor to the acceleration of the greenhouse effect in which the atmosphere traps heat radiating from Earth. Rapid climate change, a consequence of the greenhouse effect, is now visible in many forms including: global temperature rise, warming oceans, shrinking ice sheets, glacial retreat, sea level rise, extreme weather events, ocean acidification and reduced snow coverage.

Light pollution, excessive illumination, and poor lighting design waste energy. The contribution of exterior lighting alone to CO_2 has been studied in the United States. It is estimated that light pollution in the lower 49 translates to a loss of nearly 72.9 million mwh of electricity, $6.9 billion a year, and the production of 66 million metric tons of CO_2.[24] The Environmental Protection Agency estimates that eliminating light pollution would be the CO_2 equivalent of taking over 9.5 million cars off the road. [25]

23 Jonathan Bennie et al., "Ecological effects of artificial light at night on wild plants," *Journal of Ecology* 104, no. 3 (2016): , doi:10.1111/1365-2745.12551.

24 Terrel Gallaway, Reed N. Olsen, and David M. Mitchell, "The economics of global light pollution," *Ecological Economics* 69, no. 3 (2010): 658, doi:10.1016/j.ecolecon.2009.10.003.

25 Ibid.

Daylighting in architecture has been hailed not only for its ability to create pleasing environments through the controlled admission of natural light, but for its ability to reduce the need for artificial lighting during the day, resulting in lower energy costs. While there have been attempts to address the reduction of energy consumption due to artificial light at night through the adoption of new technologies such as occupancy sensors, timers or energy efficient LEDs, few explore a low-tech approach that would reduce the need for artificial light at night in the first place.

Human Health

> "Humans are animals as well, and there's no reason to give ourselves any higher level in the ranking than everything else. And so when light/dark cycles mess up season patterns of trees or breeding cycles of amphibians, which I think is quite well established, there's no reason to think it's not going to do the same for us."[26]

Humans have developed internal clocks that evolved over the trillions of day/night cycles since life began on earth. These internal clocks are known as circadian rhythm, a cycle that controls physiological processes such as body temperature, cortisol levels, melatonin production, blood pressure, and urine production. Our 'clock' plays a role in our mood and cognitive ability. Most notably it cues us to sleep, wake and eat.

Artificial light, particularly the blue-spectrum light emitted by LEDs and CFLs, is known to disrupt this natural cycle resulting in poor vigilance and memory, reduced mental and physical reaction times, depression, insomnia, metabolic abnormalities, obesity, immune impairment and a greater

26 Paul Bogard, The End of Night: Searching for Natural Darkness in an Age of Artificial Light (London: Fourth Estate, 2014), 71.

risk of cancer.[27]

In 2007, the International Agency for Research on Cancer (IARC) recognized light at night as a probable carcinogen.[28] In 2016, the American Medical Association issued a statement advocating dimming and using lights with a colour temperature below 3000K.[29]

Barriers

Past Fears

Night, as historian Roger Ekirch explains, is "the most ancient of human anxieties. It has existed from time immemorial. Night was man's first necessary evil, our oldest and most haunting terror."[30] In our early history, we had good reason to fear the dark.

Before the agricultural revolution wiped out many of Europe's forests, wild, nocturnal predators, particularly wolves were a legitimate concern in the dark of night. The cries of owls, bats and toads were considered bad omens and linked with Satan.[31]

Streams and steep terrain would have been dangerous in those dark forests. Those who had to travel at night would have had to stick to familiar paths or reserve the journey for nights with a fuller moon to avoid fatal missteps.

27 Ron Chepesiuk, "Missing the Dark: Health Effects of Light Pollution," *Environmental Health Perspectives* 117, no. 1 (2009): 24 -27.

28 Ibid., 26.

29 Louis J. Kraus, *Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting*, report no. 2-A-16, Council on Science and Public Health, American Medical Association (Chicago, IL: American Medical Association, 2016).

30 A. Roger Ekirch, *At Day's Close: Night in Times Past* (New York: Norton, 2005), 30.

31 Ibid., 39-40.

Our body's circadian rhythm reaches its nadir in the wee hours of the morning, when our blood pressure reaches its lowest point.[32] This, in turn, is the reason why many deaths occur at night and why, for centuries, the belief that night itself was a contagion was widely held.[33]

Early urban centres offered a host of reasons to fear darkness. The additional hazard of tripping on dark stairways or the evacuation of the chamber pot, which occurred after nightfall, dissuaded many from an evening stroll.[34] At night, fires were a common threat in earlier times when people relied on candlelight as a source of night-time illumination. Referring to wood and thatch construction of early England, one writer remarked, "The English dwell and sleep, as it were, surrounded by their funeral piles."[35] London's Great Fire (1666) destroyed Old Saint Paul's Cathedral, 87 churches and more than 13,000 houses.[36]

Belief in supernatural beings such as ghosts, werewolves, vampires, witches and demons further fed the terror of night.

Present Fears

While we no longer need fear being devoured by wolves, vampires or rogue chamber pots, our unease with the night persists. At night, visibility is reduced and our environments often become deserted and quiet. Believing theft or assault await us, we avoid heading out into the night. Unsurprisingly, today nearly half of city dwellers fear walking alone in their

32 Ibid., 38.
33 Ibid.
34 Ibid., 48.
35 Ibid., 48.
36 Ibid., 49.

own neighborhood after dusk.[37]

Lighting at night plays an enormous role in our perceived safety.

Normalization

Today, cities are replete with sources of illumination – traffic lights, storefronts, headlights, advertisements, street lamps. We carry it in our hands (devices) and on our feet (LED shoes). Adding to our fear of the dark, we have become habituated to this unprecedented level of light at night.

Since some light has been shown to reduce crime and allows us to navigate at night, we assume that more illumination will make us even safer. When interviewed, lighting designer Roger Narboni explained the phenomena, “If you put up more lights for safety, very often and very quickly people will say, Oh, we don’t see enough, it’s not working, people are still being attacked, and we have problems and so we should put more light. And we’re going to go up and up and up. There is no limit, because the vision gets accustomed to that and we need more.”[38]

So how do we turn back the tide of over-illumination to which we have become so accustomed? It must begin by addressing these fears and by questioning the normalized levels of illumination.

37 Inc. Gallup, “In U.S., Women, Poor, Urbanites Most Fearful of Walking Alone,” Gallup.com, November 10, 2015, accessed April 26, 2017, http://www.gallup.com/poll/186563/women-poor-urbanites-fearful-walking-alone.aspx.

38 Bogard, “The End of Night,” 71.

CHAPTER 2: PERCEPTION

Easing Fear

Darkness alters our ability to see, a sense that we rely heavily on to understand our environment. Acknowledging the absence or alteration of information as a major component of our anxiety and discomfort in the dark, this chapter will examine visual perception in dim environments. Subsequent chapters will examine through translation and design how an understanding of perception at night may allow us to reduce our reliance on artificial sources of light.

Vision

A review of the anatomy of the eye is necessary before moving on to 'night' vision.

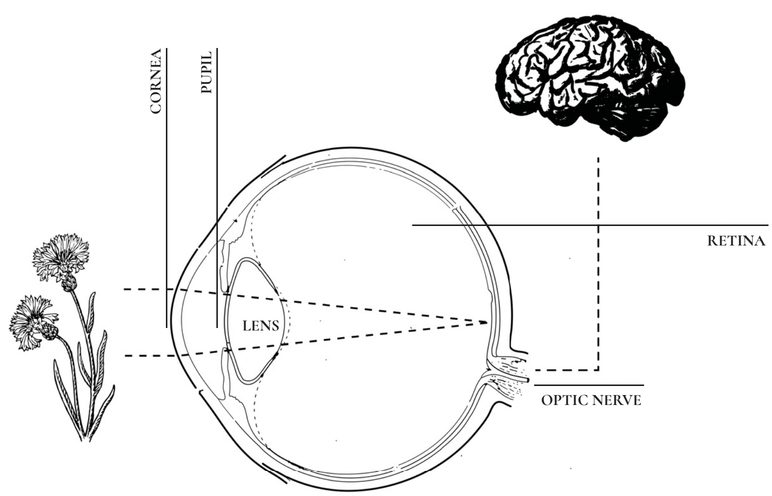

Image 12.
Anatomy of Eye.

When light bounces off an object it enters the eye through the cornea, a clear film that covers the front of the eye. The cornea bends the light toward the pupil, which dilates or contracts to regulate the amount of light that passes through to the lens. The lens focuses the light onto the outer layer of the retina where photoreceptors, rods and cones, send information by converting light into electrical activity to ganglion nerve cells in the inner retina. Information is then delivered to the optic nerve, which, in turn, passes it on to the brain to interpret. [39]

Luminance	Types of	Rods	Cones	Activity
0.00001				
0.00004	darkest night			
0.0001				
0.0004				
0.001	starlight natural skyglow			
0.004				
0.01				
0.04	quarter moon			
0.1	full moon			
0.4	deep twilight			
1				emergency lighting
4	clear sky just after sunlight			performance aisle lighting
12				emergency lighting
40	dark overcast day			club lounge
120				lobbies, dining
400	overcast day			offices
1200				demanding reading tasks
4000	skylight			
12,000				
40,000	full sunlight			some surgical procedures

Range and Modes of Vision

The human eye will never compare to species with nocturnal proclivities. Still we do have a far greater ability to see at night than many of us are aware. Our vision operates in extreme brightness, from high noon on snow capped

39 B.A Wandell, Foundations of Vision (Sunderland, MA: Sinauer Associates, 1995): 6.

Image 13.
Photopic Vision/'Night'; detail of photograph by Bryce David.

Image 14.
Photopic Vision/Day

Image 15.
Mesopic Vision/Dusk

Image 16.
Scotopic Vision/Night; detail of photography by James Faulkner.

mountains to a candle flickering miles away.[40]

Adaptation Times

Imagine that you are in a brightly lit room. If someone were to turn off all the lights suddenly, you would not be able to see well at first.

Dark adaptation is a process that takes time.

First the pupils must adjust. Finding ourselves in dim or dark environments, our iris relaxes, allowing the pupil to expand, allowing more light to enter our eyes. The dilation of the pupil is relatively fast – approximately 10-20 seconds, but that is only the first part of an adaptation process that can take up nearly an hour to complete.[41]

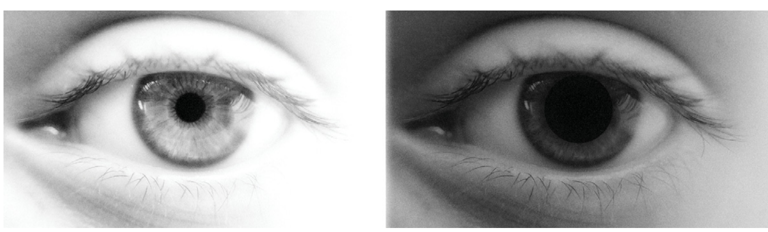

Image 17.
Pupil Dialation; adapted from 'Blue Eye' photograph from pixabay.com.

The second phase of dark adaptation is the recovery of retinal sensitivity after exposure to light, which bleaches rod and cone photopigments, reducing their sensitivity.[42] In dark environments, maximum cone sensitivity occurs after seven minutes while rods achieve maximum sensitivity after 45 or more depending on age.[43]

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40 Robert J. Snowden, Peter Thompson, and Tom Troscianko, An Introduction to Visual Perception (Place of publication not identified: Oxford University Press, 2006): 24.

41 Ibid., 34.

42 "Why does it take so long for our vision to adjust to a darkened theater after we come in from bright sunlight?" *Scientific American*, accessed July 28, 2017, https://www.scientificamerican.com/article/experts-eyes-adjust-to-darkness/.

43 Snowden et al., *An Introduction to Visual Perception*, 33.

It is crucial to recognize that our ability to see at night is not only determined by the scene currently before us, but closely linked to the previous scene as well. If moving from extremely bright settings to extremely dark settings, our eyes would require greater time to adjust than if we were to move from moderately dim to dark settings.[44]

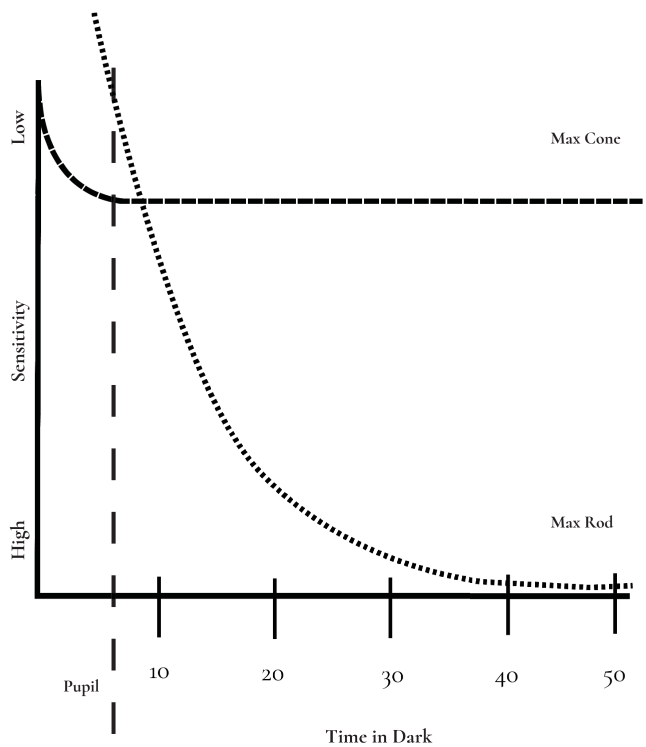

Image 18.
Dark Adaptation Curve; Diagram based on Hecht and Mandelbaum's data from From Pirenne M. H., Dark Adaptation and Night Vision. Chapter 5. In: Davson, H. (ed), The Eye, vol 2. London, Academic Press, 1962.

Unlike a camera, which produces a single exposure for an entire image, the different areas of the retina adapt locally when subjected to illumination of varying intensities or colour. After-images appear after intense or prolonged exposure to differing illumination. [45]

44 "Why does it take so long for our vision to adjust to a darkened theater after we come in from bright sunlight?" *Scientific American*, accessed July 28, 2017, https://www.scientificamerican.com/article/experts-eyes-adjust-to-darkness/.

45 R. W. Rodieck, *The First Steps in Seeing* (Sunderland, MA: Sinauer Associates, 1998): 314.

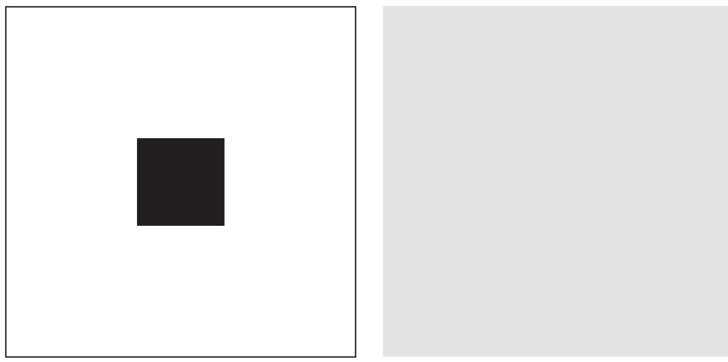

Image 19.
After-image example. Focus on the white box with the black square for one minute. Then move to the grey square. An after image of the black square should be visible.

By comparison, the process of light adaptation is much more rapid. The eye will become fully light adapted in only a couple minutes when exposed to brightness.[46] Accordingly, even brief exposure to light at night can undo the dark adaptation process at night. It is for this reason that pirates, who frequently moved between the pitch black of below deck and the sunshine above, wore an eye patch.[47] The eye patch allowed them to keep one eye dark-adapted allowing them to see in the dark.

Colour

Our ability to perceive colour is dependent on the amount of illumination. During the day or in bright conditions, cones are responsible for vision. Cones allow us to see by differentiating colour. In low lighting conditions, our cones are not sufficiently stimulated to transmit visual information to the optic nerve.[48]

At night, we see with rods. Rods do not register colour.[49]

46 Donald Kline, "Light Adaptation," *Light Adaptation*, accessed July 28, 2017, http://www.ucalgary.ca/pip369/mod3/brightness/lightadaptation.

47 Heidi Mitchell, "Burning Question," *The Wall Street Journal*, April 08, 2013, accessed July 28, 2017, https://www.wsj.com/articles/SB10001424127887323646604578404581544768850.

48 Rodieck, *The First Steps in Seeing*, 145-146.

49 Ibid., 32.

Image 20.
Differences in Scotopic and Photopic Vision, Detail from photograph by George Weinhaupl.

As a result, when our eyes are fully adapted to the dark our world is muted, appearing in black-and-white.

Acuity

Cones are equipped with individual bipolar neurons. This direct link preserves the fine details of the image, providing high acuity (sharpness).[50] Rods, on the other hand, are bundled together, sharing bipolar neurons.[51] While the convergence of rods is responsible for their sensitivity in low lighting conditions, we are unable to distinguish among multiple signals, resulting in a loss of acuity (blurred image).[52]

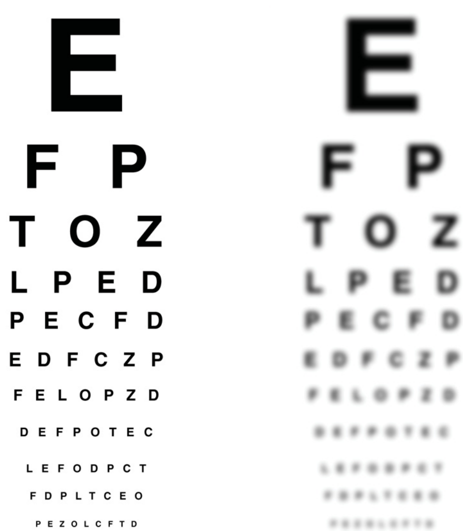

Image 21.
Acuity decreases from left to right.

Contrast

As our acuity is diminished and our colour vision is at best compromised or at worst nonexistant in dim conditions, contrast plays a significant role in our ability to see at night. Contrast sensitivity is the ability to perceive different

50 E. Bruce Goldstein and James R. Brockmole, *Sensation and Perception* (Boston, MA: Cengage Learning, 2017):60.

51 Ibid.

52 Ibid.

luminance levels in a scene. Our ability to detect contrast is influenced by the overall brightness of a space as well as the intensity of both ambient and background light. Large objects require less contrast sensitivity and are easier to process. Details and patterns require greater sensitivity.

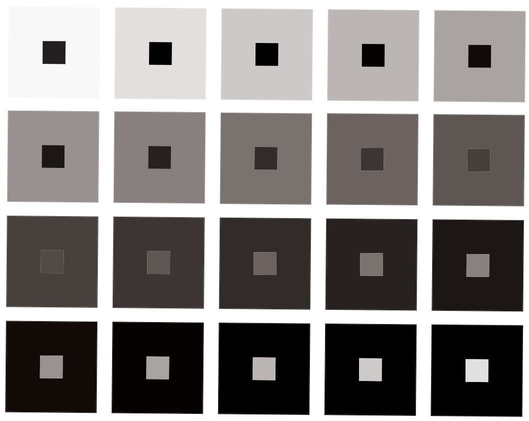

Image 22.
Contrast.

Peripheral

Cones and rods are distributed across the retina differently. Cones are primarily concentrated in the centre of the retina, in a small depression named the fovea, while rods are located in the periphery of the retina.[53] As a result, at night, our peripheral vision is enhanced.[54]

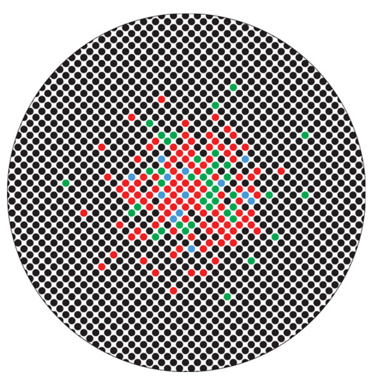

Image 23.
Diagram of distribution of cones and rods.

53 Snowden et al., *An Introduction to Visual Perception*, 34.

54 Ibid.

Affective Perception

It is important to recognize that while enhancing our ability to collect visual information is a part of designing for comfort at night, the mechanics of the eye are only one component of environmental perception.

As William Lam explains in *Perception and Lighting as Formgivers for Architecture*, "perception is not simply a passive recording process which receives and processes all incoming sensory stimuli indiscriminately [...] The unconscious biological mechanisms of perception handle most of this sorting and selecting automatically, although they require time and experience to learn how to do so."[55]

For Lam, three qualities influence our affective evaluation, our emotional response, of a space: expectation, order and hierarchy of foci.

I will also discuss a fourth quality - colour temperature.

Expectation

A positive or negative assessment of a space is related to whether or not it meets our expectations.[56] Visual gloom is experienced when the luminous environment lacks an expected or desirable quality such as a lack of information or appropriate focal points. This is aggravated, according to Lam, by the awareness of a better alternative. He explains, "generally speaking, we expect interior spaces to be bright during the day, while dimly lit spaces seem perfectly natural at night because of adaptation and orientation to the

55 William M. C. Lam, *Perception and Lighting as Formgivers for Architecture* (New York: McGraw Hill, 1977):17.

56 Ibid., 52.

nighttime environment with its typically low light levels. Thus a dark cocktail lounge will never seem gloomy at night because of a lack of light."[57] The context of light/darkness influences our perception of it.

Order

Order is comforting. According to Lam, "observable order and organization set up strong expectations, and when these expectations of consistency are not fulfilled, the environment may be perceived as disorderly and chaotic." [58] He suggests that lighting closely related to an overall building pattern or structure, is preferred.

Hierarchy of Foci

Lam uses a chandelier in a theatre as an example. If lit during the performance, it is a glaring distraction. During intermission, on the other hand, the same lamp is interpreted as a beautiful ornament.[59] The most brightly illuminated objects should be the intended subject.

Colour Temperature

Additionally, colour temperature may have an impact on our perception of a space. Cool (blue-white) temperatures are thought to provoke a fight or flight (startle) response, especially in dim settings.[60]

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57 Ibid., 54.

58 Ibid., 52.

59 Ibid.

60 M. R. Basso, "Neurobiological Relationships Between Ambient Lighting and the Startle Response to Acoustic Stress in Humans," *International Journal of Neuroscience* 110, no. 3–4 (January 1, 2001): 147–57, doi:10.3109/00207450108986542.

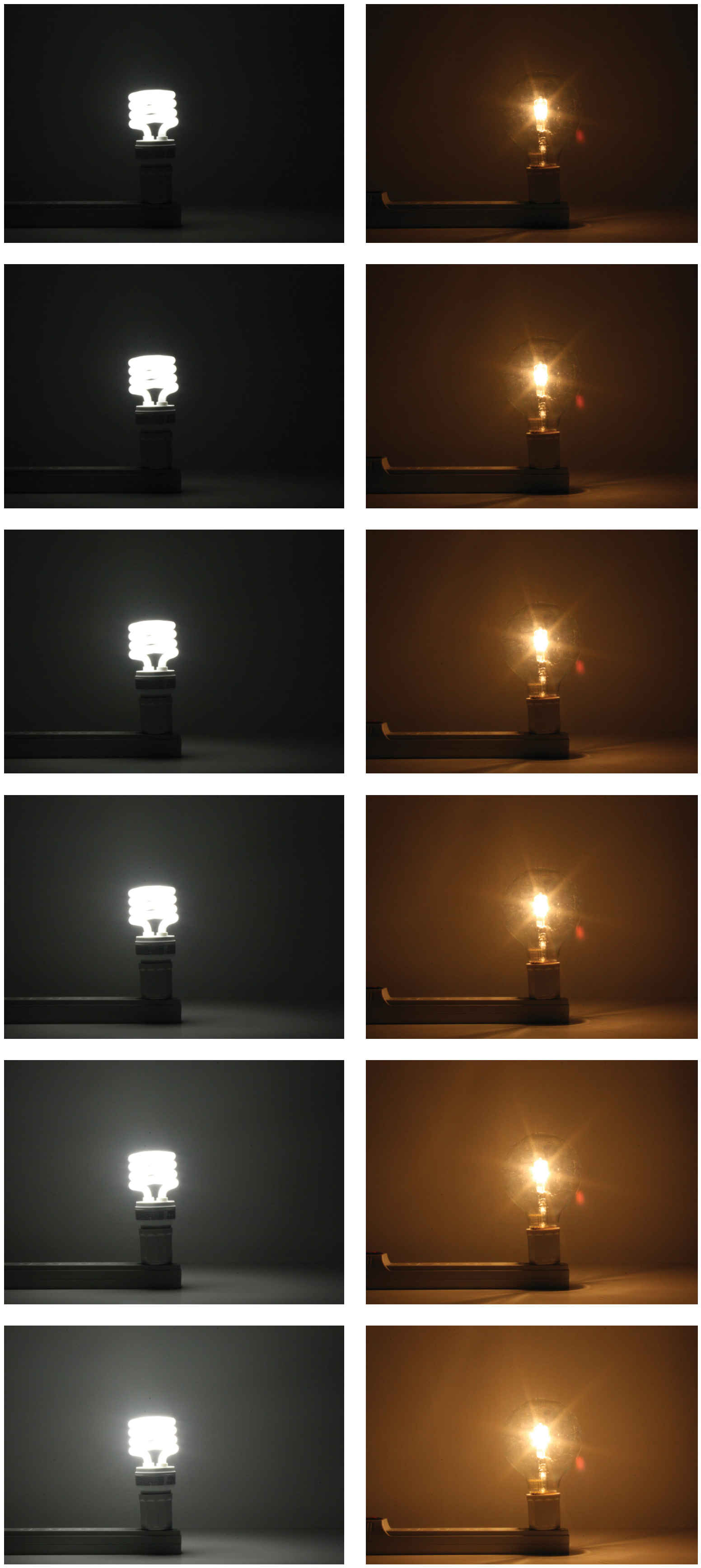


Image 24.
Cool white CFL vs warm incandesecent bulb

Case Studies

A range of sites were studied to understand and uncover the qualities of succesful nocturnal environments.

De Wallen, Amsterdam, Netherlands

Image 25.
Red-Light District; photograph from Pixabay.

The boundaries of De Wallen, the famed red-light district of Amsterdam, are clear. They are marked by the introduction of the soft, red glow of neon signs and tall, human-sized shop windows. The consistency of the district allows low lighting. Visitors do not question or fear the relative dimness as it appears to be an intentional characteristic of the district.

The subject of the red light district is evident. Sex workers in the windows are lit while ambient lighting is reduced. Additionally, their movement draws visitors' attention. They create a visual distraction from the night.

While some street lighting exists in the district, it is warm and soft. It does not compete with the subject of the district. Generally lighting is kept low to the ground as opposed to overhead lighting. In some areas, the streets and alleys are lit by the warm glow of the shop windows themselves. The lighting is shared by performer and audience.

The Highline, New York, United States

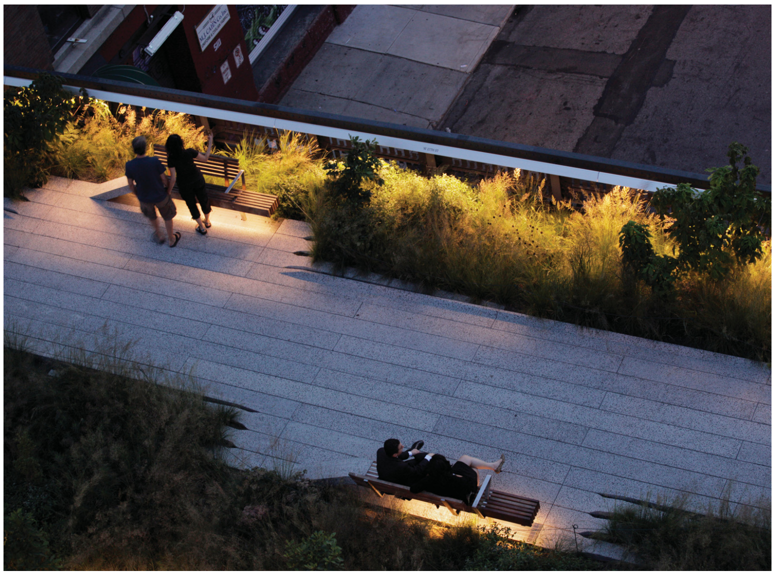


Image 26.
The Highline; photograph by Emile Dubuisson.

Similar to De Wallen, the Highline is a cohesive district with a consistent material palette, lighting scheme and architectural style. Rather than illuminating the Highline pathway itself, lighting is primarily utilized along the edges of pathways, where it is integrated with vegetation. Tall grasses provide not only a soothing subject for contemplation, but temper any glare from the bulb. Additionally lighting is integrated with benches, which direct it downward.

The separation of vehicle and pedestrian traffic further reduces the need for higher levels of illumination and creates a distinct break from the rest of the city. The position of the street below prevents light sources that may offend the adapted eye, such as headlights or advertisements, from reaching it.

Waitomo Caves, Waitomo, New Zealand

Image 27.
Glow Worm Caves New Zealand; photogragh from Artofvizuals via flickr.

The Waitomo Cave, found on the North Island, is home to a species of glow worm. These caverns illustrate how distraction, in this case delight and wonder, can contribute sense of ease in dimly lit environments, even in those which, under most circumstances, would be unappealing.

Alley, Vancouver, Canada

Image 28.
Alley; photograh by Cat Wong

Unlike the three prior case studies, the alley is brightly lit by cool-white lamps. It illustrates that high illumination levels alone do not guarantee a sense of ease in the urban environment. The scene lacks visual interest and illuminates objects and qualities, such dumpsters and isolation, that may be perceived in a negative light.

CHAPTER 3: SITE

To recover the night, the integration of artificial light and architecture is explored through the design of a 'dark' district, a city block, in the heart of Vancouver, British Columbia. While the motivations behind the design of a district will be discussed in Chapter 5, Chapter 3 will discuss how the site itself was selected.

City Selection

Canada, with its long winter nights, is among the most light polluted countries in the world (in terms of percentage of population exposed to light pollution).[61]

Vancouver, a major city on Canada's West coast, was chosen for a variery of reasons. Primarily, its proximity to the water, above average yearly cloud coverage, high density and increasing population make this coastal city particularly vulnerable to light pollution.

Image 29.
Vancouver at Night; photograph by Matthew Grapengeiser.

61 F. Falchi et al., "The New World Atlas of Artificial Night Sky Brightness," Science Advances 2, no. 6 (2016): , doi:10.1126/sciadv.1600377.

Site Selection

Contributing to Vancouver's propensity to overillumination, the city has a historic affinity for artificial lighting. Midcentury, "there were 19,000 neon signs in the city of Vancouver — one for every 18 residents."[62] Granville Street was the most decorated street in the city.

Today, it continues to be one of the most brightly lit sections of the city. The street is a major transit thoroughfare traversing the downtown core and cutting through business, shopping, entertainment and residential areas.

It was an appealing choice for this experiment in two ways. First, it serves as a stark contrast to the proposed district, highlighting my critique of current illumination levels. Second, it provides an opportunity to exam how we might transition from light to dim or dark within the urban environment.

The district will begin at the southern end of the Granville Street corridor, at the outskirts of the popular entertainment district. It will then stretch eastward, away from the bright lights of the city centre, toward Yaletown, a residential neighbourhood on the edge of False Creek.

62 John Mackie, "Bright lights, old city: Remembering Vancouver's neon glory," *Vancouver Sun*, accessed July 30, 2017, http://www.vancouversun.com/Bright lights city Remembering Vancouver neon glory/2221273/story.html.

Image 30.
Granville Street 1; photograph by Cat Wong.

Image 31.
Granville Street 2; photograph by Cat Wong.

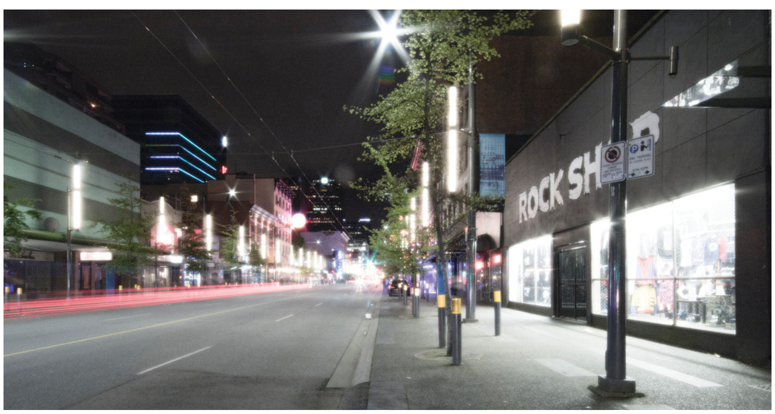


Image 32.
Granville Street 3; photograph by Cat Wong.

Image 33.
Granville Street 4; photograph by Cat Wong.

Image 34. Granville Street 1968; photograph from Vancouver Public Library Historical Photographs.

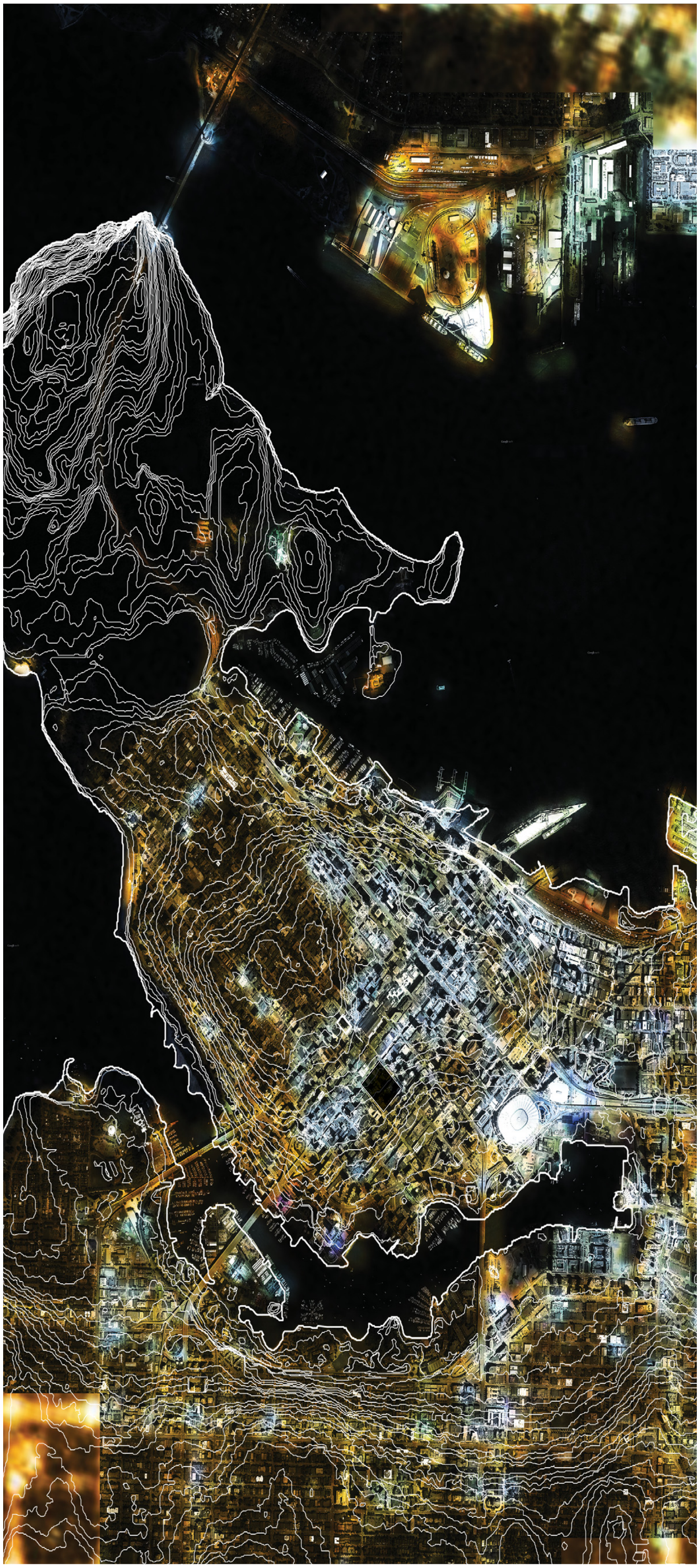


Image 35.
Topography with Satellite Overlay from NASA.

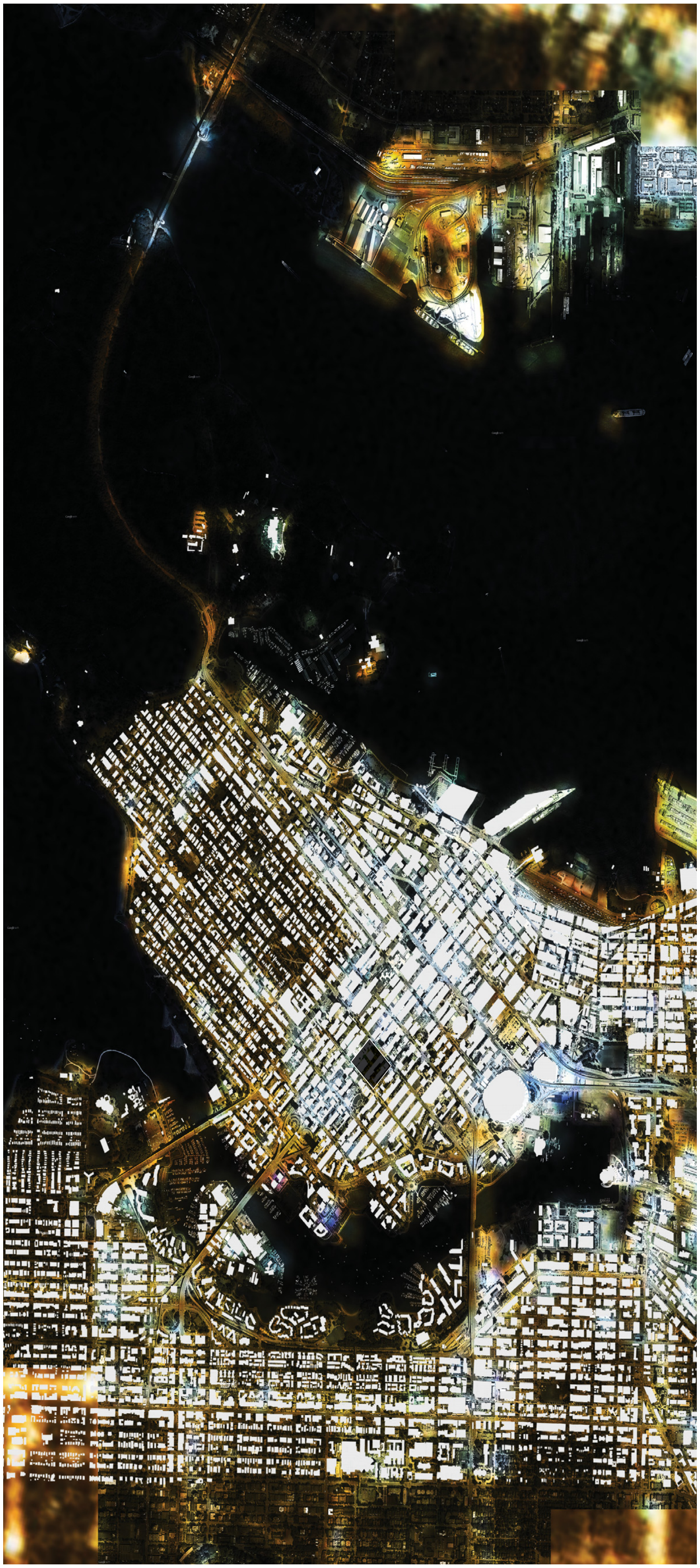


Image 36.
Building footprints with Satellite Overlay from NASA.

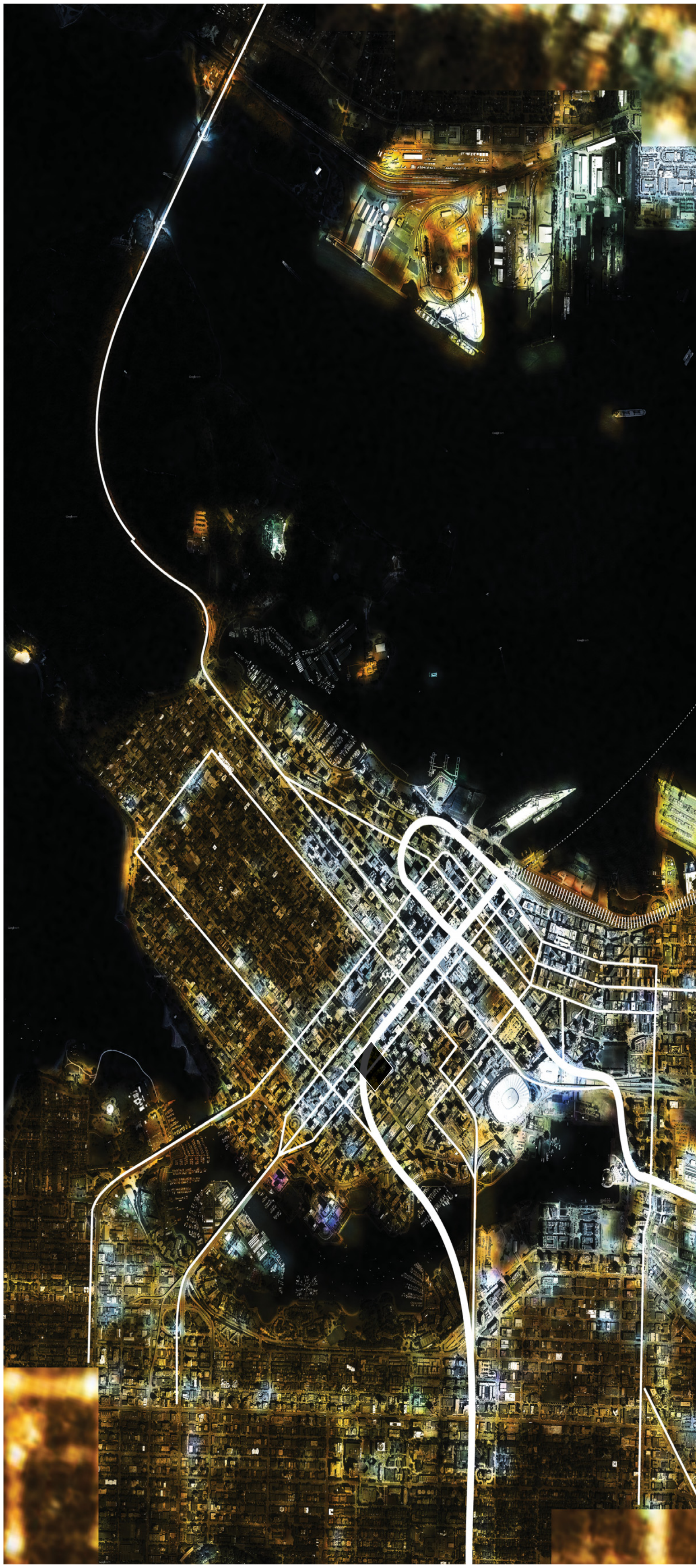


Image 37.
Transit and Light with Satellite Overlay from NASA.

Image 38.
Site and with Satellite Overlay from NASA.

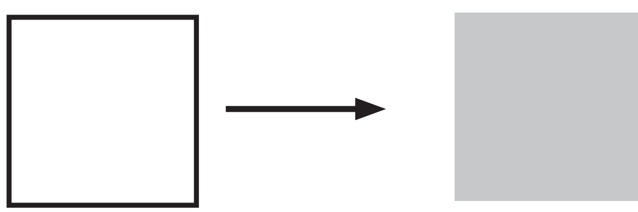
CHAPTER 4: PRINCIPLES

From the initial research and subsequent design experiment, principles were developed to assist in the future design of the nocturnal habitat. These principles endeavor to promote ease in low-lighting, urban environments after the sun has set so that we might again enjoy a true night.

Principles of Adaptation

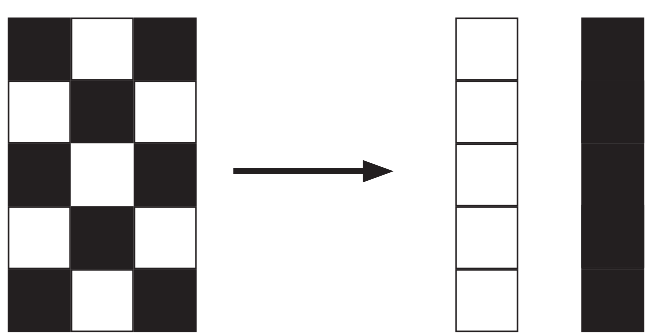
The principles of adaptation focus on how architecture could assist our eyes in adjusting to the dark and maintaining dark adaptation by reducing re-exposure to bright light.

Principle of Visual Perception #1: Acknowledgement



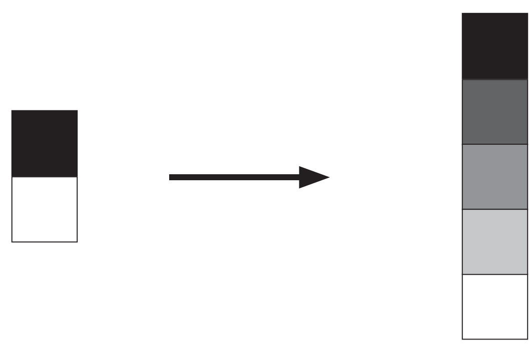
Acknowledge that our eyes can adapt to lower levels of lighting than to those we are habituated. Question standardized lighting levels and consider context.

Principle of Adaptation #2: Separation



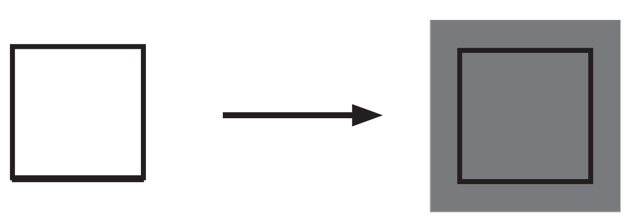
Program should be separated, when possible, according to lighting requirements. For example, separating vehicular traffic and pedestrian traffic, two activities that require substantially disparate lighting, allows for reduced lighting for both activities. Drivers require less illumination when pedestrians are removed from the equation. Pedestrians simply do not require the illumination levels as drivers. Within buildings, visually demanding program, such as kitchens, require more light than living space or circulation.

Principle of Adaptation #3: Sequence



Arrange program according to illumination requirements (light to dark). By moving through progressively dimmer environments, the eye is able to adapt to the changing light conditions. The use of intermediary program is important so that the eye does not move directly between extremes. As adaptation takes time, the sequence may constitute many steps or few if the intermediary activity is of sufficient duration.

Principle of Adaptation #4: Protection

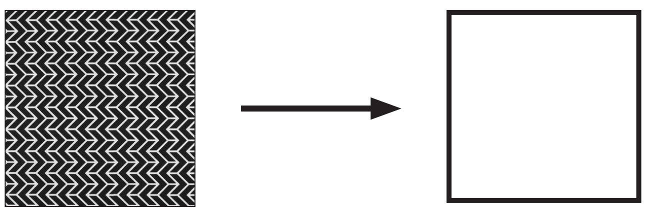


Protect vision by blocking sources of illumination that may interrupt adaptation levels. Dark adaptation can be maintained by shielding brightspots through form (for example, walls, recessed or shielded fixtures). Dark adaptation can also be protected through screening, which reduces the amount of light that reaches the eye.

Principles of Visual Perception at Night

In dark settings, our mode of vision changes. Principles of Visual Perception assist this mode of vision.

Principle of Visual Perception #1: Reduction



Reduce visual clutter. Judicious use of negative space (unlit/low lit space) allows important features (such as the sidewalk edge) to stand out. Visual clutter, such as multiple sources of light or numerous objects casting shadows, can create confusion. Basic shapes and straight lines are easier to read when our acuity is compromised.

Principle of Visual Perception #2: Contrast

Contrast can be used as a tool to navigate dim environments by highlighting edges and other important features (handles, etc). When a light wave strikes an object, it can be absorbed, reflected, or refracted by the object. As a result, we can use materials to create contrast in low lighting environments. For example, the reflection on a smooth surface (metal) would stand out against the absorptive surface (wood). Contrast can also be achieved with light and altering the intensity of light.

Principles of Affective Perception

Principles of Affective Perception concern our emotional response to our environment. These principles build upon Lam's qualities of affective perception, as previously described, and are influenced by personal observation, case studies and the design process.

Principle of Affect Perception #1: Intention

Dim lighting must appear intentional. For example, a dim, flickering flourescent bulb compared to the soft glow of candle conjourn two different affects. The same can be said for architecture. Intentional dimming can be conveyed through the integration of lighting and architecture. For example, if the building emits little light due to a wooden screen facade, this is more pleasing than fully glazed storefront dimly lit. Intention can also be conveyed through cohesion. This could mean a consistent architectural style, light quality, material or degree of translucency. For example, the use of red light throughout the Red-Light District defines the quarter.

Principle of Affect Perception #2: Distraction

Utilize visual distraction to highlight pleasing elements in the nightscape. Unexpected elements such as change in colour, light intensity or pattern distract users. For example, casting relatively more light on a beautiful tree would focus the attention of the user on the tree. In addition to landscape features, distinct architectural features create visual interest, distracting users from their fears of the night.

Principle of Affect Perception #3: Warm

Utilize warm colour temperatures (2700K or less) to reduce stress response.

Principle of Affect Perception #4: Order

Utilize order. Employ symmetry and repetition in the building form, circulation and lighting design. This makes the environment more readily discernible in low lighting conditions. For example, by creating a regular pattern, we are able to fill in the gaps (presented by low-lighting) as we move through space.

CHAPTER 6: DESIGN

Framework

All too often architectural designers prioritize the day, while ignoring the other half of human experience: the night. Lighting design is relegated to final stages of the design process when major decisions such as programmatic organization and structure have already been made and there is little flexibility left. Furthermore, lighting decisions are often guided by an obsession with luminance values rather than the relationship of the light to elements in the visual field.[63]

The design of a 'dark' district is an experiment guided by the understanding of perception presented in the previous chapters. The design is derived from the perspective of nighttime inhabitation primarily. Rather than serving as an afterthought, artificial light plays a generative role in the design process.

Program

Three public institutions were reimagined within the district: the Bath, the Library, and the Market. This program allowed for the exploration of lighting requirements, in terms of both intensity and temperature. Furthermore, these institutions, compared to private residences as an example, are often evenly and powerfully illuminated in the North American context.

Restaurants and theatres typically utilize low lighting. As such, they do not present an opportunity for reconsideration. Some specialized, task-oriented facilities, such as factories

63 Lam, *Perception and Lighting as Formgivers for Architecture, 11.*

and hospitals, are rigid in their lighting requirements.

District

Early on, I considered a series of rooms scattered throughout the city. Yet, this seemed at odds with my newly found knowledge of the mechanics of the eye and affective perception. For example, a lone dark building among a myriad of bright lights might appear out-of-place or even frightening. From the perspective of adaptation, it would appear excessively dark.

The district solves these issues. First, it allows for a longer time transition between light and dark. The eye is able to adapt as the user moves into the district from the brighter surroundings. Peripheral buildings act as seives to facilitate adaptation.

Second, an overall lower illumination level is required as the eye is able to maintain its adaptation due to the consistency that the district is able to provide. Building facades temper the amount of light that reaches the street. Within each building, effort is made to further reduce light that might be counterproductive to maintenance of adaptation. Other offenders to adaptation, such as cars, are banished.

Third, a cohesive district alleviates discomfort as it provides order and establishes expectations. For example, a district of lanterns would certainly be more pleasing that a strip of dimly lit, fully glazed storefronts. The nature of the glazed storefront begs to lit, when it is not, the environment appears amis.

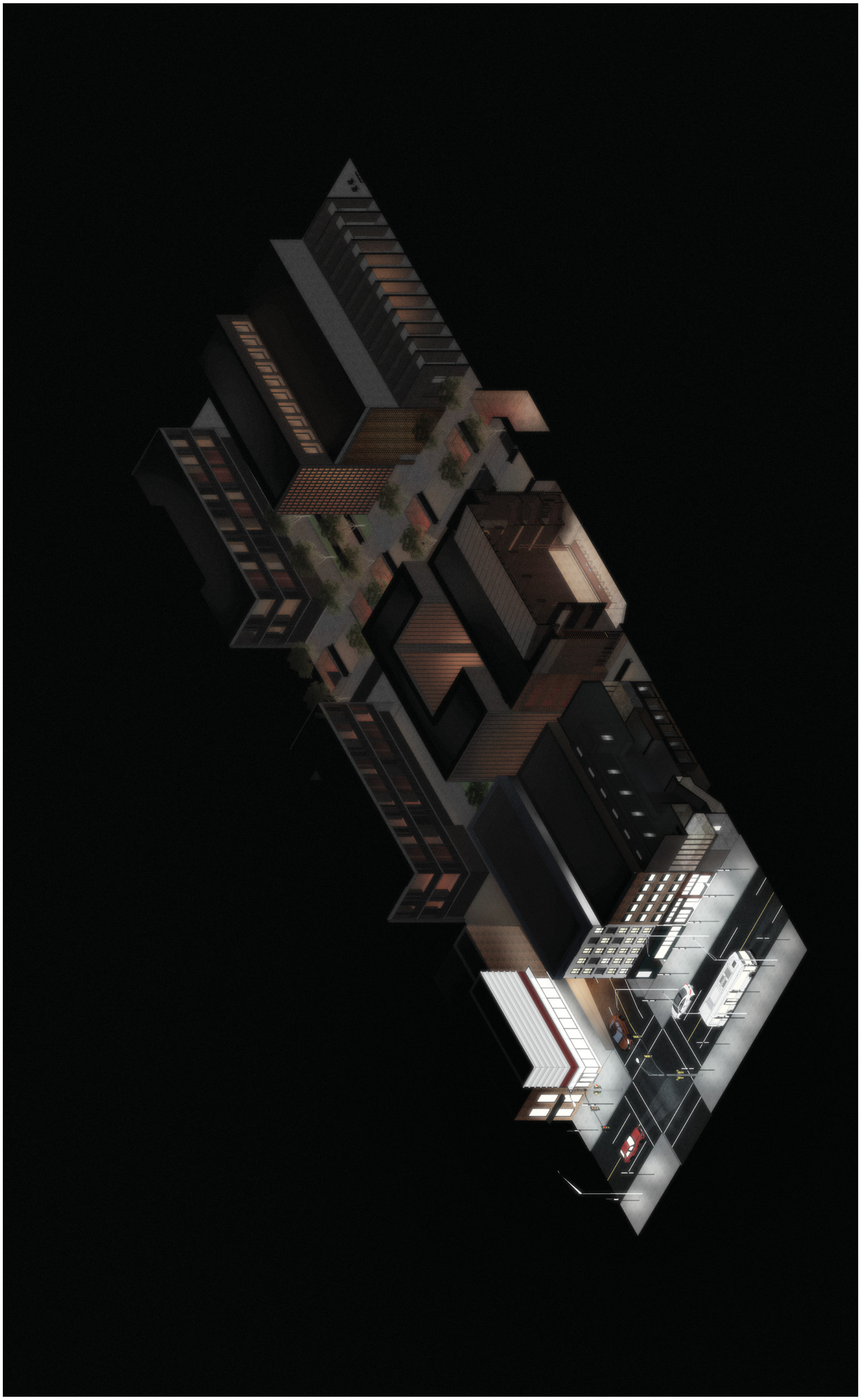


Image 39.
Granville Street 1.

Bath

The first part of this investigation focused on how programmatic organization could assist our eyes in adjusting to the dark. This was examined through the bath.

The bath acted as a portal, assisting users in moving from brightly lit Granville street to the new district.

The bath is organized in a progression from light to dark. Rather than utilizing corridors, the bath is a series of rooms through which the users move in a linear fashion. Users first enter the bright change room. The lockers here can be accessed through the dark change room so that there is no need to return to this first more brightly lit room.

Users then ascend the stairway to a series of pools that grow successively dimmer. The level of illumination for each pool corresponds with the adjacent levels. The first pool faces vivacious Granville St. The intermediary pool faces the alley. The final pool is open to stars above.

From the final pool, the user has a choice to ascend to the sleeping chambers or descend to the dark change room and exit. If the visitor chooses to exit the building, the scissor stairs provide a route to the second changeroom, illumination increases here slightly, but as the eyes are dark adapted the light required to negotiate the interior space is reduced.

Image 40.
Axonometric
Bath

Image 41.
Section and Plan Bath

Additionally, I was curious as to how architecture could protect the adapting or dark adapted eye from bright light. The decision to move from room to room rather than from corridor to room to corridor was motivated by a desire to maintain adaptation. Moving from a dark room to a lit corridor to a dark room would disrupt adaptation.

The dark adaptated eye is further shielded by the use of turns. For example, the u-shaped circulation from the first to third pool protects the eye from the lights of Granville Street. The use of high, shielding walls on the third level further protects the eye from unwanted light, allowing a better view of the stars above.

The bath sought to satisfy affective perception requirements as well. For example, the reflection on the concrete wall at the entrance is a purposeful use of minimal light. That is, the user would register the minimal light as an intentional effect. The use of glass floors to transmit light provides a certain novelty to distract users from the reduction in illuminance levels.

Finally, the bath aims to support vision at night by utilizing contrasting materials to enhance environmental knowledge. For example, the edge of the pool is demarcated by the refractive quality of water and the diffuse reflection of matte concrete. The specular quality of metal highlights handrails and edges.

Image 42.
Exterior Bath

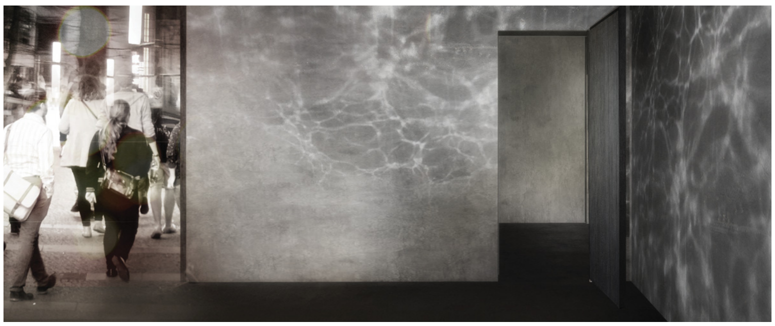


Image 43.
Entry

Image 44.
Change room 1

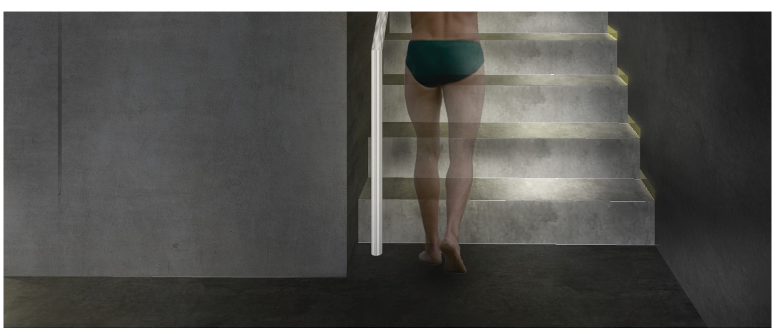


Image 45.
Stair 1

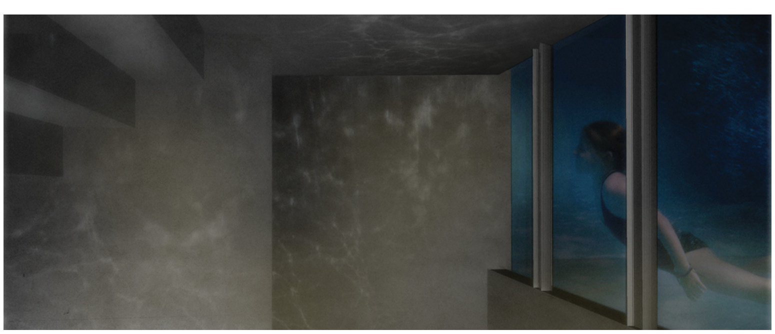


Image 46.
Stair 2

Image 47.
Pool 1

Image 48.
Pool 2

Image 49.
Pool 3

Image 50.
Pool 4

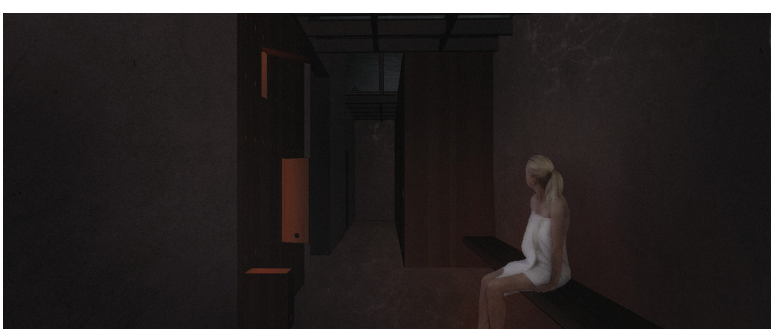


Image 51.
Change room.

Image 52.
Roof

Reading Room

The reading room takes a nested approach to adaptation. Program requiring the most illumination, in this case reading, is concentrated at the centre of the building. Shielding and screening is utilized to create a transition space between the bright and dark program – the reading area and the street. Additionally, the brightest light is sunk below street level, meaning that passerbyers are treated to the soft glow of a lantern.

The lighting scheme is heavily tied to the overall organization of the building.

Image 53.
Reading Room Entrance.

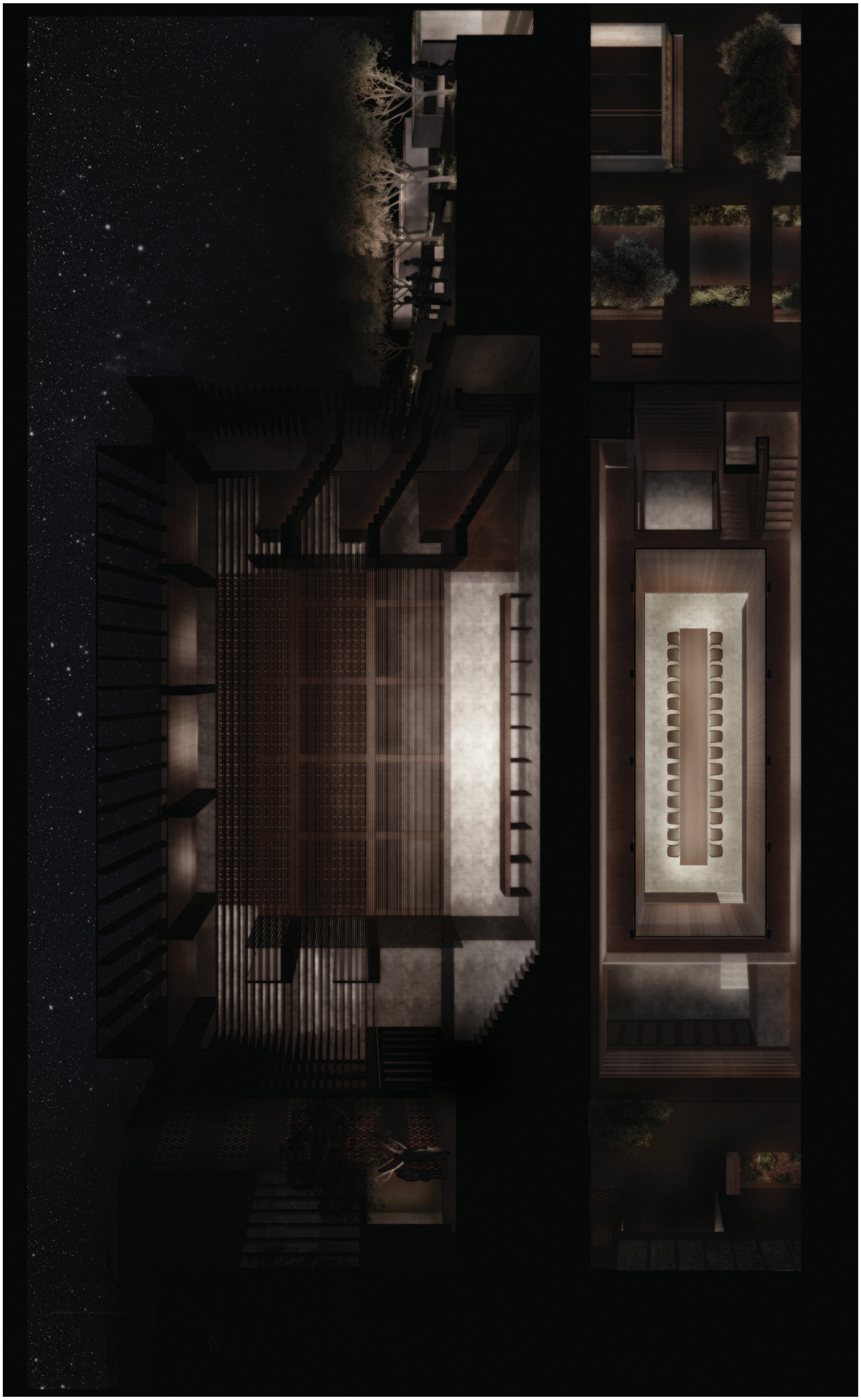


Image 54.
Section and Reading Room

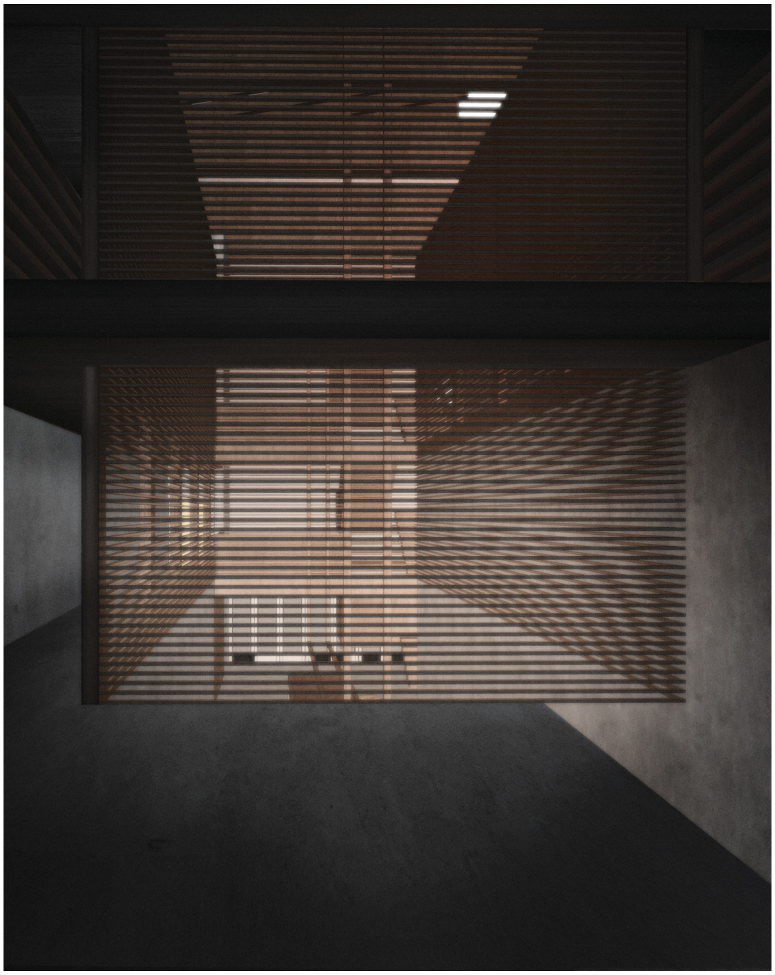


Image 55.
Vestibule

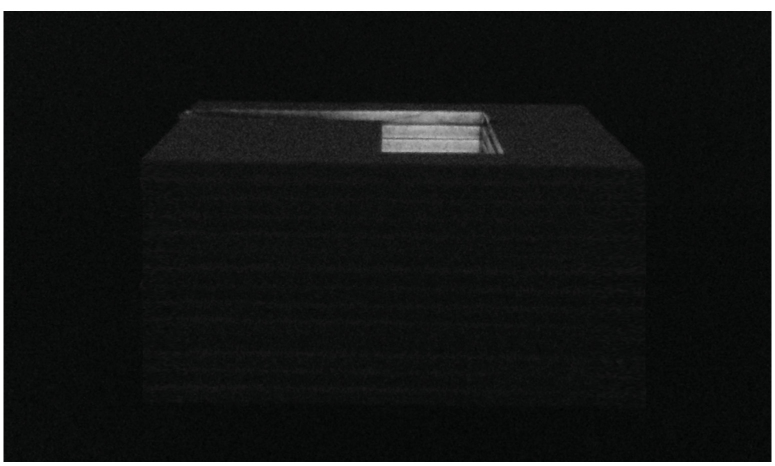


Image 56.
Maquette

In the reading room, the play of volume and light allows the visitor to perceive edges. This is most visible in the entrance stairs, illuminated by light from the reading room. The transition between levels is exaggerated by the edge of the

Image 57.
Reading Room.

slab. The pendant light is hung well below grade, located just above the table where it is needed most.

On the upper levels, where the stacks are located, the halls are lit by the soft glow of the reading room. Additional lighting is built into the stacks and directed at the books to maintain a clean, cohesive appearance.

Light from below highlights the volume of the stair, creating an edge and highlighting the railing.

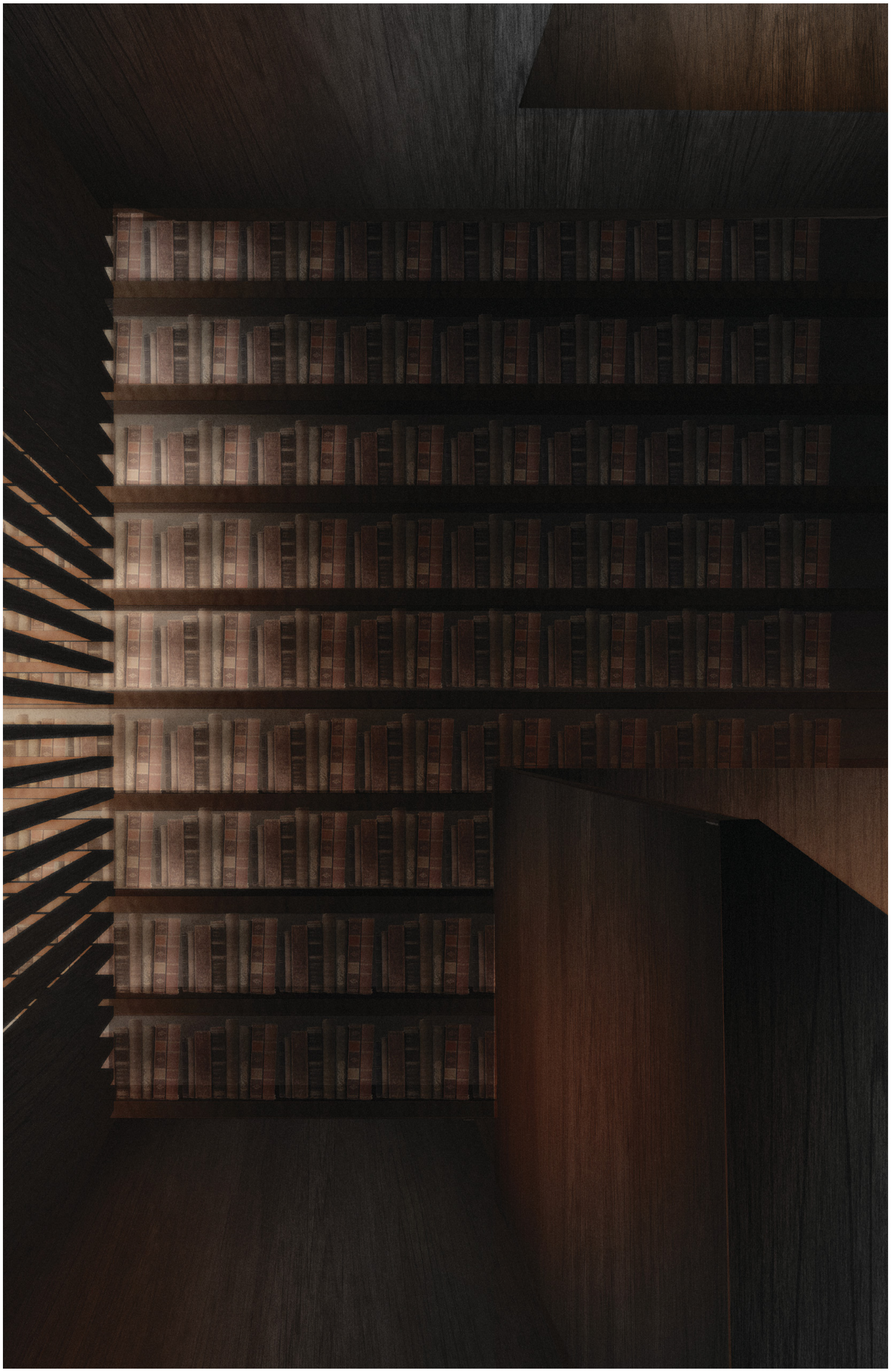


Image 58.
Stacks

Image 59.
Entrance 2.

The Market

At the market-arcade, program requiring more light is again concentrated in the centre, easing the transition from light to dark.

Image 60.
Exterior Market.

Image 61.
Section and Plan Market

Image 62.
Market open

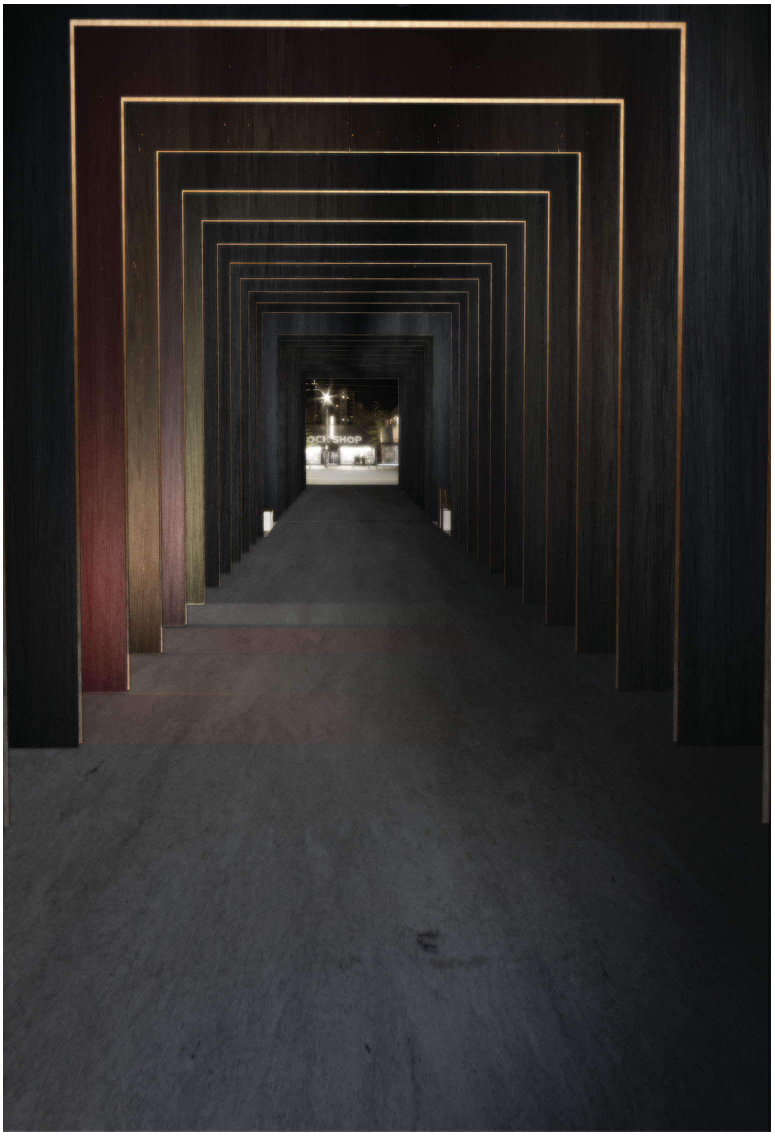


Image 63.
Market Open with Varying Colour Temperature

In the market stalls, the source of illumation is shielded from view. Escaping illumination is tempered a second time by the use of the arcade wings so that when the market is viewed from the street, the escaping light is reduced.

When the market stalls are open, the growing brightness draws users into the space to investigate. The quality of the light (such as colour temperature) distinguishes the individual vendors.

In market-arcade, it was necessary to create a structure that

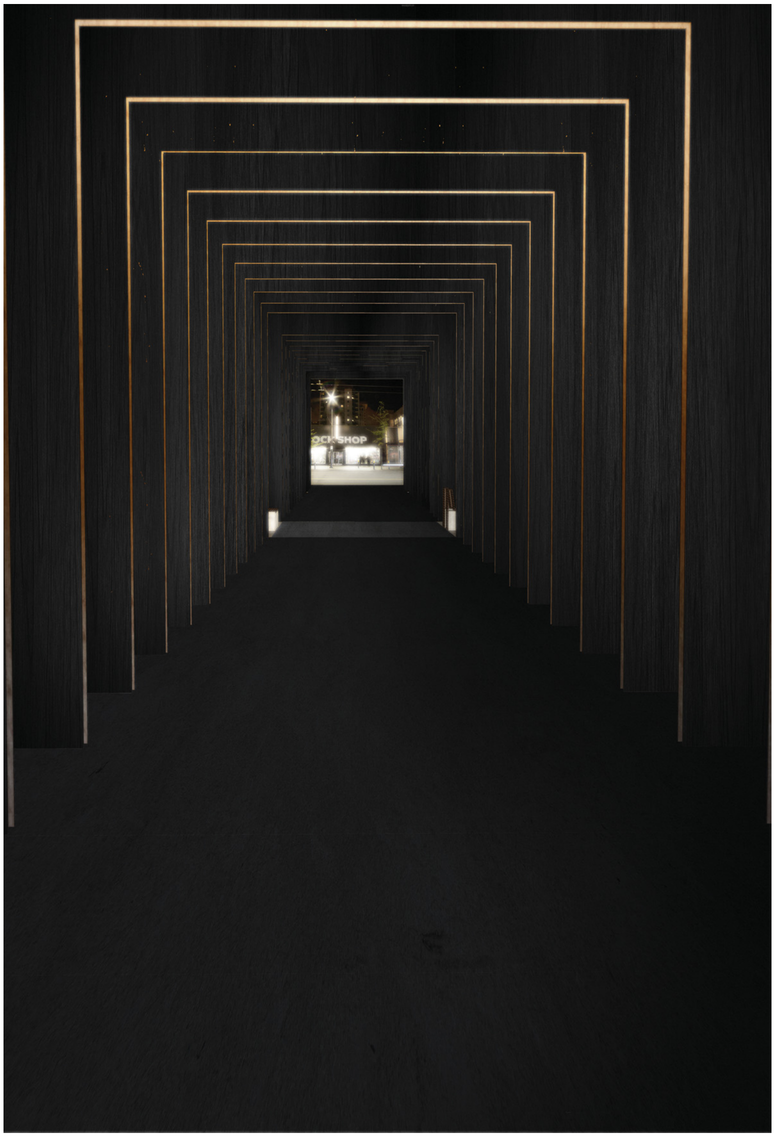


Image 64.
Market Closed

did not appear desolate when the vendors closed at the end of the night. The market is highly ordered and visually purposeful.

When the market is closed, the incorporation of the light and structure of the wings creates strong contrast with the absorptive nature of a dark wood, marking the main circulation route without the use of evenly distributed illumination as is the norm.

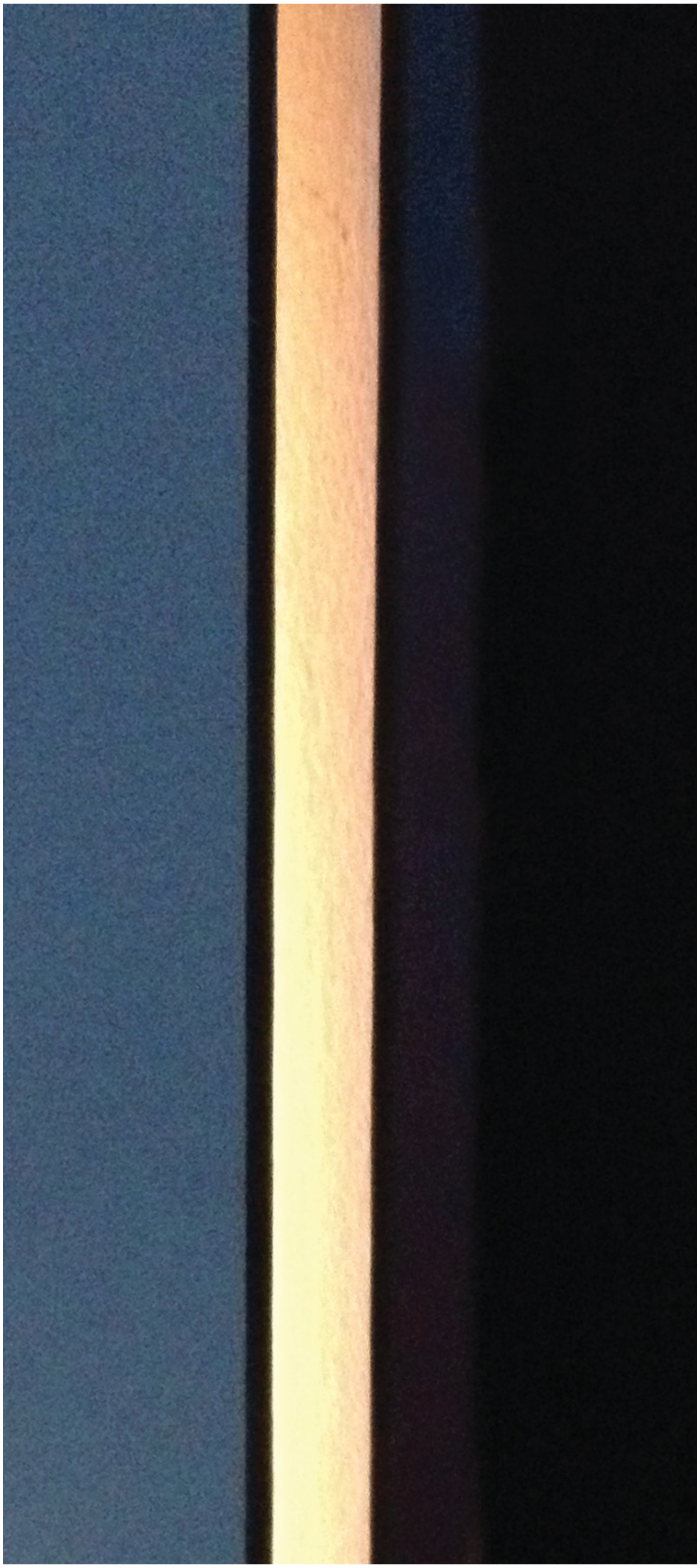


Image 65.
Maquette.

Daytime

By considering the day, I discovered that the use of contrast can be problematic. While high contrast in materials may be useful at night, during the day it can sometimes appear aggressive. The pairing of glossy and rough surfaces, as opposed to light or dark, can also create contrast that does not appear odd during the day. The use of lighting contrast to emphasize an important edge in addition to material change can alleviate this issue as well.

Image 66.
Exterior Market Day - High Contrast.

Image 67.
Exterior Market Day - Reduced Contrast.

The visualizations of the street highlight this problem. The first depicts a scene with strong colour contrast to assist vision at night. It is harsh. The second visualization is more subtle. Contrast is derived through lighting contrast (via shielding or spotlighting) and the juxtaposition of surface qualities (for example, specular or diffuse). The bike path is delineated by the textural contrast.

While the design focuses on ways to control the amount of artificial light emitted from the building during the night, it is also important to consider how natural light might enter the building during the day. In the bath, the refractive quality of water is used to bring light to the lower levels. The reading room, on the other hand, utilizes skylight (operational louvres to prevent light from escaping at night). During the day, circulation space around the reading room could provide seating areas with better daylighting opportunities.

Image 68.
Bath Day 1

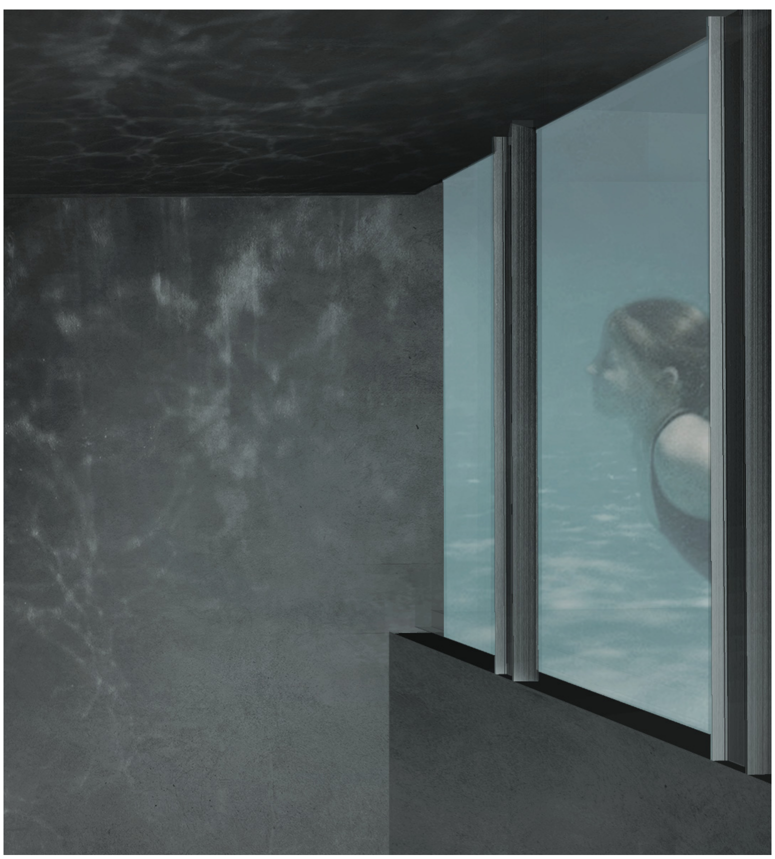


Image 69.
Bath Day 2

Image 70.
Reading Room Day 1.

Image 71.
Reading Room Day 2.

CHAPTER 6: CONCLUSION

> Designers [....] have yielded the control which they once exercised over the luminous environment to others: to electrical engineers, who have been primarily trained to meet minimum footcandle requirements; to building owners, who come to them with misconceived programmatic objectives; and to misguided government officials, who have been brainwashed by propaganda from the lighting and power industry into adopting and enforcing irrelevant and obstructive codes in the name of progress. This abdication of design responsibility- conscious or unconscious – by the design professions must be reversed.[64]

Dimming the City began as a project aimed at the reduction of light pollution. I contend that it remains so. Yet, rather than simply a bandaid or a slew of tactics to address symptoms, it sought to confront the root of the problem: acclimatization to the overuse of artificial light and our discomfort with the dark.

Through the reimagination of a city block, an understanding of perception was utilized to investigate how the integration of light and architecture might ease our discomfort with low light conditions.

While I chose to investigate from the perspective of vision, the other senses, – touch, sound, smell – also allow us to collect information and interpret our environment. Additionally, environmental features and social variables, such as lack of concealment, possibilities for escape, maintenance, or surveillance (eyes on the street), all play an important role in our perception of safety. Moving forward, design for the urban night would benefit from further study of these areas.

Most importantly, this experiment is a critique.

64 Lam, *Perception and Lighting as Formgivers for Architecture, 10.*

It is a critique of urban design and architecture that does little to address the night as a biological need, exacerbating our dependence on light. It is also a call to architects and urban designers to consider artificial illumination early in the design process.

In offering design examples demonstrating how the integration of minimal light might be informative, beautiful and comforting, this experiment has been, in my view, a first step in acknowledging an other half of human experience: the night.

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