THE EXPLORATORY STUDY OF LIGHT IN THE FUTURE OF CARING CITIES AND PERSONALIZED LIGHTING DESIGN IN THE PUBLIC SPACE

by Kamin Phakdurong
B.Eng., Information and Communication Engineering, Chulalongkorn University, 2013

and Yangyang Yang
BA (Hons) Product Design, The Hong Kong Polytechnic University, 2016

Submitted to the Integrated Design and Management Program in partial fulfillment of the requirements for the degree of

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Authors Signature redacted Signature redacted
Kamin Phakdurong, Yangyang Yang
Integrated Design and Management
May 18th, 2018

Certified by Signature redacted
Edward Schiappa
Professor, Head, Comparative Media Studies/Writing

Certified by Signature redacted
Warren Seering
Weber-Shaughness Professor, Mechanical Engineering

Accepted by Signature redacted
Matthew S. Kressy
Director, Integrated Design and Management

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Abstract

Light plays a significant role in urbanization throughout human history. And as the number of people living in the cities has already exceeded half of the world's population, people are facing many challenges like poor infrastructure, social problems, etc. To overcome the burgeoning populations, the lighting innovation is necessary. This thesis presents a solution to the challenges of a *light* and *caring city*. We present a lighting system that integrates design strategy, system architecture, and product design. The thesis begins with exploratory research at the intersection of the keywords, *light* and *caring city*. We discuss six support roles of light in daily life and twenty features of the caring cities from case studies. We dive into issues of well-being and work-life balance with the hypothesis that there lies an opportunity to make a meaningful impact with innovative lighting.

To get the holistic view of the challenge, primary and secondary research were conducted to understand user needs before developing the design concepts of the lighting product or service. The design iteration uncovered feedback from users and professionals in the lighting industry, revealing valuable insights and a critical puzzle piece that the industry still struggles to answer: how can personalized lighting support citizens' activities in shared spaces? We believe our solution will make a significant impact to people in their daily lives.

The thesis develops a 'smart lighting' solution to personalize and support daily activities, as envisioned for futuristic *caring cities*. Using a co-working space as the concept demonstration, the thesis introduces the Intelligent Connected Lighting System and a five-layer ruleset. This ruleset integrates a human's biological clock, weather effects, shared space occupancy, activities performed, and custom settings made by users. Our system automatically adjusts luminaires to meet user needs in real-time. Also, to support the flexibility of the system, two additional intelligent lamps were designed with installation suggestions.

Thesis Advisor: Edward Schiappa
Title: Professor, Head, Comparative Media Studies/Writing

Thesis Advisor: Warren Seering
Title: Weber-Shaughness Professor, Mechanical Engineering

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We feel grateful to have the opportunity working with MIT Design Lab. We would like to thank the director of Design Lab Yihyun Lim, the research group members Doctor Laura Varisco, Eytan Mann, Sultan Sharrief, Scott Penman, and Milica Pavlovic, the administrative assistants Lizzie Bundy and Caroline Celia Reyer, who have provided innovative thoughts, valuable feedback, and technical support on the design of lighting and future city. It is Design Lab that makes the project happens with the connection of Philips Lighting, and make our thesis go smoothly.

To our thesis sponsor Philips Lighting, we thank for the opportunity visiting their office and research group at Cambridge, studying their frontier research on lighting and future caring city. We would like to thank Alexandru Darie, Jose dos Santos, Meg Smith, and Jin Yu from Philips Lighting, for not only providing this opportunity to write the thesis with but change our notion on the role of light in the future caring city.

Finally, we thank each other's time and efforts that have contributed to this project throughout the year, for our understanding, trust, encouragement, and support towards each other, and our common belief to do a valuable research, to create the desirable, feasible, and viable design, and to contribute our tiny efforts to make the world a better place.

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Chapter 1
Introduction

1.1. Background

The 21st Century is the century of cities. More than half of the world's population has been living in urban areas since 2008. And by 2030, towns and cities will be home to almost 5 billion people (UNFPA, 2007). Facing challenges from overpopulation, what could civic leaders and communities around the world do to handle the series of uncertainties, such as the lack of infrastructure, safety, or healthcare?

As cities have entered a new era of connected infrastructures and technologies, the term *caring city* is introduced as the intelligent city that cherishes heart and soul of its citizens as well as providing support for people to live and grow happily.

At the same time, the *connected lighting* is introduced, along with the wave of Internet-of-Things (IoT) revolution, as the programmable smart lighting that utilizes data to provide the dynamic lighting solution. Mostly, the goal is to reduce the energy consumption. However, the other possibilities to use connected lighting for good are still left unexplored. This thesis discusses the possibilities for using the connected lighting to help tackles rising challenges from growing cities as a way towards the vision of futuristic caring cities.

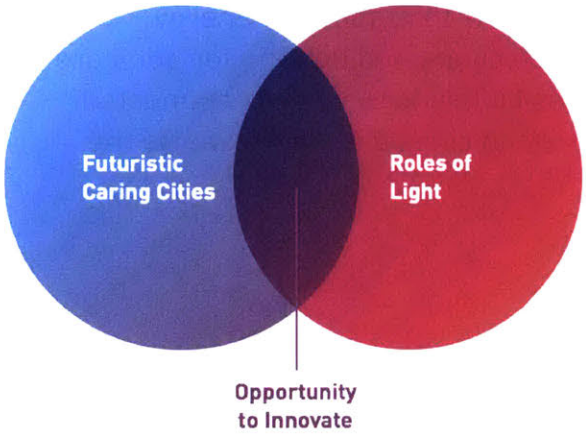
1.2. Thesis Structure

The thesis contains two primary sections: the exploratory study to find the right question and the design process to develop the solution for that question. The journey starts with exploring the relationship between light and cities of the future without presumption. Through the lens of the human-centered design, the opportunities are explored and selected using as the problem statement. The secondary research, primary research, and user testing are then used as the learning process as we dive into the problem. The problem statement is then redefined into how could we personalize lighting in the public space. Finally, the thesis purpose the design strategy, system architecture, and product design as the solution for the personalized intelligent lighting that helps support well-being and activities in the public space.

This project is collaborative research with MIT Design Lab and Philips Lighting.

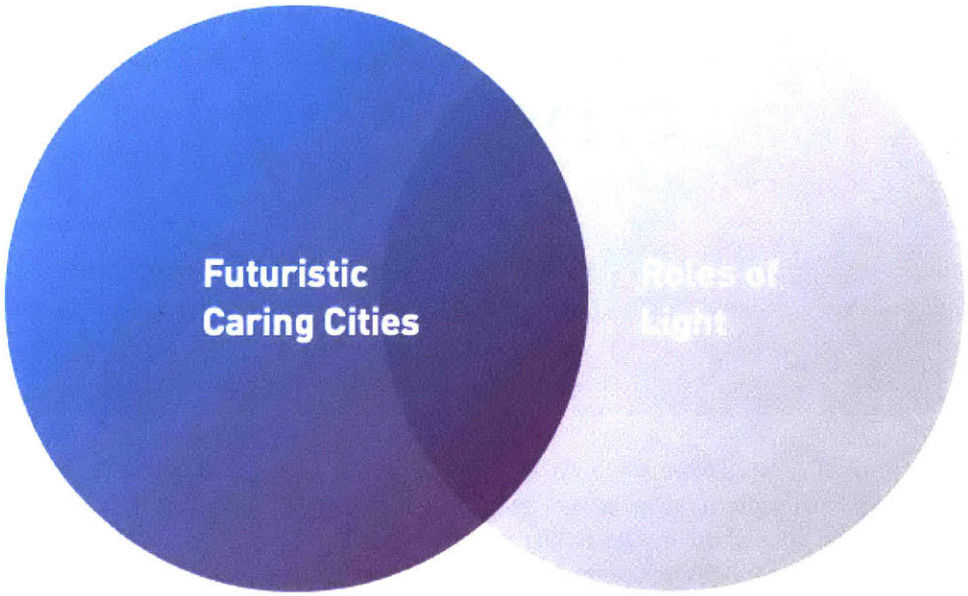
Chapter 2

Exploratory Research on Caring Cities and the Roles of Light



This chapter begins with the discussion from exploratory research on the future of caring cities and the roles of light, attempting to find opportunities for innovation that lie in between.

2.1. The City of Future

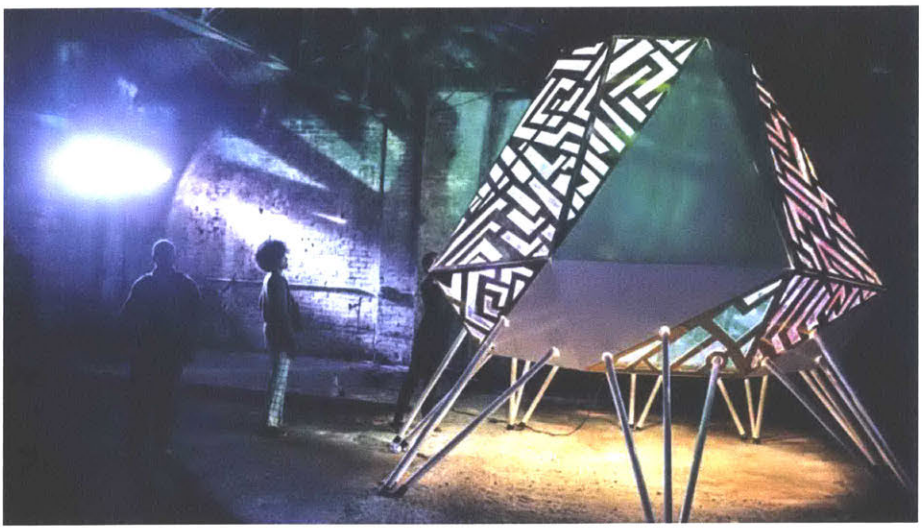


In 2008, more than half of the world's population are living in cities. According to City Mayors Report (2018), Tokyo, as the largest city in the world has around 38 million populations and still growing. Expanding cities are facing challenges in many areas: infrastructure, safety, physical and mental health, and so forth.

To accommodate the rising problems of excessive urbanization, people around the world join the conversation in a quest to reimagine the future of the city. As we dwelled into debates about what the futuristic city will look like (or should look like), these are the visions that are widely received by many countries and organizations.

2.1.1. Creative City

In 2004, the United Nations Educational, Scientific and Cultural Organization (UNESCO) formed the UNESCO Creative Cities Network (UCCN) to promote the idea of having creativity as a strategic factor toward the sustainable urban development (UNESCO, 2015). The creative city requires infrastructures beyond the roads or buildings, but the city's atmosphere, incentives, and regulatory regime to fosters creativity among citizens. In 2018, the network consists of 180 cities from 72 countries covering 7 creative fields: crafts & folk art, design, film, gastronomy, literature, music, and media arts. This initiative demonstrates the commitment to work towards the vision of the city where the creativity and cultural industries are the core of their development plans and actively share their best practices at the international level.



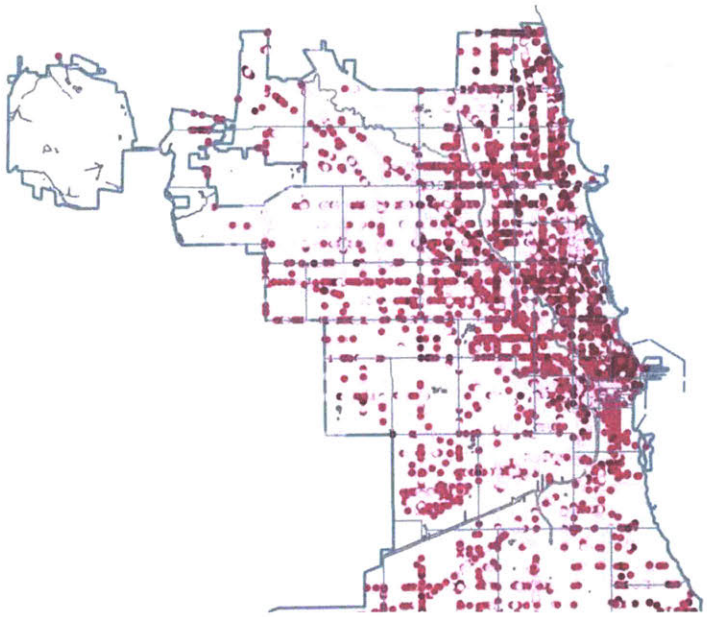
Detroit, a member of UCCN as a Creative City of Design since 2015, considered to be a cradle of American modernist design. Not only by hosting various gatherings dedicated to designs like the Detroit Design Festival but also, in 2010, opened up the Detroit Creative Corridor Center (DC3) to provide the leadership and resources for the design community, nurturing city's global creative economy.
(Detroit City of Design Summit, 2017)

This vision then joined by Charles Landry and Jonathan Hyams who proposed Creative Cities Index as a method to assesses cities' creative abilities and potential, aiming to provide a strategic tool for measurement and aspire cities to work towards the vision of the creative city (Charles, 2018).

2.1.2. Smart City

Well-received by numerous countries, international organizations, private sectors, and media. The smart city is arguably one of the most popular and controversial concepts when referring to the future of the city. Having information and communication technology (ICT) at its core, smart cities utilize data collection sensors to collect big data which is used to manage assets and resources efficiently and improve the quality of government services and citizen welfare. In 2010, The European Union (EU) had developed programs under Europe's Digital Agenda, a long-term plan towards the goal of transforming cities into the smart cities, to tackle major technological, economic, and environmental changes (Paskaleva, 2009). Many cities in the U.S. also adopted this mission as well, as listed in the Intelligent Community Forum Awards from 1999 to 2010, the city's Department of Innovation and Technology in Chicago developed an algorithm that looked through big data to prioritize the restaurant inspections to

prevent the violation. This demonstrates an excellent case of how the concept of the smart city could tackle arising issues as the city grows (Totty, 2017).



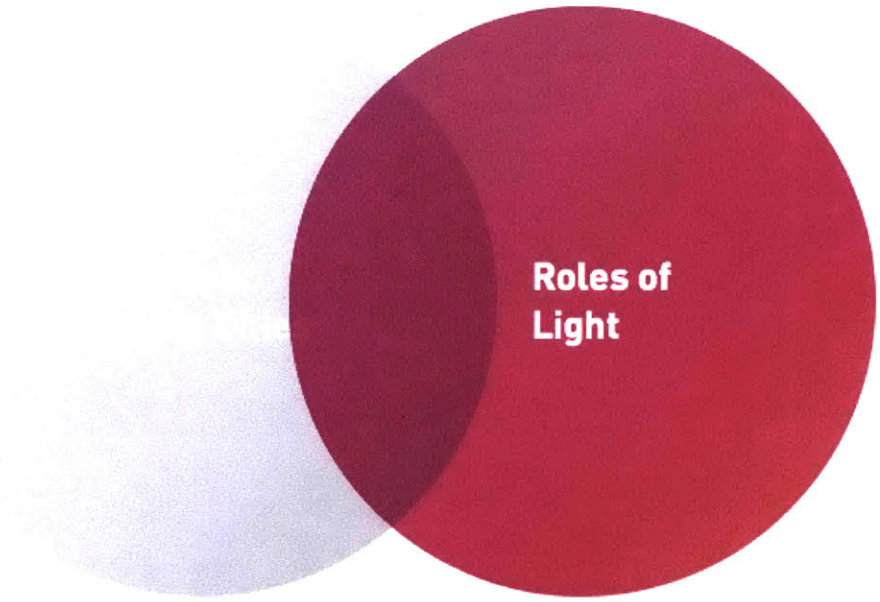
The pink dots represent the coordinate of restaurants where the violation occurred before. The municipal's data team also look at ten more variables such as the weather and the year of operation to come up with the analysis. (City of Chicago, 2015)

2.1.3. Futuristic Cities Scenarios in 2035

Philips Lighting allows us to access the internal publication predicting four scenarios of how we might experience cities in the year 2035. Using the Scenario Planning analytical method designed to handle uncertainty, the research team outlined extreme yet plausible future scenarios that the drivers of today's trends might reach based on research and interviews with experts around the globe from different backgrounds, which challenge us to think for the better in the uncertain future.

Internal Report from Philips Lighting. Four scenarios and their drivers from today: Fablab, Campsite, Sandbox, and Resort (Future of cities - Scenarios that show how people may experience cities in 2035, 2017)

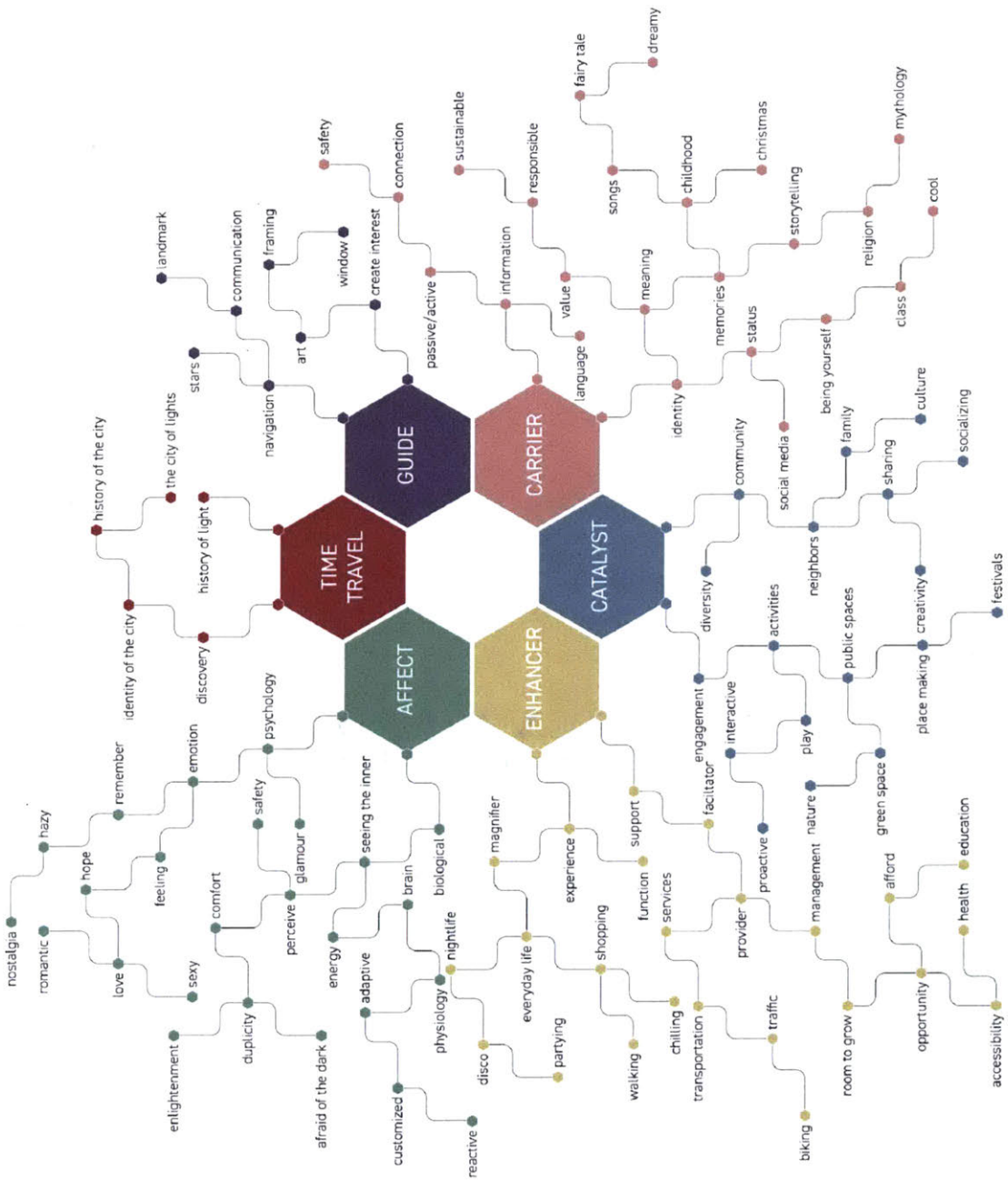
2.2. Roles of Light



Now, we transition to research on the roles of light. The goal is not only to understand the functional use but also biological and psychological effects it does to our body.

The preliminary research expands the significance of lighting in cities beyond its traditional role of providing color, brightness, and viability to cities, but to include the values of communication and shaping the way we perceive, feel, and inhabit in urban spaces. The history of light tells a story of technological progress that is deeply tied to human interaction and public life, as the invention of lights has introduced new possibilities at night. Before artificial light was invented, natural light and fire were used in the dark, and the latter bore multiple meanings from functional to social to spiritual, which gathered people together and created social structure. After the first gaslight was introduced to London in 1807, most of the cities in the Europe and America started to have streets illuminated by gas lamps, where the crime rates dropped, but yet no policy could maintain the infrastructure as it requires tremendous efforts, until the arrival of the electricity.

With the team at MIT Design Lab, we horizontally explore the various meanings incorporated into light by case studies and extract six key categories of lighting for caring cities: Time Travel, Guide, Carrier, Catalyst, Enhancer, and Affect.



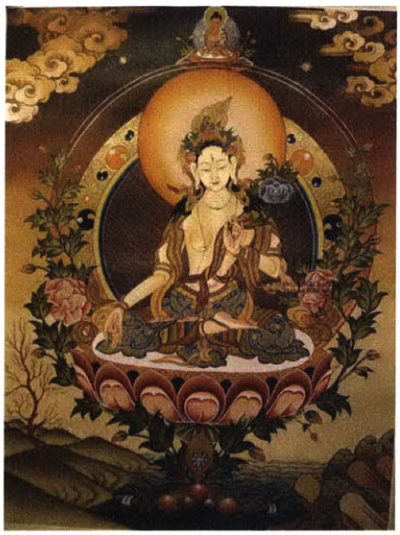
Graphic designed by Laura Varisco

2.2.1. Time Travel

Light is tied to the symbol of belief in a way that helps people think and feel of great things in the past.

In cultures across countries, light is one of the most universal and fundamental symbols, which usually represent the spiritual, the divine, illumination, intelligence, and symbols of guidance. It is the source of goodness and the ultimate reality, and it accompanies divinity in Christianity, Islam, Judaism, and Buddhism. In Eastern culture, Buddhism, Siddhartha became Buddha under the Bodhi tree by attaining enlightenment, which transformed his life forever (Hall, 2006). Light is energy, knowledge, purity, morality, and the avenger of evil forces; In Western culture, in the Age of Reason, Enlightenment rationality was more rationally applied to light. The movement of Lumières (literally in English: Enlighteners), originated in France and spread throughout Europe, was lead by philosophers such as Baruch Spinoza and Isaac Newton (De Voltaire, 1738). The intellectual and cultural renewal resulted in the Renaissance humanism, was understood by "light coming from within oneself" in France and meant "light from outside" in other European countries.

Light brings memory and senses to people, and usually bear a special relationship to nostalgia. As nostalgia is associated with people's a wistful yearning of the past, their personalities, and events, the "good old days" or a "warm childhood." Together with light, smells, touch, and music can all be strong triggers of nostalgia.



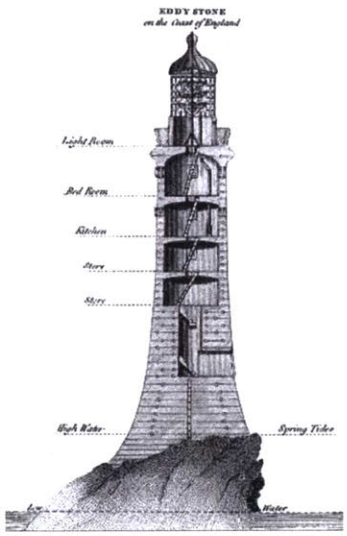
Goddess Tara thangka:
Goddess of Compassion & Wisdom

(part of) Cover of Éléments de la philosophie de Newton "Elements of Newtonian Philosophy" (De Voltaire, 1738)

2.2.2. Guide

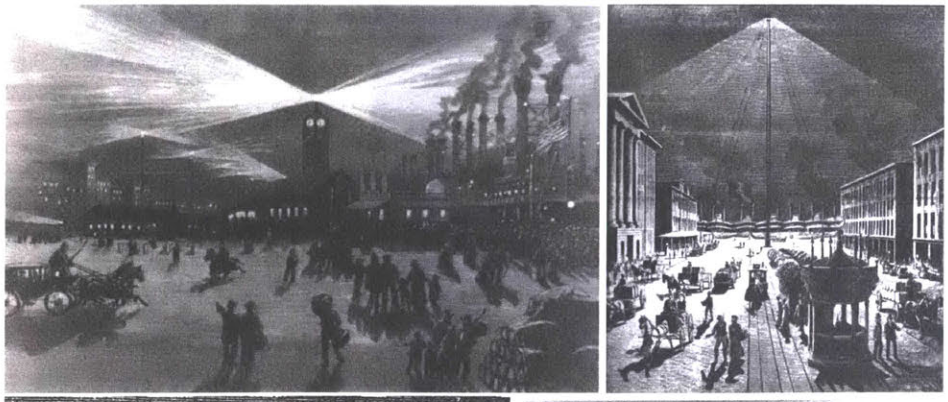
Light guides us in various ways, which is crucial for navigation both in ancient times and modern cities. Before Thomas Edison's invention of the electric light bulb, in the darkness, stars acted as the navigation. By studying the night sky, a helmsman was able to find the direction during the voyage. Along with stars, the sun and the moon are also major navigation sources. By calculating the relationship of earth-sun or earth-moon, people planned agricultural cultivation according to the seasons. The solar and lunar calendar was made based on their movements.

Peter Apian's Cosmographia - Geocentric celestial spheres Antwerp, 1539

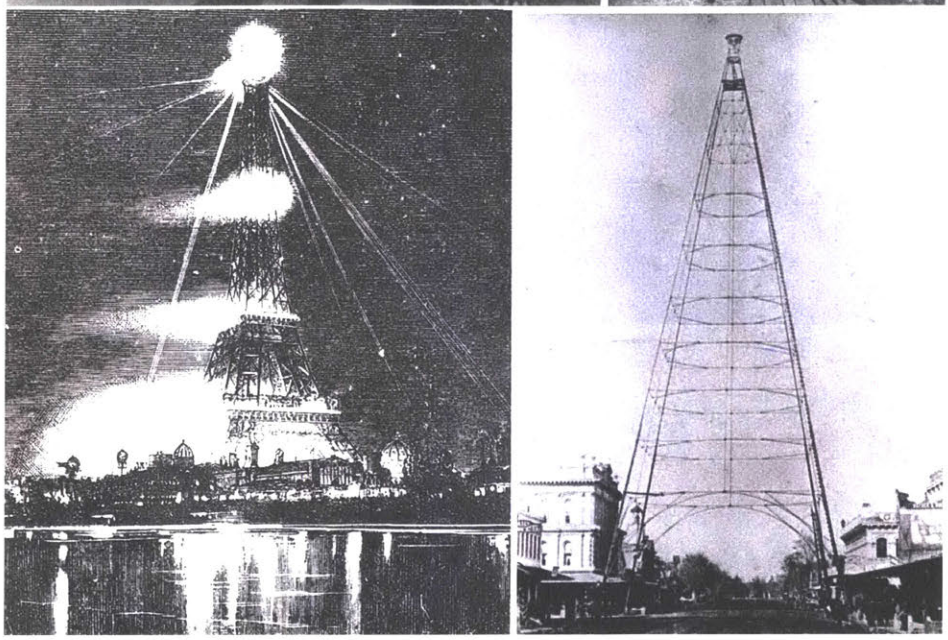


John Smeaton - rebuilt version of the Eddystone Lighthouse 1759

Later, the lighthouse was introduced, which became symbols of hope for marine-cultures. The same idea was adopted into the urban life on solid ground, performing as a landmark and enabling orientations in cities of the nineteenth century. The landmark of Paris, Eiffel Tower, is one of the examples, which replaced candles with powerful arc lights (Decker, 2009).



Moonlight towers, 1883

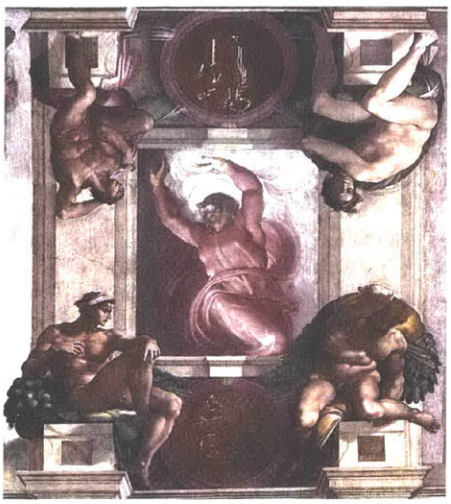


Ei el Tower and San Jose' tower, 1881

With the development of light technologies in the last century, the notion of a light tower illuminating the whole city has been replaced by the multiplicity of electric light in our city to communicate a wide range of information. Now there are traffic lights with color-coded lighting to convey different transportation instruction, flashing color lights with alarm whistle to raise people's awareness, and billboards with words to indicate specific information.

Lights with guidance functions

2.2.3. Carrier

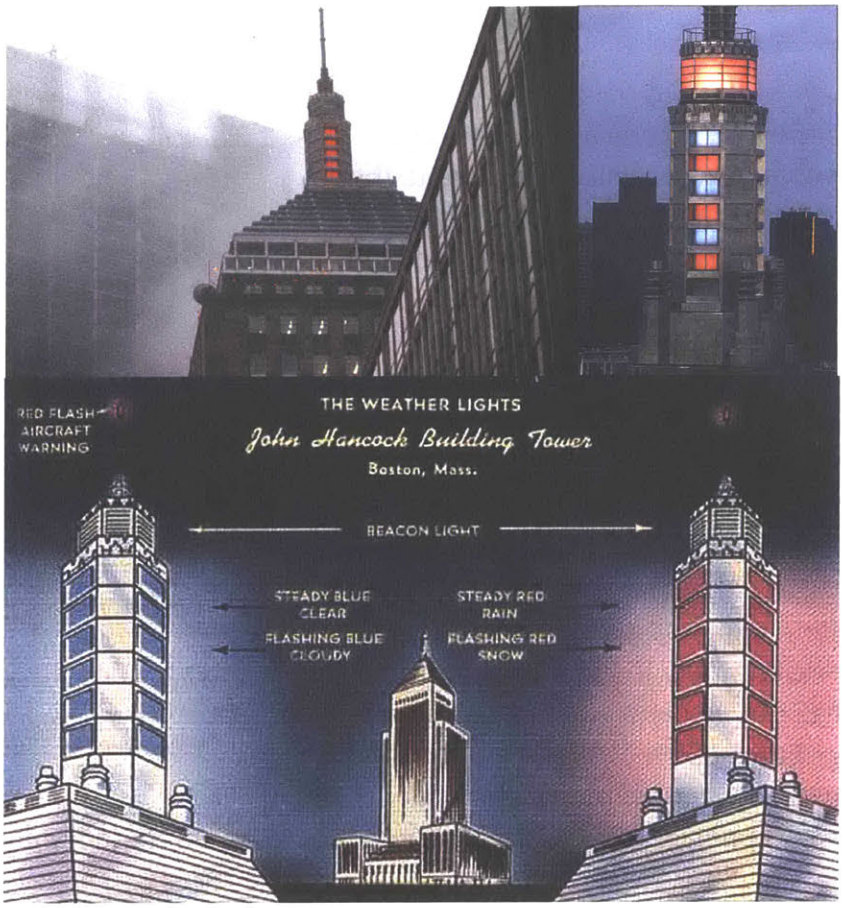


God Divides Light from Darkness, Sistine Chapel ceiling, Vatican City (Michelangelo, 1508 – 1512)

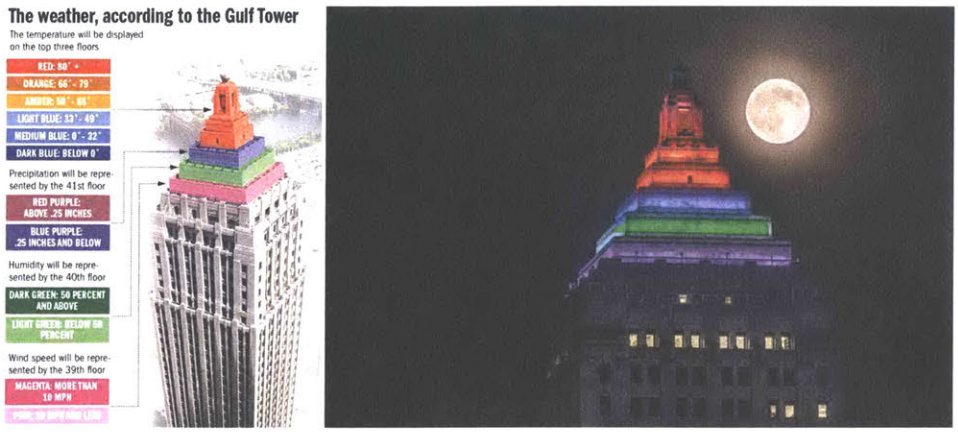
In almost all primitive religions and myths, light plays an indispensable role, which represents the origin and the order of the world. In the Bible, the presence of light is the metaphor of God, good, truth, faith, knowledge and righteousness; in Hinduism, Diwali, known as the festival of lights, is a celebration of the victory of light over darkness; in Buddhism, light is mentioned numerously in scripture, such as a Buddha of Boundless Light, a Buddha of Unimpeded Light, and a Buddha of Unopposed Light (Watson, 2016). The light was regarded as a mysterious power of nature throughout history before science was introduced. Today, light is most notably thought as a physical phenomenon that can be controlled by the human. Still, we take light as a carrier of information, the expression of love, the symbol of identity, the connection between people, and the celebration of our shared memory and belief.

The color of light has been used in infrastructure to deliver concise information as a norm. Red has the longest wavelength and easily to be recognized, which is widely used to arouse attention and used as signs of stop and caution. Whereas green indicates safety, conveying a message of guidance and relaxation. Safety-relevant infrastructure like emergency & information pillars, police, and ambulance are using blue (or partially blue) to calm people down.

A simple combination of colored lights can be used to convey information effectively. The column of lights atop the Berkeley Building in Boston conveys weather forecast message by colors and flashing in a lucid way: four weather conditions are forecast by the combination of red or blue with steady or flashing light signal: steady blue means clear view, flashing blue means cloudy, steady red means rain, and flashing red means snow (Grant, 1973). Whereas the weather beacon atop the Gulf Tower in Pittsburgh is way more complicated, which is hard for citizens to memorize and recognize (DiCello, 2016).

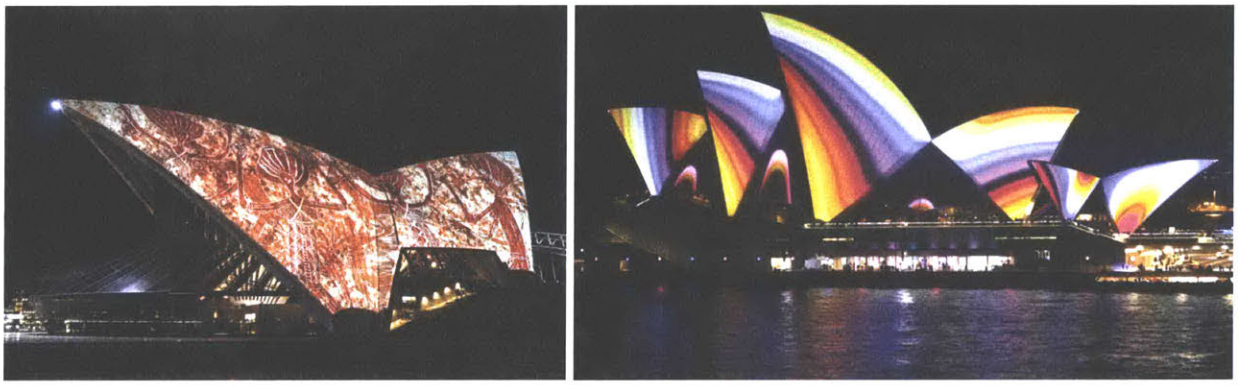


The Weather Lights. Messages conveyed by the column of lights atop the Berkeley Building (The old John Hancock Tower), Boston, MA. Steady blue means clear view, flashing blue means cloudy, steady red means rain, and flashing red means snow. When the Red Sox broke The Curse and won the 2004 World Series, the light flashed red and blue for the first and only time in its 60-year history (Grant, 1973)



The KDKA-TV Weather Beacon. The Gulf Tower, Pittsburgh, PA. Weather information with floor by floor breakdown. 39th floor: wind speed; 40th floor: humidity; 41st floor: precipitation; 42nd - 44th floor: temperature. (DiCello, 2016)

Illuminations nowadays are no longer the only function of lights. Lights reveal the identity of a city. In Sydney, starting in June 2017, the Sydney Opera House glowed every night with the projection of Australia's First Nations culture stories. The light artwork has become an essential first contact point for the eight million people who visit the iconic venue from overseas and around Australia, which has turned the landmark into a place for celebrating and honoring the traditional custodians of the country (Boud, 2017).

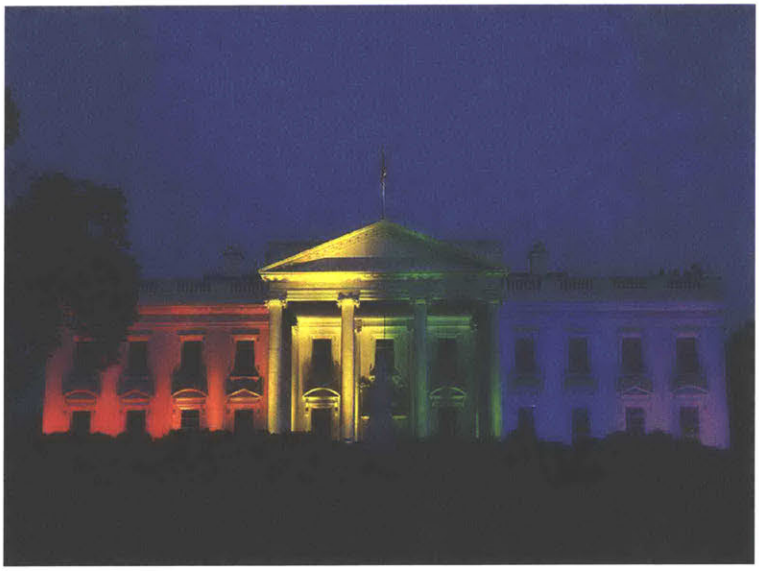


Water Light (Boud,2017)

In the metropolis, regardless of origin, lights bring people together, evoke people's shared memory, and reinforce their sense of belonging. Under the light, people express their feelings of celebrations towards festivals, best wishes for ideal life, and memorial towards catastrophes. Festivals across cultures around the world are celebrated with light. Pumpkin lanterns for Halloween or paper dragon lanterns for Lantern Festival are always attached to the light. Landmarks light up for special events. White House, Supreme Court, and Empire Building were illuminated in rainbow colors to celebrate

the achievement of the same-sex rights movement. Memorials are also expressed by lights, such as a large scale of candles was set for the memorial of passing life in tsunamis and earthquake, as people believe that light represents the cycle of life.

Halloween Pumpkin Lantern in the US and Lantern Festival in Hong Kong

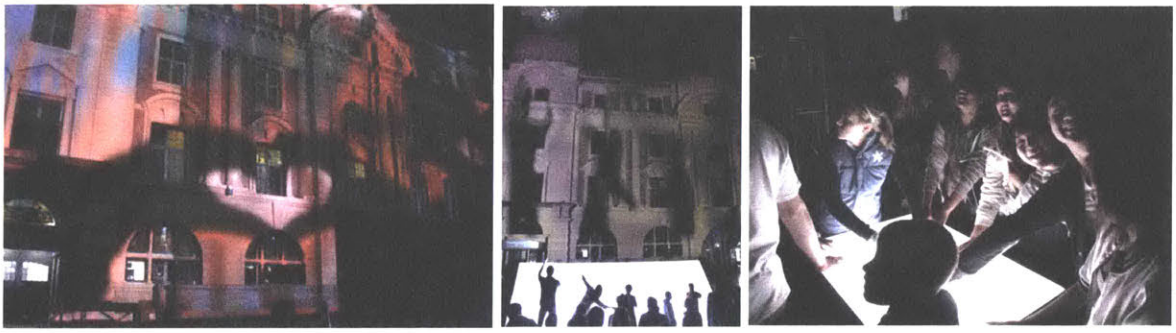


White House shines rainbow colors to hail same-sex marriage ruling, June 30, 2015 (Vucci,2015)

2.2.4. Catalyst

In the city, light often plays the role as a catalyst, which engages, triggers and makes people participating in provoking actions and reactions. Light can be used in interactive systems like performances, games, educational installations, and architectures, turning the static space into life by changing colors and patterns reacting with people's actions.

Light can mediate a playful experience by creating interactions with the surrounding space. At an urban scale, light controlled by individuals can make the public space personal and entertaining. A light design collaborative project of YesYessNo and The Church turned the Auckland Ferry Building into an interactive playground, which not only brought vitality to the traditional building but also changed people's behaviors, allowing visitors to get involved, to merge as a part of the lighting projection and urban environment (YesYesNo, 2010).

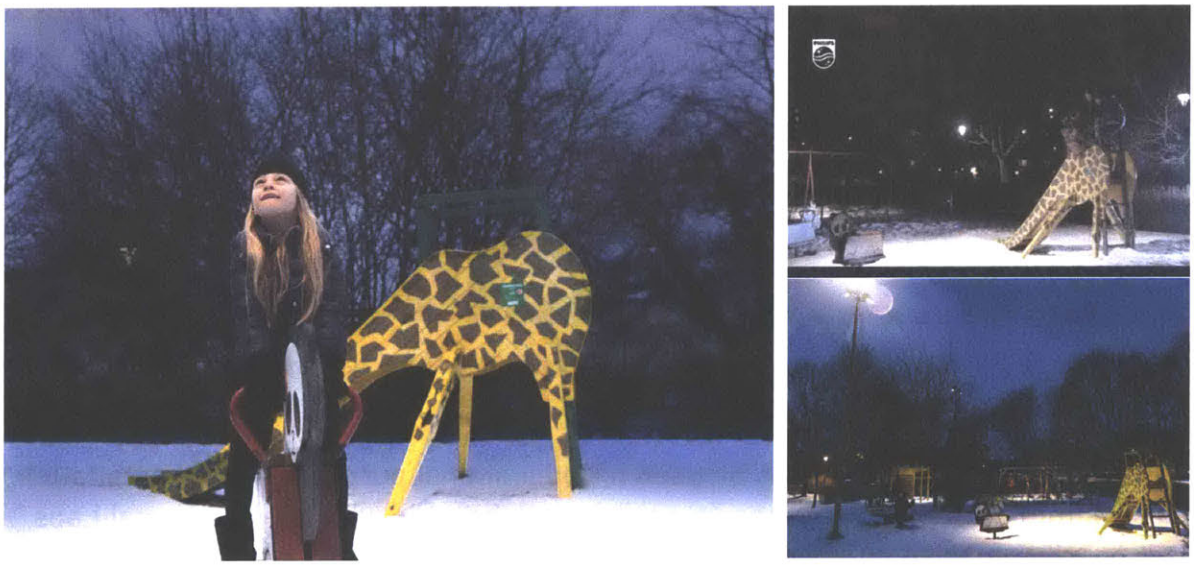


The Church, Inside Out and Electric Canvas - Night Lights Auckland Ferry Building (YesYesNo, 2010)

Light in interactive installation can be used for educational purpose. A light installation called Quantum Space made by Igor Tatarnikov collaborated with Ku-Flex Visual Labs made it possible for users to become shape-shifting digital humanoids and interacted with a quantum representation of self. Light, turning the invisible knowledge into vivid images and movements, helps children to better involved and understand. Just like what Tatarnikov has said: "When you come into Quantum Space, you break down into the quantum of light and you communicate with the universe." (Sims, 2017)

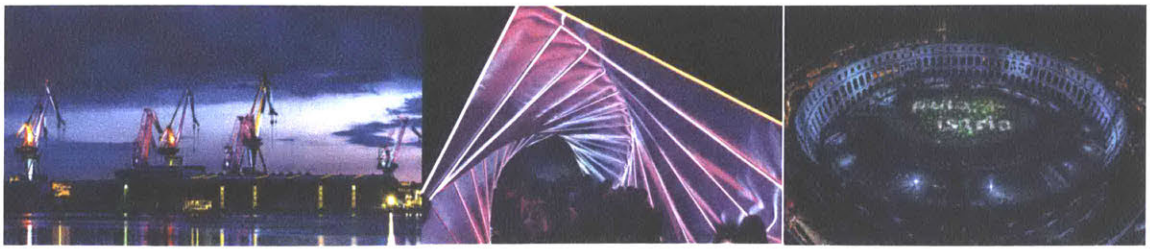
Particle Mirror, Museum of Science, Boston, USA (Sims, 2017)

Light in the residential area brings positive effects to citizen and improve their overall well-being. In Uppsala, Sweden, the darkness falls earlier than 4 PM during the winter. As light plays a crucial role in children's well-being, including regulating circadian rhythm, the natural biorhythms of the body clock, and in the production of hormones, a light solution provided by Philips called Light Up the Dark brings back the daylight to the playground in the evening, which has increased around 37% more of children's time playing outdoors (Bjerking & Philips, 2014).



Light Up the Dark, Uppsala, Sweden (Bjerking & Philips, 2014)

In a caring city, performances or festivals with light acts as a catalyst, aggregating people to celebrate their shared belief, excitement, and memory. Known as the most famous lighting festival in Pula, Croatia, Visualia gathers artists, performers, and audiences to celebrate with dynamic creative lighting and performances. During the Festival, not only the light on the stage, but also public light infrastructures are illuminated with colors, which represent an active actor in the creation of communities, sharing experience, thoughts, and stories.

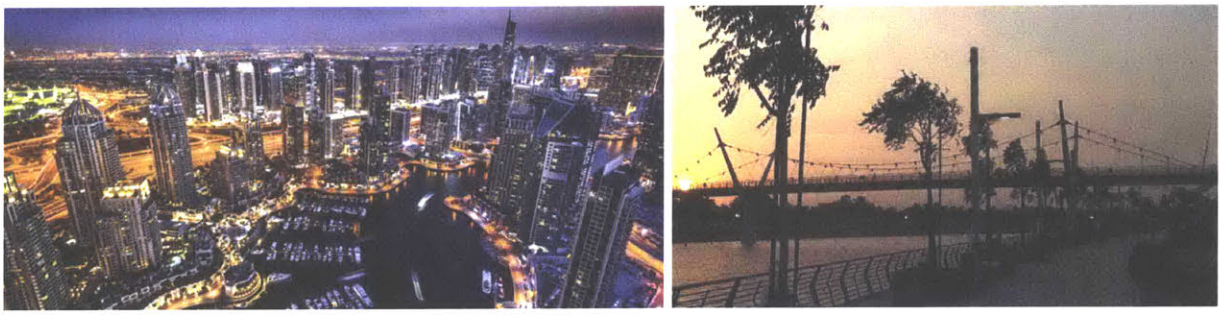


Visualia Festival, Pula, Croatia (Emre, 2017)

2.2.5. Enhancer

Living in the city is a collection of experience from everyday life to occasional activities. Light as an enhancer for these experiences plays a crucial role in both the infrastructures of the city and the single augmented activity envisioned by innovative projects.

A city street lights provide safer traffic conditions and represent a great improvement to the city's architectural touristic and commercial output. InteliLight is one of the intelligent street lighting control systems with IoT like LonWorks PLC, LoRaWan, NB-IoT, and Sigfox, that guarantees a continuous, seamless and autonomous street lighting operation, and allow the city planner to choose pre-programmed schedules according to different user demands across the city (InteliLight, 2016).



InteliLight, Dubai Water Canal (2016)

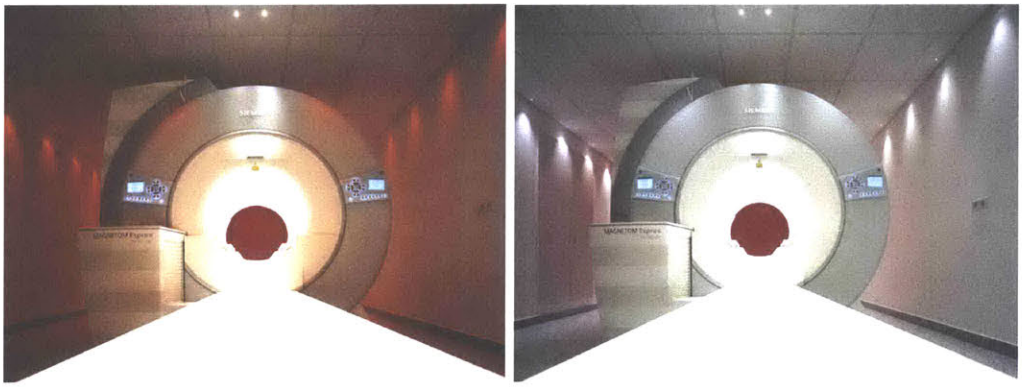
By adding LED on the shoulder of sports shirts, Nightro T-shirts guard runners and cyclists' safety at night (Kickstarter, 2014). No battery is needed, which reduce the weight and time for charging and improve users' performance. Not merely for safety reason, Nike designed sports light for Nike Unlimited Stadium for augmenting the experience. The 200-meter-track with LED wall along with it can show up to 30 runners' figures. Runners can compete with themselves by referring to their own figures, which helps enhance their performance.

Nightro T-shirts (Kickstarter, 2014)

Unlimited Stadium (Nike, 2017)

2.2.6. Affect

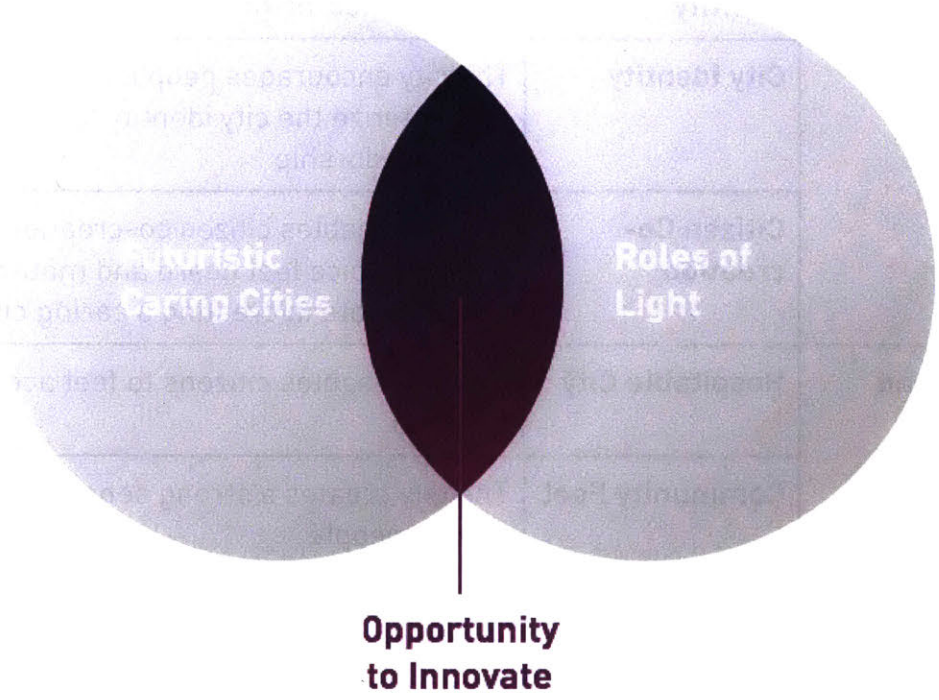
"Lighting design is creating an environment where people feel comfortable without thinking about why. It gives a better feeling". Just as what Peter Andres said, light has a big impact on people's emotion (Sharma, 2016). All lighting designers work with the same tool: brightness, color, direction, contract, and time, to create emotional environments for people. Designers manipulate light these tools to convey emotions: hard light, with crisp shadows, confers a harsh, mysterious environment. Soft light, with soft transparent shadows, confers a happy, smooth, and untextured environment. With this feature, light is used for therapy with various wavelengths. In Siemens Healthcare and Lightlife, a modular medical system has been built to create a cozy environment. When entering the examination room, the patient has already been welcomed with the preferred color with the acoustic sounds. Personal devices like Philips Light Therapy provides the similar experience for individuals. It simulates the light of sunrise with music to wake the user up, and the light of sunset to help users to fall asleep.



Siemens Healthcare Center, Lightlife modular medial system (Rummele 2010)

Sleep and Wake-up Light (Philips Lighting)

2.3. Feature Selection: Well-being



In the previous section, we investigated different versions of the futuristic city and the utility of light. These essential pieces of the puzzle allow us to see the holistic view and serve as the ground for exploring the possibility for innovation using the Opportunity Mapping.

2.3.2. Opportunity Mapping

Opportunity Mapping is a methodology that helps prioritizes the opportunities for new products or services based on ideas and concepts generated from the research. This process encourages us to explore the opportunities at a high level and analyze each opportunity in every aspect before beginning developing the solution.

As the starting point in the opportunity map, we use the Philips Lighting's internal research: Empathic Smart City which suggests five key features (with four more inside each) of the caring city to support its citizens.

Promote Identity and Self	**Personal Identity**	The city supports individuals to explore and express their identity
	Neighborhood Identity	The city supports people to participate in shaping their neighborhood identity
	City Identity	The city encourages people to help characterize the city identity to the point of ambassadorship
	Citizen Co-creation	The city enables citizen co-creation, making people's voice feel heard and motivate them to participate in creating a caring city
Belonging and Sociability	**Hospitable City**	The city enables citizens to feel accepted and at home
	Community Feel	The city creates a strong sense of community among people
	Social City	The city helps people to network with like-minded people or interests regardless of location
	Planning Heart and Soul	The urban planning makes sure the essence of the neighborhood remains regardless of any new urban renewal project
Attractiveness and Opportunity	**Flexible City**	The city offers spontaneous or occasional surprising experiences to keep people excited and break from the usual routine
	Aspirational City	The city support people to pursuit their aspiring personal and career development
	City as a Platform	The city becomes a platform that open possibilities for entrepreneurial or social initiatives
	City as Lab	The city functions as an incubator for Smart City innovations, allowing citizens to partner with municipal in large-scale projects

Inclusion and Mobility	**Inclusive City**	The city allows everyone to equally take part in the society without being hindered regardless of gender, race, or any social status
	Edges of City	The city embraces the fringes of the city and those who live work there as part of the caring city without taking control or creating tension
	Urban Habitat	The city develops in a sustainable way that also protects the ecosystem and biodiversity
	Flow of the City	The city enables cost-efficient and timely transportation for passengers and distribution of goods
Safety and Balance	**Safe City**	The city's municipal effectively prevents crime and make people feel safe through urban design
	Health City	The city fosters a healthy lifestyle
	Need to Wind Down	The city helps people to relax, wind down, and live a well-balanced life
	City Foundation	The city provides reliable utility infrastructure such as gas, electricity, waste disposal, etc.

Five Main Features of the Futuristic Caring Cities (Philips Lighting, 2017)

These features suggest the different values that people need support from the city. The next step is to select the specific opportunity that we want to pursuit.

2.3.2. Opportunity Selection: Light for Well-being

First, we evaluated the opportunities using The Six Thinking Hats technique by Edward de Bono (De Bono, 2017). The Six Thinking Hats is a methodology that helps individuals to adopt a variety of perspectives on the certain topic as if they are wearing different hats. As the individual wears a particular thinking hat, they will role play and think in a particular perspective. For instance, the team member will only look for the logical benefits when he/she wears the yellow hat. This method helps us to explore different perspectives towards a complex decision such as evaluating the opportunity in this case.

Then, we considered these criteria:

- Level of the impact if the project success
- Room for creativity or possibility
- The problem can be solved by the effects of light
- Match with our expertise

This pushes us to look at each opportunity in every angle possible to make the final decision.

Finally, the selected opportunity is the combination of "Health City" and "Need to Wind Down." With plenty of room for creativity, we believe it is feasible to develop an impactful lighting solution that would help people to live a well-balanced life that suits their needs. However, as we now dive into a more specific area, further research is needed to get more understanding of user needs.

Chapter 3
Research in Lighting for Well-being

The selected opportunities of "Health City" and "Need to Wind Down" are described as the need for people to unwind from the stress, relax, and fosters a healthy lifestyle. It redefines the role of the city from being a facilitator, providing infrastructure to the caring environment that supports work-life balance and promotes physical and mental well-being. This chapter will discuss literature research on the main obstacle to well-being – stress, and the result from user interview to understand the people we are designing for. Additionally, we explore the existing solutions that creatively use lighting to promote good health among citizens.

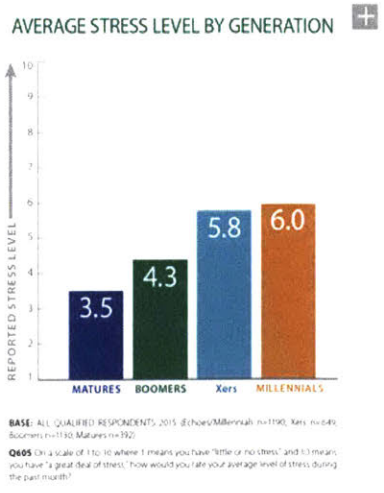
3.1. Literature Review

The secondary research aims to justify why a caring city needs to reinforce people's interaction and encourage people to live a healthy and balanced life.

According to "6 New Stress Statistics to Convince You to Slow Down" (The Busy Lifestyle, 2018), in the U.S, around 40% of the population experience high to moderate stress, with increasing percentages of adults reporting extreme levels of stress. Many of them report stress has a negative impact on their mental and physical health, which can be regarded as disorders. Research by Anxiety and Depression Association of America (2016) has found that anxiety disorders are the most common mental illness in the U.S., affecting 40 million adults in the United States age 18 and older, or 18.1% of the population every year. Nevertheless, anxiety disorders are highly treatable, yet only 36.9% of those suffering receive treatment. Possible reasons of not receiving treatment can be: the sufferer and its kinfolk have not yet realized the symptom can be regarded as an illness, the illness is downplayed, or the sufferer and its kinfolk are afraid of seeking for help from the physician.

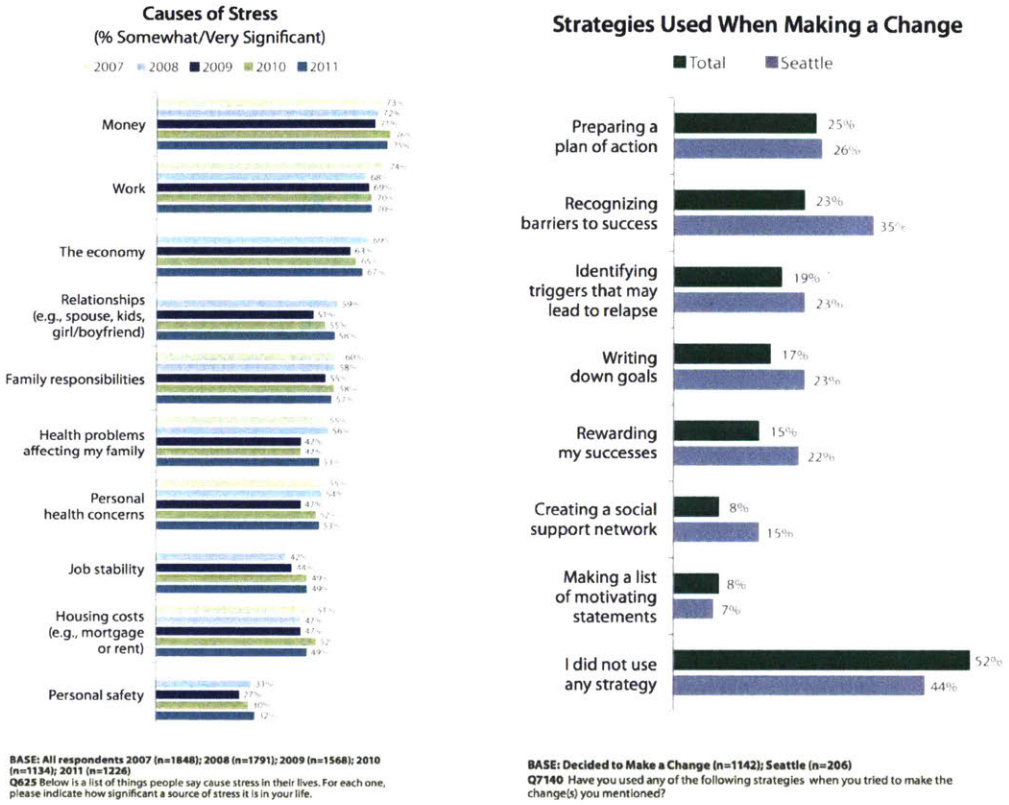
Over time, younger generations are undertaking higher stress level. According to the report "2015 Stress in America" by American Psychological Association (2016), millennials have reported the highest average stress level within four generations, whose score is 6.0 (on a scale of 1 to 10 where 1 means have "little or no stress" and 10 means have a great deal of stress). The rest scores are: 3.5 for matures, 4.3 for boomers, and 5.8 for Xers, which reveals ascending trend. Women and younger generations consistently have struggled with stress. The populations have reported higher average stress levels more than their counterparts compared with the data of 2014.

Why people feel so stressful nowadays? The report "Stress in America: Our Health at Risk" written by American Psychological Association (2012) has shown the causes of stress from 2007 to 2011, in ten of which, "money", "work" and "the economy" are kept as the top three ranked factors. "Hardworking brings success in the long run", "People have a chance to escape poverty." Sayings like these reveal the busyness culture that American believes work leads to success. The more people believe that one has the opportunity for success based on hard-working, the more people tend to think that for those who



Average stress level by generation (American Psychological Association, 2016)

skip leisure and work all the time have higher standing (Bellezza, Paharia, & Keinan, 2016).



Causes of stress, Strategies used when making a change
(American Psychological Association, 2012)

To alleviate the high pressure, several strategies have been proposed by researchers from American Psychological Association (2012) and 1142 surveys have been filled out by American all over the country. Though most people believe managing stress is important, the result shows reach up to 52% people do not use any strategy. In addition, according to "6 New Stress Statistics to Convince You to Slow Down" (The Busy Lifestyle, 2018), in reality, top stress management strategies identified are: watching television/movies for more than 2 hours per day, surfing the internet, sleeping, alcohol drinking and smoking. Not too many of these techniques can be incorporated into a healthy lifestyle.

Base on the evidence above, besides providing professional medical care, to design products and services for daily care that aim to release anxiety and improve overall well-being is imperative.

3.2. Interview

To further understand people's attitude towards balanced life and well-being in the city, primary research is conducted. Three methods are commonly used to gather raw data from customers: interviews, focus groups and observing the product in use. According to Griffin and Hauser, one 2-hour focus group reveals about the same number of needs as two 1-hour interviews, which the latter are usually less costly and allow the research team to experience the use environment of the product (Griffin and Hauser, 1993). In this primary research, interviews are the chosen approach.

Before designing the personalized lighting experience in the city, we believe that the study of people's behaviors and thoughts of city life can help us to find the right problem context to focus on. The interview aims to understand what an ideal balanced lifestyle means to people, and how an innovative city can better support citizens. Eight qualitative interviews were conducted with people of different age and occupations. General questions include but not limited to:

1. What's your definition of balanced life?
2. How do you think your life so far? Are you living a balanced life now?
3. What do you usually do for relaxation?
4. Any tool that helps you with relaxation? How/Where can you get the information of relaxation activities?
5. Does the city you live in / have been lived in support you to have a balanced life? As a city, how to support people to live a balanced life?

Base on the age, background, and specific answer of each individual, personalized questions were asked such as "Do you think your parents have a balanced lifestyle" for a freshman interviewee, "How to keep a balance of working and time with family members" for a father, and so forth.

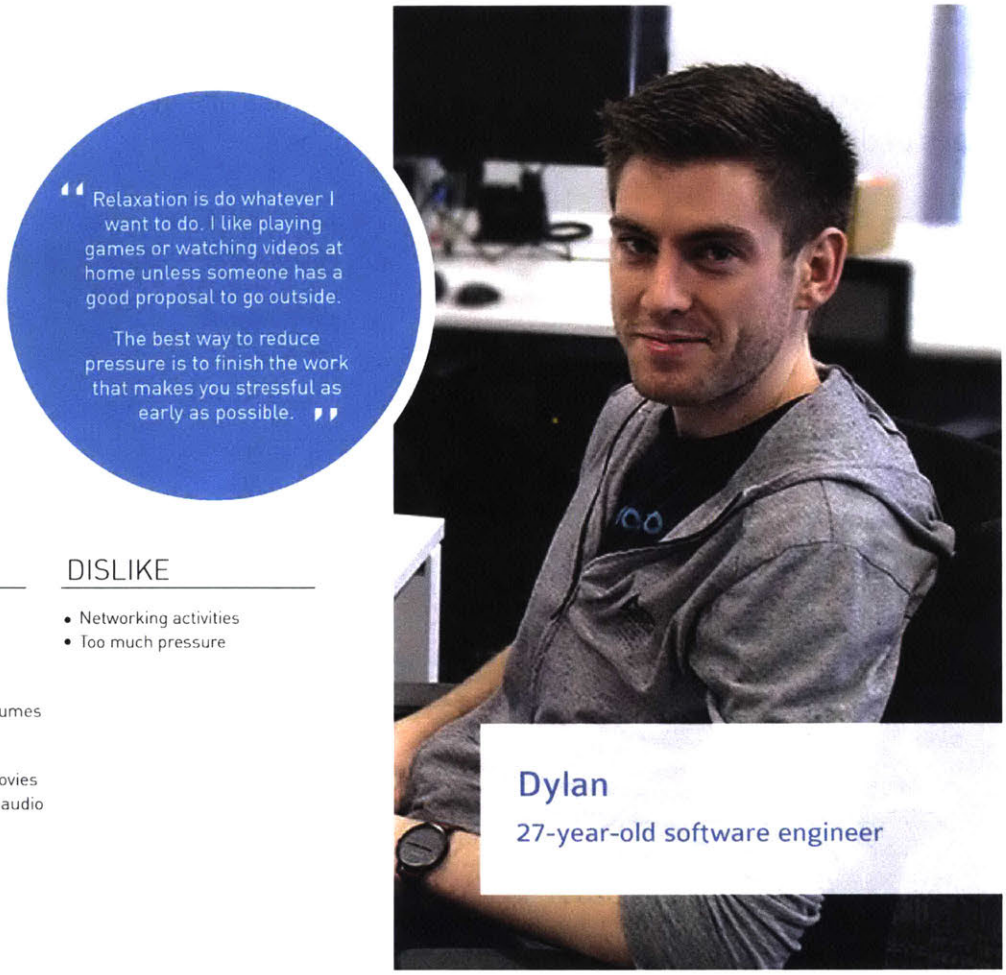
3.3. Personas

By summarizing the eight interviews, three personas are generated, which represent users of different characteristics and preferences.

Persona A:

This type of people are mainly students who study and do research on the daily basis. Their schedule is relatively fixed during the weekday, and they might enjoy some leisure time during the night and weekend. Normally, their pressure comes from study burden, so the definition of balanced life is tied down having a right amount of study load – neither too much homework nor not having to study at all. Gaining the new knowledge is one of the important elements towards the balanced lifestyle. Apart from studying, having good meals, hanging out with friends, working out, shopping, exploring new stuff in cities, and traveling are what they need. Among these, having good foods is the most important activity to relieve pressure. Equipping with a spirit of adventure, this type of people are willing to explore new things in the city.

Persona B:



This type of people strives for a feeling of accomplishment. When feeling stress out, the best way to get relieved is to complete the task that causes them anxiety as soon as possible. In their leisure time, the gym, where the pressure can be released and a healthy figure can be built, is their destination. Apart from working out, indoor activities like playing computer games, playing board games, and watching videos are more attractive to them than exploring new places (unless it is the vacation escape). They seek higher performance not only in working out and in the game, but also in their everyday life. In order to be their best, listening to self-management audio books helps them to pursue the ideal lifestyle they wish for.

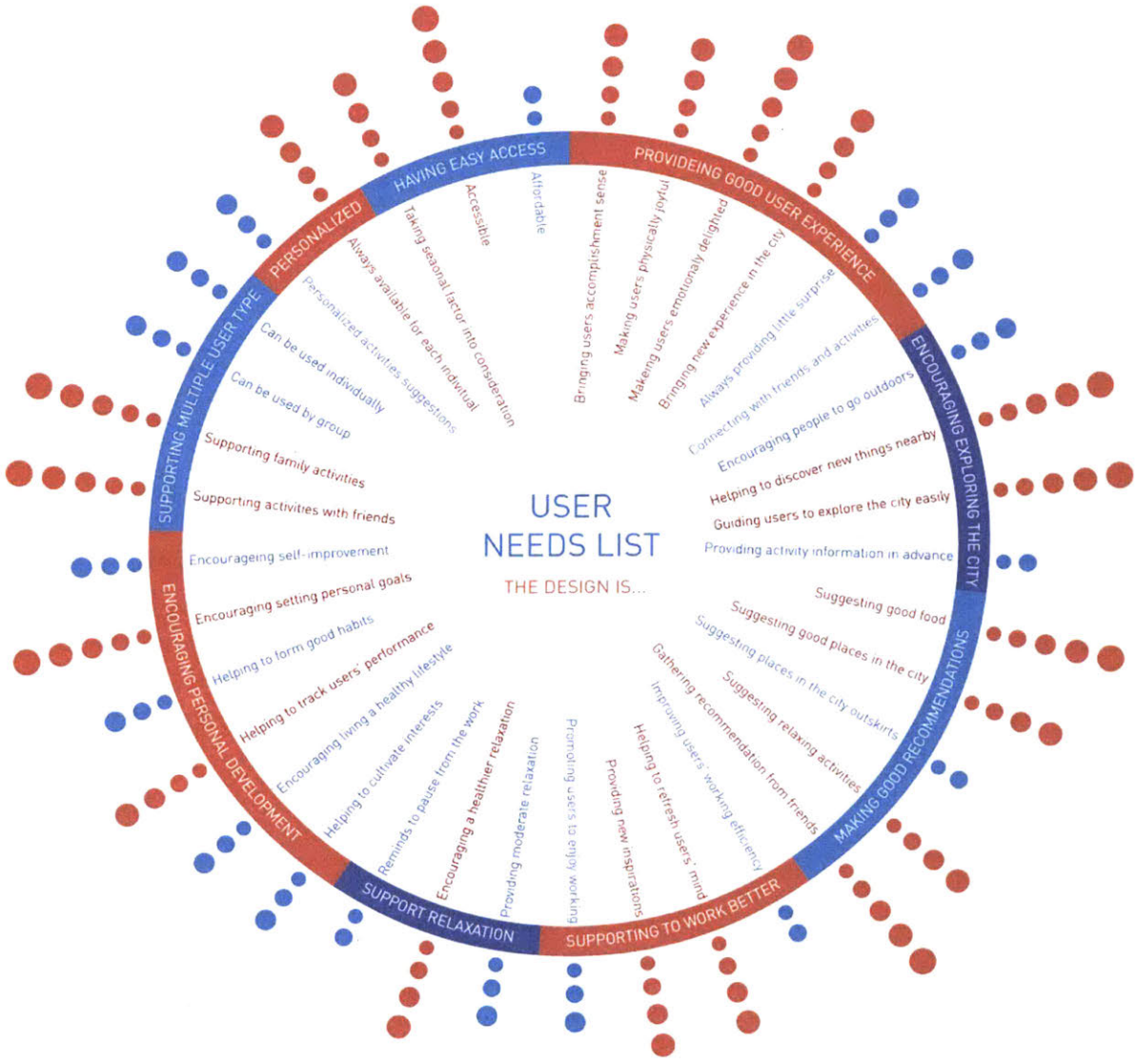
Persona C:

This type of people enjoys living healthy and straightforward life. They have a nine-to-five job, steady income, and a happy family. During the weekday, they prefer to finish all tasks within the working hour and relax by going for a walk or watching TV at the end of the day. During the weekend, they spend time with family, taking them to visit historical sites, museums, parks, or even go hiking. To them, a balanced life means having a straightforward schedule. Being close to nature and familiar things makes them feel comfortable. For them, getting used to new things usually takes time, especially in the age of rapid development in science and technology.

3.4. User Needs List

From the eight interviews, user statements and observation are collected and interpreted into user needs. According to Eppinger and Ulrich (2015), there are five guidelines for writing needs statements: Express the need in terms of what the product has to do, not in terms of how it might do it; Express the need as specifically as the raw data; Use positive, not negative, phrasing; Express the need as an attribute of the product; Avoid the words must and should.

Base on the guidelines above, a list of nine primary user needs with graded secondary needs is generated. Secondary needs are graded from 1-5 (denoted by numbers of dots in the graph below) according to the importance, within which latent needs are denoted by blue dots.



User Need 1: The design provides a good user experience.
As a human-centered design, providing a good user experience is vital. Making users emotionally delighted and physically joyful are two important features that improve the user experience. Plus, adding freshness and a sense of accomplishment to the design are ways to maintain the good experience.

User Need 2: The design encourages users to explore the city.
To help people to pursue a balanced lifestyle, encouraging people to step out of their office/home and explore new things in the city is a good approach. A good design can not only help users to discover new places and events nearby but also guides users to explore the city easily according to their preference.

User Need 3: The design makes good recommendations.
Many people do not lack motivations to go outdoors but have no idea where is the best place to go. To that end, providing good recommendations such as restaurant, spots, and activities will fulfill users' need. In addition, gathering recommendation from friends can also help people access varies activities for a balanced life.

User Need 4: The design supports users to work better.
According to users' statements, the definition of balanced life is not equal to relaxation or no pressure, but a combination of work/study and relaxation, a lifestyle with medium pressure. Some people have mentioned that if the pressure is from the work or study, the best way to release pressure is to get the work done. Hence, helping people to work and study better, including improve efficiency, refresh mind, and arise new inspirations will reduce the stress and make people emotionally satisfied.

User Need 5: The design supports users' relaxation.
There are different ways of relaxation, but some of them can only provide temporary relax and bad for health in a long run. To encourage people to have a balanced lifestyle, healthier relaxation activities are better to be suggested by the design.

User Need 6: The design encourages personal development.
More and more people have started to focus on personal development and purchase relevant products or services. To achieve that end, the design will encourage users to live a healthy lifestyle and helps users to form good habits.

User Need 7: The design supports multiple user types.
Both inclusiveness and personalization need to be considered as a design aim at the future city. To better serve multiple activities and user types, the design needs to be used both individually and by group.

User Need 8: The design is personalized.
With the rapid development of artificial intelligence, In the future, the design in public space can both fulfill general needs and personal needs. Data is collected for suggesting activities based on personal preference.

User Need 9: The design has easy access.
For users in need, the design is both accessible and affordable to provide good service and experience.

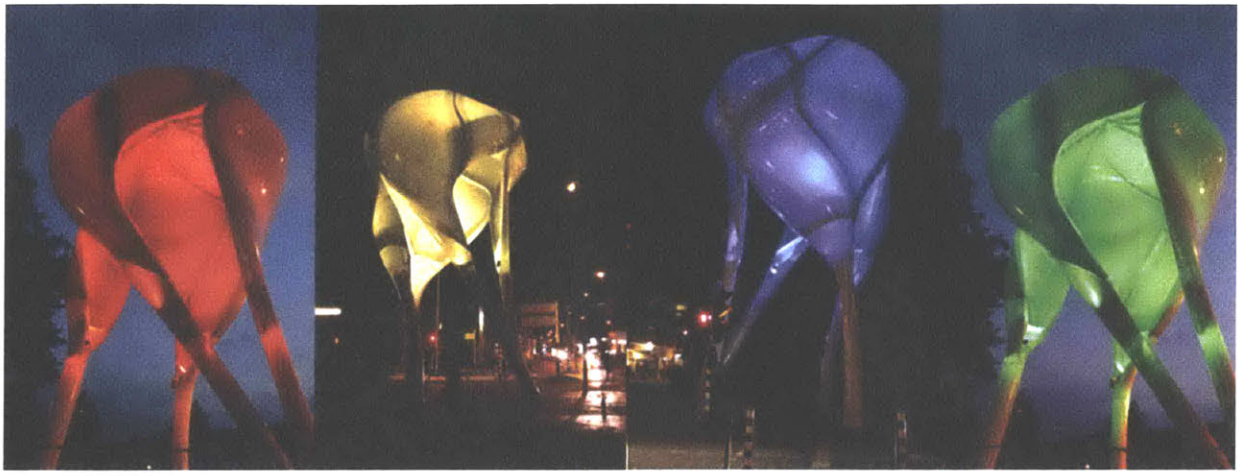
3.5. Existing Solution Analysis

In many cities, light cares for people's feeling by connecting with stories of happiness and sorrow between the individual and the city. When darkness falls, neon lights are lit. People relieve the burden from work and hang out at the pub, dancing and laughing. They get together in the square, celebrating and praying. They are alone in the subway station, recalling and crying. Light magnifies these emotions, bearing witness to thousands of different stories in the city.

In San Francisco, the stories of the city are present on the top of Salesforce Tower via 11,000 LEDs installed on the top six floors that display the daily life story recorded by multiple cameras placed around the city.

Salesforce Tower, San Francisco. 11,000 LEDs were installed on the top six floors, displaying the daily life story recorded by multiple cameras placed around San Francisco. (Campbell, 2017)

In Doetinchem, citizen's collective satisfaction is represented by the colors of light using a hybrid of different media: a physical structure (the tower), a questionnaire, and a website. Citizens' emotions are collected by the questionnaire and shown by the light (green for hate, red for love, blue for happiness, and yellow for fear).



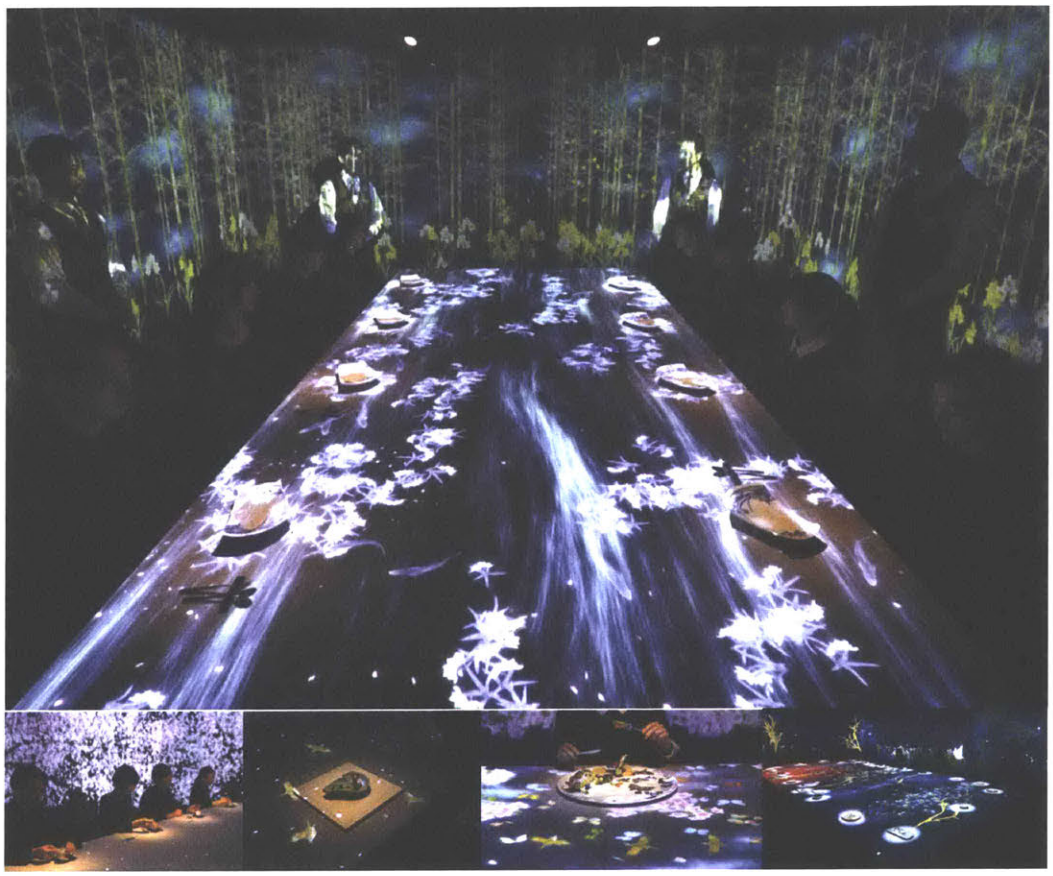
D-Tower, Doetinchem, The Netherlands. It is a hybrid of different media: a physical structure (the tower), a questionnaire, and a website. Citizens' emotions are collected by the questionnaire and shown by the light: green for hate, red for love, blue for happiness, and yellow for fear. (Serafijn, 2005)

In Boston, each night of December, the top of Prudential Tower is lit a different color in support of that night's partner. 31 Nights of Light was created to help community organizations gain key visibility during the holiday season. Participating groups will "flip the switch" each night, with a host of musical performances and speakers each night. Light is a reflection of stories in cities.

Prudential Tower – The Center goes for Bruins Foundation, Boston, MA (Weyant, 2016)

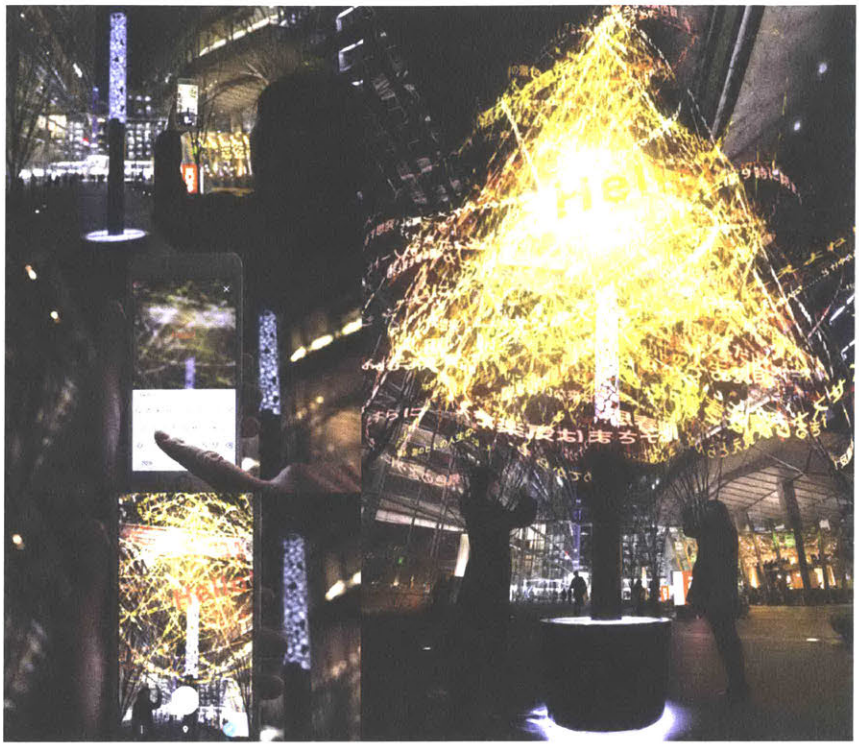
Lights in cities take care of people's well-being by enhancing their daily experience. Augmented dining experience Worlds Unleashed and then Connecting designed by TeamLab utilize light projection has changed traditional dinner into a digital lighting

feast. A room settled with long table and chairs with projectors, when a dish is placed on the table, the world contained within the dish is unleashed, unfolding onto the table and into the surrounding space. The worlds unleashed from each dish connect in the external space creating a new larger world. The worlds unleashed are affected by the other dishes on the table, such as a bird released from one dish can perch on the branch of a tree unleashed from another, and the trees grow from each dish are not identical, whose sizes and shapes are affected by the worlds unleashed by the other dishes on the table. With the changes of people's behaviors, the light projection changes, which in turn affects people's behaviors.



Worlds Unleashed and then Connecting (TeamLab, 2015)

Another lighting design combined with Augmented Reality called Message Pillar designed by TeamLab enhances people's communication in the city. With the App on the personal device, messages from other people spinning around the light pole can be seen through the screen. Users can post their own message by editing and upload the contents from their phones. The design encourages people to explore the hidden world in the city and bridge people by sharing individuals' comments and feeling.



Message Pillar (TeamLab, 2016)

Lights in cities take care of people's well-being by educating people in an entertaining way. In Phillip and Patricia Frost Museum of Science located at Miami, the LED dancing floor in MeLaß helps people, especially children, to explore ways human's body and mind work together, and how people's daily choice can make it all work better. Children dance together in circles of different sizes and colors shown on the LED floor. A result of individual energy consumption, collective energy consumption, steps and the goal of today presents after each dancing session, encouraging people to form their own exercise plan and keep a healthy lifestyle.

MeLaß, Phillip and Patricia Frost Museum of Science, Miami

3.6. Next Step

Approaching from three angles; the statistical research provides the evidence for the need to support the well-being at the macro level, the interview suggests the underlying needs, serving as the necessary attributes that our solution must provide, and the existing solutions exploration inspires us creatively for the innovative solution. This helps us prepare for developing the lighting solution in the next chapter.

Chapter 4
The Pivot

The beauty of the design process is learning through iteration by challenging our initial assumption. This chapter presents the process of developing the initial design concept, getting the user feedback, and reframing a new problem statement. The result helps set the course of our project in a new meaningful direction and focus at a real pain point.

4.1. Design Iteration

According to the research, 26 design concepts are developed by the brainstorming session, aiming at promoting people's well-being in the futuristic caring cities through the lighting solution.

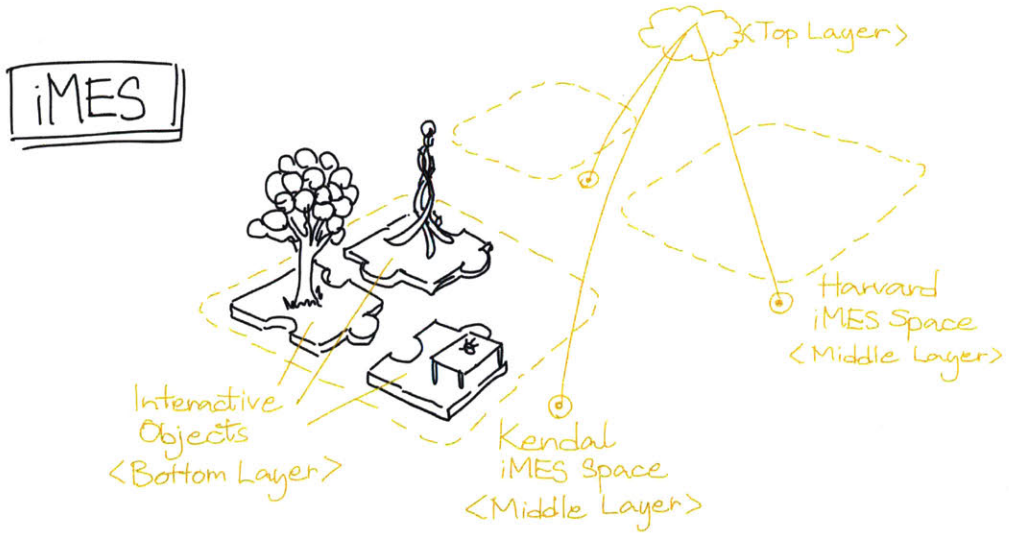
DESIGN CONCEPTS

We use the Concept Scoring decision matrix (Eppinger and Ulrich 2015) to downselect the concept. Each column represents different design concept from number 1-26. We then use eight selection criteria: desirability, viability, feasibility, the relevance of topic in the future, disruptivity of the solution, room for creativity, project scope, and match with our expertise. To simplify the scoring process, we simply give the score on a scale from 1 (bad) to 3 (good).

	Opportunities																								
Selection Criterias	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Desirability	1	2	1	1	1	3	3	2	1	1	2	2	2	3	1	1	1	1	1	1	1	1	2	1	1	2
Viability	2	1	1	1	3	3	3	3	1	1	1	2	3	3	1	1	1	1	1	1	1	1	1	2	1	2
Feasibility	2	3	2	3	2	3	2	2	3	2	3	3	3	3	2	3	3	3	3	3	1	3	3	2	2	1
Topic last long in future	1	3	2	1	1	3	3	1	3	3	2	3	3	3	1	3	1	1	2	2	3	2	2	2	1	1
Disruptivity	3	1	1	1	1	2	2	2	2	1	2	1	1	2	1	2	1	2	2	2	2	1	3	2	2	2
Room for creativity or possibility	2	1	1	1	2	2	3	3	1	1	1	2	2	3	3	2	1	2	2	2	1	2	2	2	1	2
Project scope for thesis	1	3	3	3	1	3	2	2	3	1	1	2	2	3	1	2	2	2	2	2	1	3	2	2	3	1
Our Skills	1	2	1	3	1	3	3	2	1	1	2	2	2	3	1	2	2	2	3	3	1	2	2	2	2	1
Score	13	16	12	14	12	22	21	17	15	11	14	17	18	23	11	16	12	14	16	16	11	15	17	15	13	12

Concept Scoring

Base on the calculation, No. 6, No. 7, and No. 14 were selected. As three concepts share some commonality, we combined them into one design concept called "Integrated Modular Experience Space" (iMES).



iMES Concept Sketch

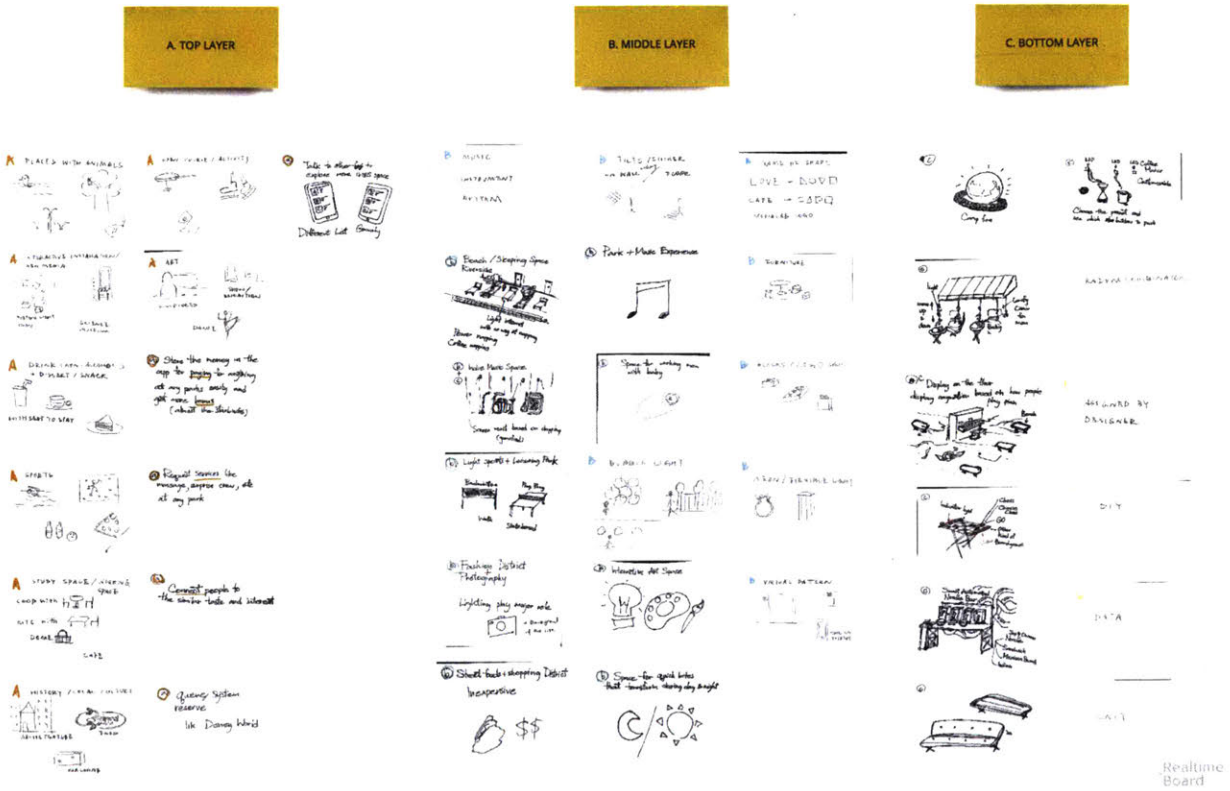
The iMES aims at the demographic who live and work in the city to improve their wellness and promote work-life balance. It is a framework for creating parks for relaxation using different lighting modules. The design concept consists of three layers of modules for creating a cohesive experience:

- Various lighting interactive installations as the bottom layer, like Lego pieces, are installed inside each iMES space. An example is the lighting installation that changes color when people dance.

- Each different iMES space as the middle layer is built and customized from "different pieces of Legos." For instance, an iMES space with two light installations: a dance floor with the interactive screen and a light art installation that shifts color based on how people dance on the dance floor.

- The top layer represents the system (applications) as a whole that connects different iMES space to provide seamless lighting experience. For example, iMES space #2 can personalize the experience to the visitors if they have visited iMES space #1 before on that day.

This framework is used as a guideline for building the interactive attractions around cities that help people to relax. For each layer, we brainstorm multiple ideas and prepare for further development and user testing.



To test the design concept with users, we made UI prototypes of the mobile application that help people to discover iMES spaces around the city, and use a humidifier lamp with QR code as a low fidelity light installation. After testing with only four people, the result surprises us.

4.2. Feedbacks and Pivoting

According to the feedback from users, only a few people are eager to explore the new attractions, especially for the light art installations. Moreover, many challenges if the connectivity between installations that supports the cohesive experience is necessary. The quality and quantity of the lighting installations are what only matters to them.

Nevertheless, the interview revealed some unexpected insight that urges us to pivot. First, people are sensitive to the quality of light at some places comparing to the other. Especially the place where they regularly spend long hours. For instance, home, library, or office. Moreover, lighting plays a significant role in influencing people's lives consciously, subconsciously, psychologically, and biologically. As a result, we took a step back from attempting to occasionally spark joy using the light art installations to an approach that subtly supports the well-being of people in their daily routine.

4.3. Redefining the Problem

Focusing on lighting solutions that subtly support the well-being of people in their daily routine, we reframe the problem statement before diving into the final design: In the future of caring cities, how can the cities provide daily care on people's overall well-being with the personalized lighting experience designed in the public space?

Focusing on lighting solutions that subtly support the well-being of people in their daily routine, we reframe the problem statement before diving into the final design: In the future of caring cities, how can the cities provide daily care on people's overall well-being with the personalized lighting experience designed in the public space?

The term "public space" is sometimes referred to as the space owned by the public sector such as the street or public library. However, in our case, the public space is a place utilized by many regardless of whether publicly or privately owned. Also, the level of personalization that we aim at is the lighting should be able to adapt based on different needs required by a variety of activities of each individual or a group of people. Moreover, the lighting has to help support, not only the functional needs but the emotional needs of the diverse demographic in a subtle way that is not distracting or create the tension among groups of people who are doing different activities. This problem statement is based on the fact that the existing lighting solution in the public spaces is commonly a result of the lowest common denominator from diverse needs of each demographic without specifically addressing any.

As we have clearly redefined the problem, we will discuss and design the solution that responds to the problem statement in the next chapter.

Chapter 5
Lighting Solution for Personalized Experience in the Public Space

In this chapter, nine personalized lighting experience people might have in the future of caring city are discussed, and one experience is selected as a paradigm for further development. Research methodologies including field visit, experts interview, users observation are conducted, and the relationship between light and activities types, circadian rhythm, weather, and work style are explored. Base on the study, we propose a smart lighting system including lighting control ruleset, luminaire designs, and their application.

5.1. Scenarios Analysis: The Personalized Lighting in the Future of Caring Cities

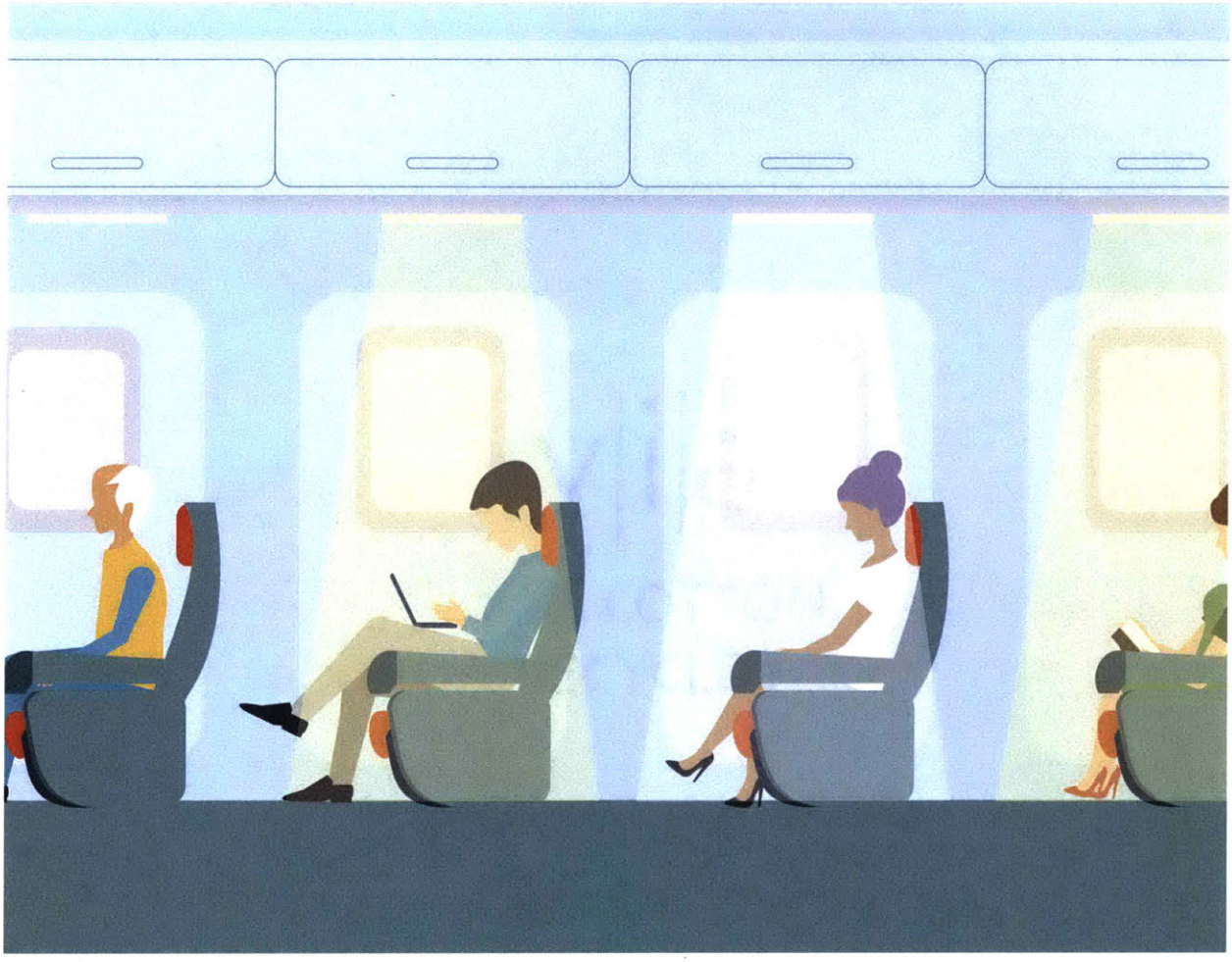
Scenarios are stories representing the future. Base on the redefined problem statement, nine personalized lighting scenarios are designed based on the analysis of the uncertain but important trends that might happen in the futuristic caring cities. Possibilities of how lighting technology, such as Philips Hue, can be utilized to support individual activities are pointed out in the scenarios. These are seed concepts to be further developed by city planners, public venue owners, and light designers.

To better showcase the design, we use Nina's Day in City X to introduce these nine personalized lighting experience design concepts:

Nina, a 28-year-old entrepreneur, who just started an online platform with another three co-founders from different cities. She is ready to travel to City X for a team meeting. Although they have been working together for nearly half year, this is the first in-person meeting they have ever had.

05:30 am Flight

On the flight to City X, Nina has a good rest. Re-energized by Photon Shower above the seat, she is feeling well without jet lag.



Design Purpose:

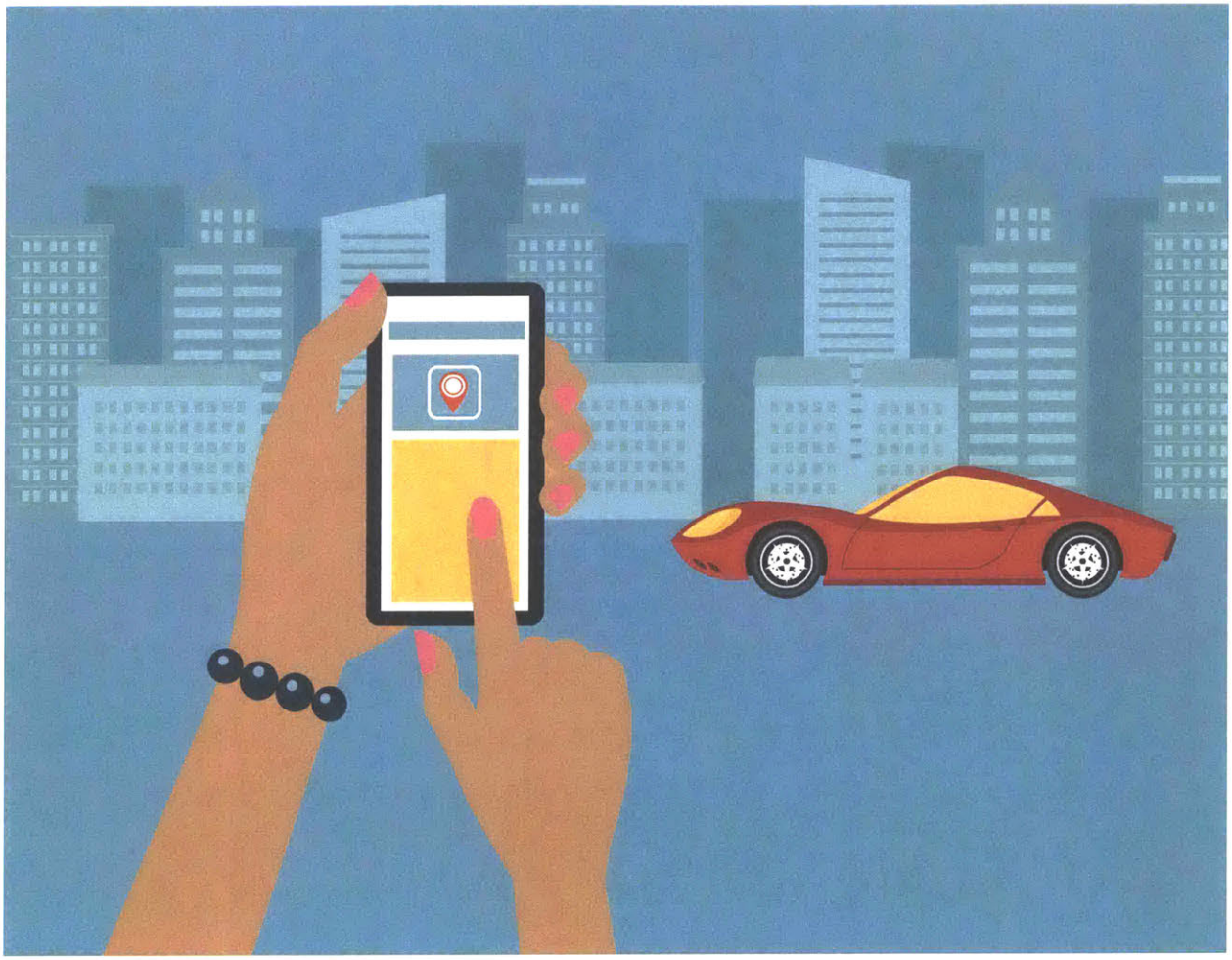
The design helps frequent travelers to better adapt to the timezone of their destination with photon shower according to the route and time of the airline.

Technology:

Data of geolocation and time are used as input. The scene of light changes according to the data or users' preference. The technology is powered by Wieden+Kennedy New York who has developed the working prototype for Delta Airlines.

06:00 am Outside the Airport

Early in the morning, after arriving at City X airport, Nina chooses to take an autonomous carpool to her accommodation. After the request, with the light indication in the car, she can easily find the one and gets in the car to her accommodation.



Design Purpose:

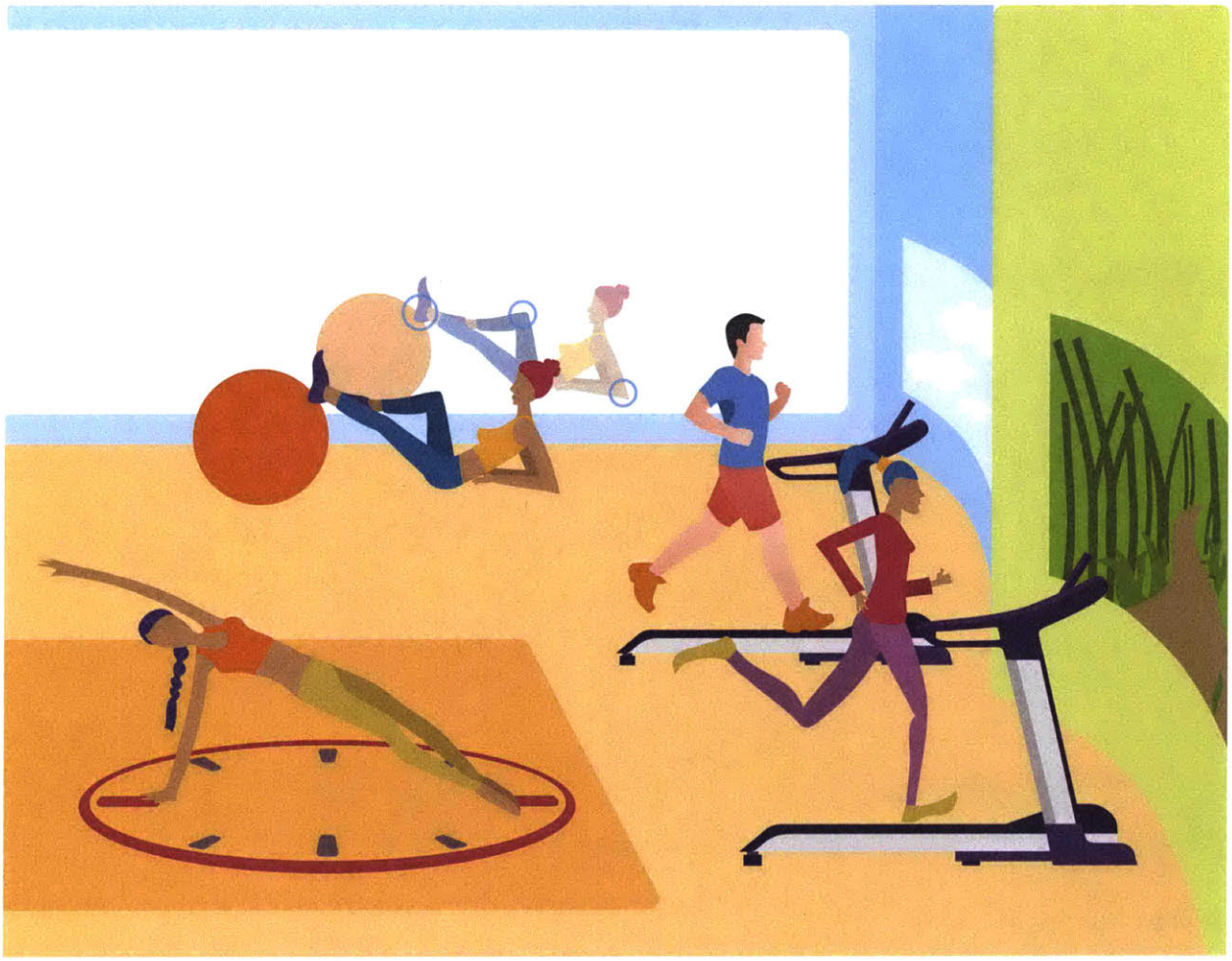
The design provides eco-friendly, socialized, and personalized public transportation experience with customized lighting and music base on users' data, which provide an emotional-joyful journey and trigger communication among passengers.

Technology:

Carpool calling application with lighting control API and music API to control the interior lighting and music in the car.

08:00 am Gym

After everything has been settled down, there are still two hours away from the meeting. Nina decides to follow her daily schedule as usual: doing morning exercise. Arriving at the gym located on the 30 floor of the self-service accommodation, she goes for flexibility exercise on an LED coach mat. Simply by following the LED guidance, she has finished 12 sets of different flexibility exercises.



Design Purpose:

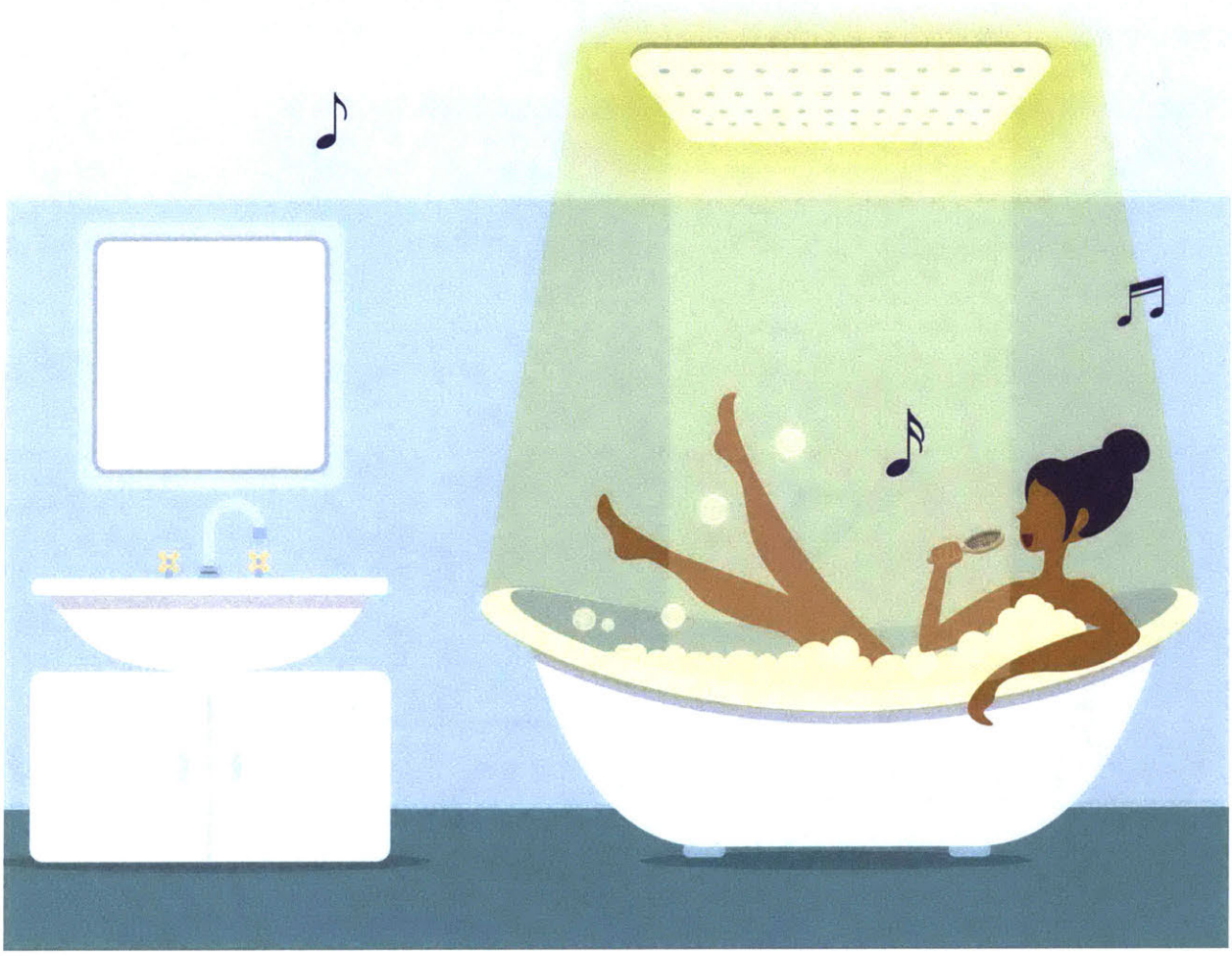
The Gym with multiple facilities supports highly personalized training plan. Treadmills with personalized contents on screens provide unique running experience. Mirror and yoga mat with LED exercise tutorial guide people to train specific part of the body.

Technology:

By connecting personal smart device or account stored with personal training plan to the facilities, users' performance and well-being can be enhanced by the LED guidance.

08:50 am Accommodation

Going back to her room, Nina takes a warm bath with her favorite music accompanied by energized lighting. Refreshed by the workout and the bath. Nina is ready to start her new day in City X.



Design Purpose:

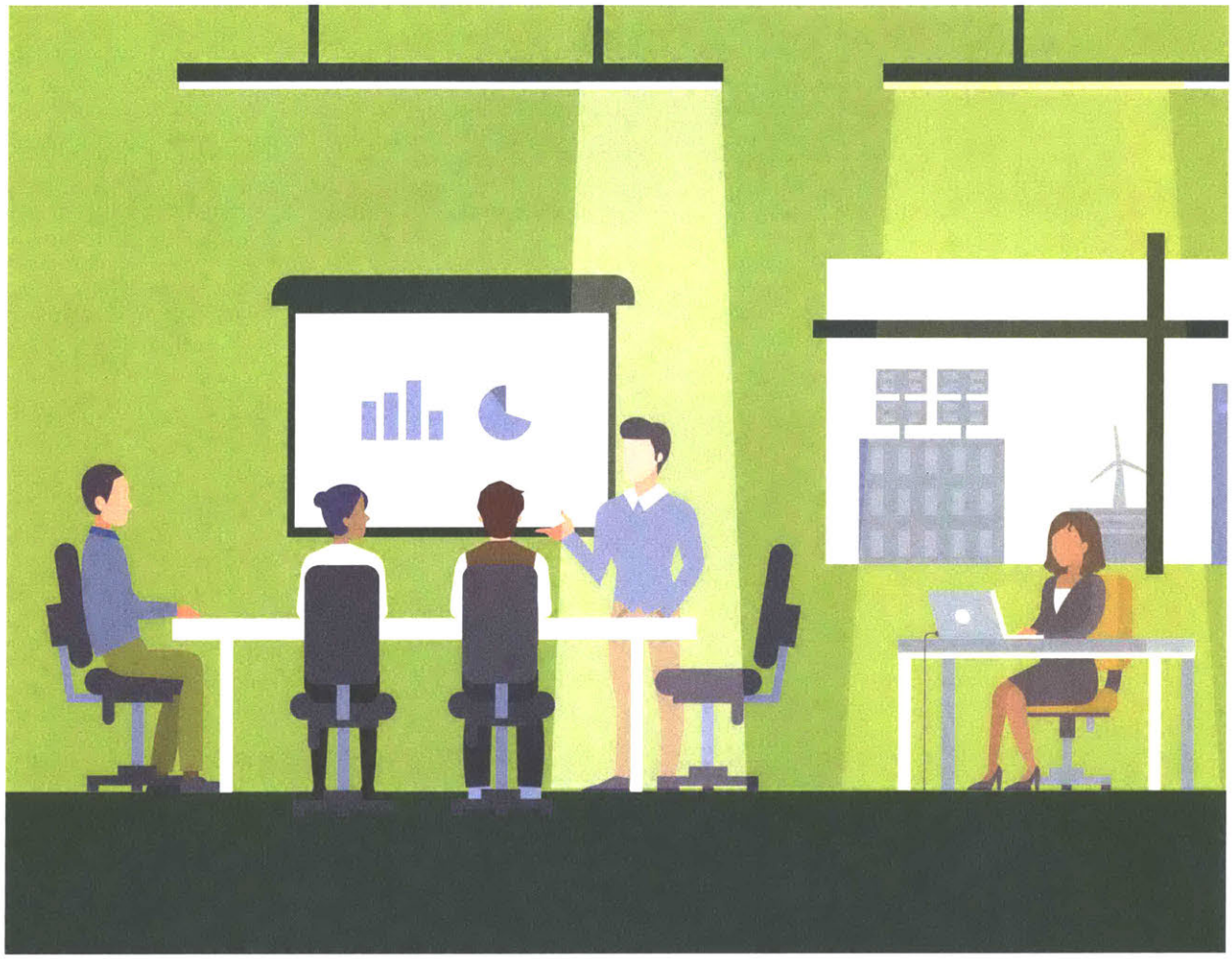
A combination of light and music aims to refresh or bring relaxation to the user.

Technology:

Personal device with music API plays the user's favorite music and has the light color changing according to the music data.

11:30 am Co-working Space

The meeting starts at 10 am in a co-working place. Everyone feels excited to see each other. After each person has presented his/her idea, the team runs a brainstorming session and has a discussion of what next steps will be. With the intelligent light in the co-working space, everyone feels creative, and the meeting runs smoothly.



Design Purpose:

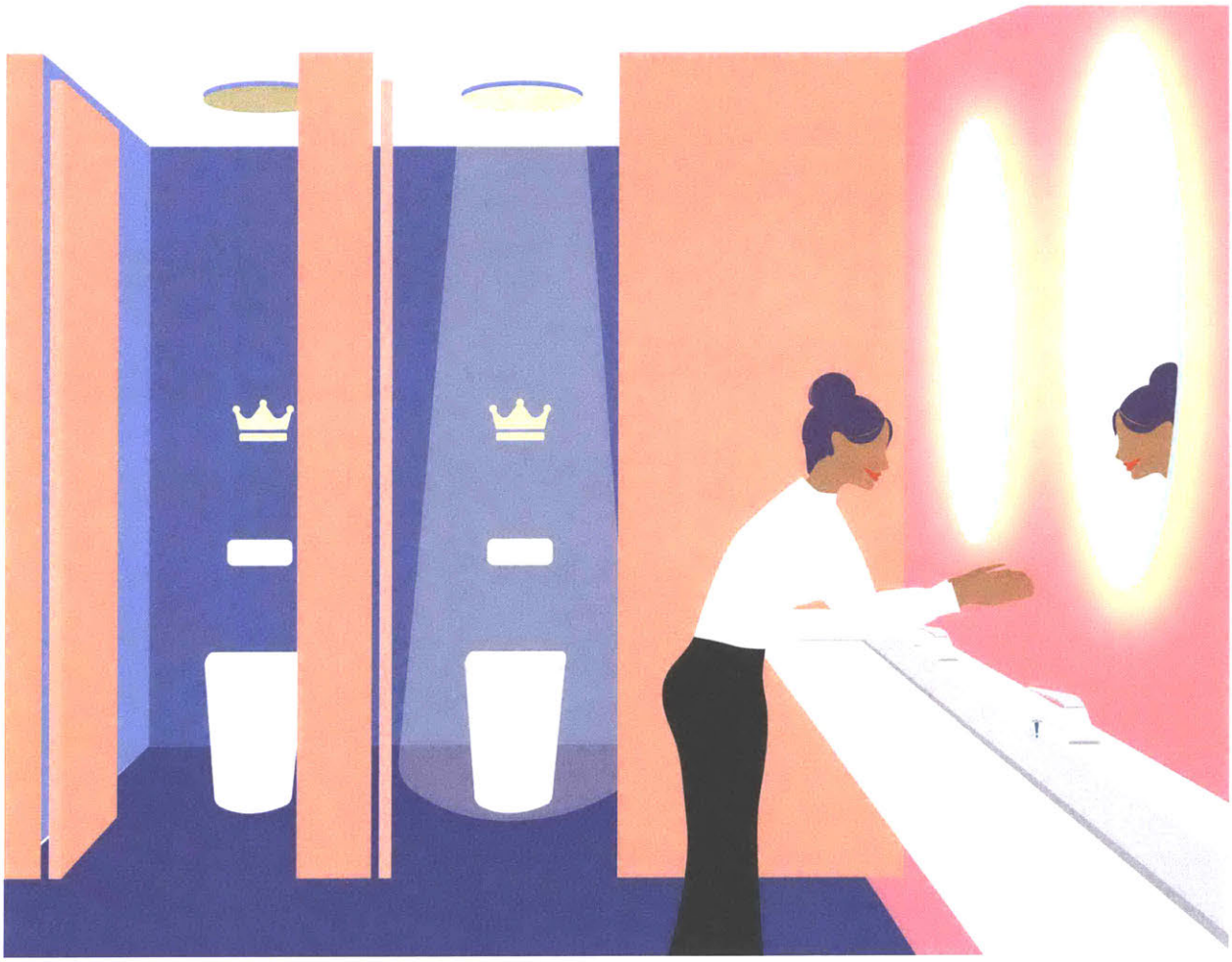
The design aims to provide different lighting solution according to diverse activities, productivity personalities, and environment factors in the co-working space. By helping people to work effectively and reminding people to break accordingly, the light support people to live a balanced life.

Technology:

Philips Hue scenes controlled by the user's personal data and sensors data such as motion, temperature, time, and luminance can support various activities.

14:05 pm Public Restroom

During the break, Nina comes to the restroom. She feels a bit tired after the long meeting. In the mirror with well-designed light, she can see her pretty and healthy face, which makes her come up smiling again.



Design Purpose:

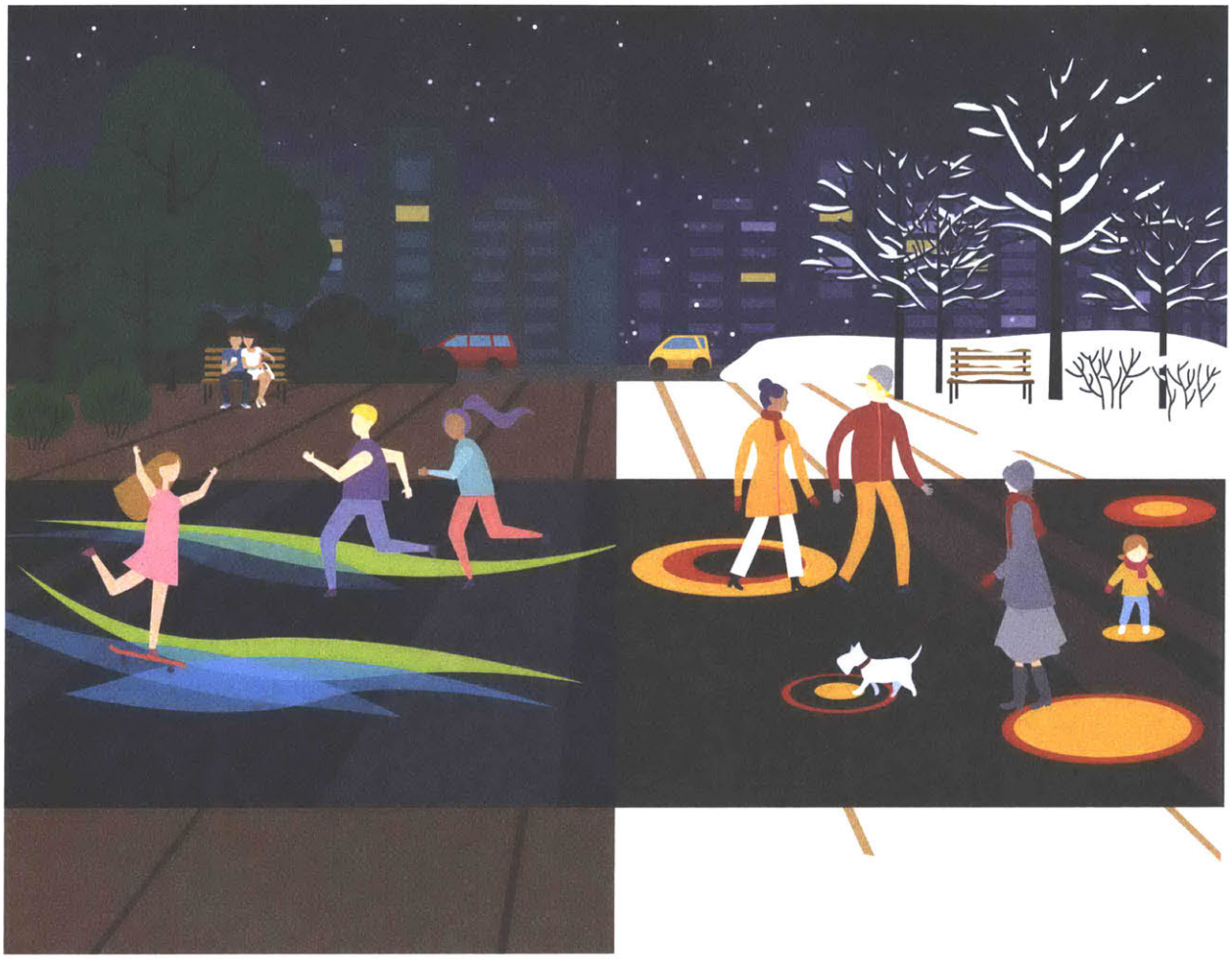
The design makes people look healthier according to the environment and motion, and help people to relax and re-energized during the short break.

Technology:

Motion sensor with light scene designed according to the environment makes people looks healthier.

17:30 pm Central Square

The night falls when the meeting comes to an end. Stepping out of the co-working space, Nina heads to the central square, where her old friend John, who lives in City X, is waiting for her. Although it is cold at night, the warm color light casts from LED floor tiles make the square a cozy place.



Design Purpose:

Interactive LED floor tiles are designed for entertaining citizens and emotion adaptation. The color changes base on the temperature, proving cool feeling in summer and warm feeling in winter. Patterns react according to people's motion.

Technology:

Pressure sensor and temperature sensor data are used in the LED tiles.

19:15 pm Restaurant

Reunion with old friends, Nina and John walk to a theme restaurant nearby. John orders the famous seafood for Nina. Immersed in the undersea world, they have a pleasant long chat from their childhood stories to their recent life.

Design Purpose:

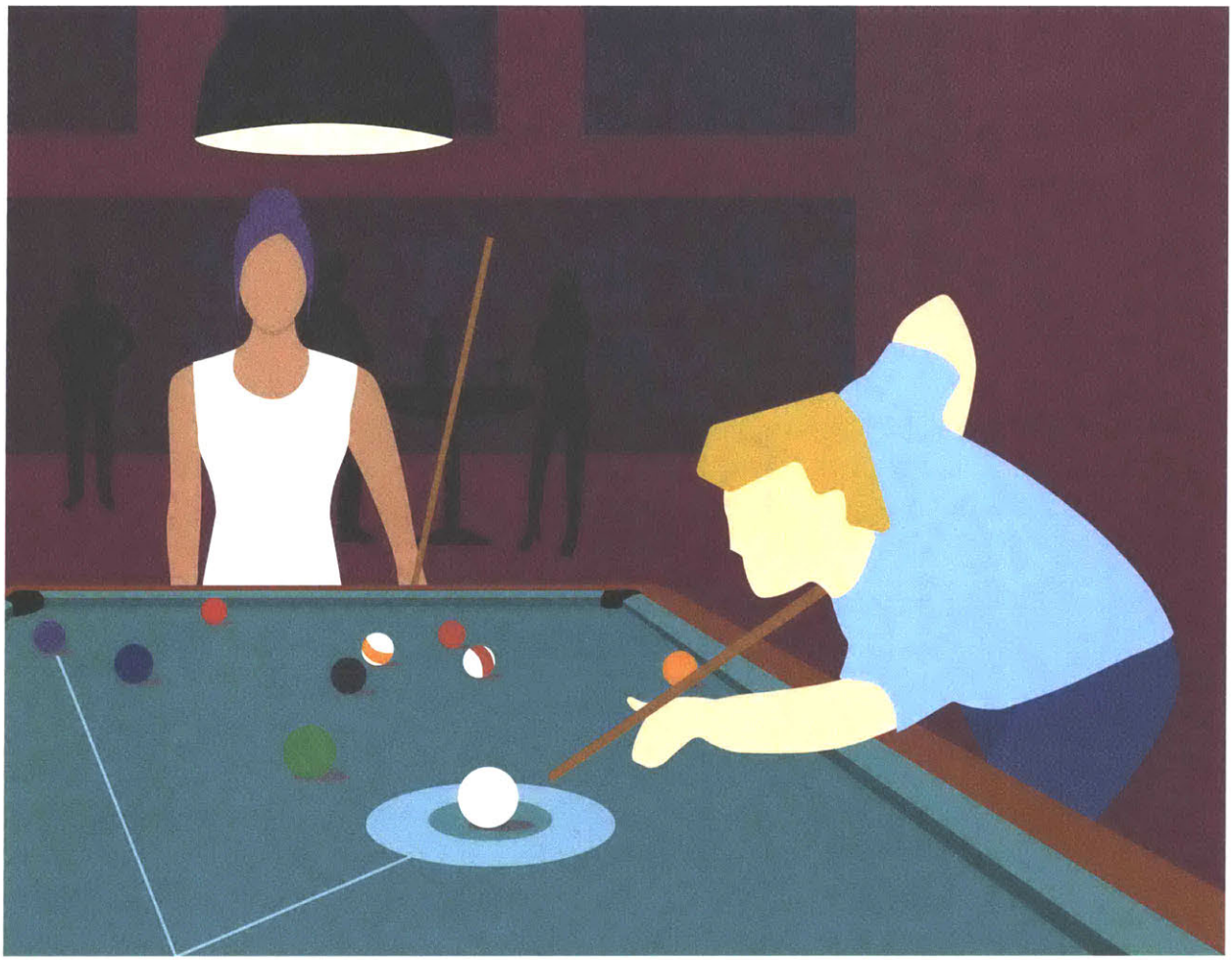
As having a great dinner has been regarded as one of the most important way for keeping well-being, interactive lighting according to the theme of the dinner is design to enhance the dining experience.

Technology:

The light and screen can be changed base on diner's selection on digital menu or image recognition.

21:20 pm Bar

After the dinner, Nina is curious about how the nightlife looks like in City X. With the recommendation of John, they come to a bar not far from here, where various of activities are going on. Nina wants to try billiards but has never played before. With the laser tutorial, she quickly gets the technique and starts to enjoy the game with her old friend.



Design Purpose:

The light is designed for recreation purpose such as billiard tutorial and dancing tutorial, helping people to fully relax after a whole day's work or study.

Technology:

Motion sensor is used to track user's location and actions. Technology is powered by PoolLiveAid.

5.2. Focus on the Personalized Lighting in the Co-working Space

Within the nine scenarios, we pick the co-working space to design in detail, for a demonstration about how light can provide daily care to each individual.

Co-working space is the shared workplace, typically for independent professionals, startups, and freelancers which are usually not employed by the same organization. The goal of co-working spaces is not only to provide the physical space for working but to establish the community of people who share values and help grow their network with professionals.

A few studies suggest the number of co-working spaces and available seats has roughly doubled each year from 2006-2015. Some colleges may also have their co-working space for students to support their entrepreneurial activities. It is undeniable that co-working space is more than a trend and will play a big part in the future of the city.

Also, co-working space is the place where the users usually spend long hours working, making the effect of lighting more significant. It is also the place that is prone to adopting new technology. That is why we chose the co-working space as our focused scenario.

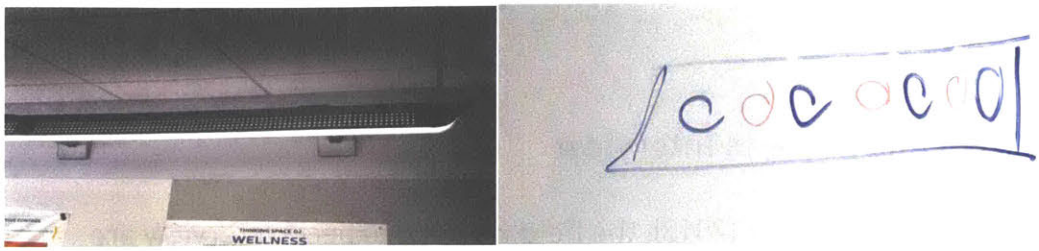
5.3. Research

5.3.1. Field Visit and Experts Interview

According to the study by Kumar (2013), the field visit and experts interview are methods for getting up to speed quickly on the area of interest. To get updated on the latest lighting technology applied to working space, we visited the office of Philips Lighting in Cambridge and interviewed the lighting experts there.

Field visit at the office of Philips Lighting, Cambridge, April 17th, 2018. Philips lighting researcher Meg Smith showed us the ongoing research project with Philips Hue.

Philips Lighting researcher Meg Smith showed us their human-centric illumination solutions designed for the office. They take time and activities as two main factors when considering the light scenes design. The changes of color temperature base on time can bring the positive impact on people's circadian rhythm and better adapt themselves to the current activities: exposing to blue light or cool light after lunch can re-energize people, helping them to focus on the work; exposing to orange light or warm light during evening can assist people to relax and sleep well. While the changes of color and luminance help support various activities, such as presentation, group discussion, and video playing, which bring an effective and cozy working environment for users. To control, users can press the button on the wall and choose the scenes accordingly with the task happening in the space.



LED light for office. The light temperature and color can be changed as LEDs of two colors are installed at every other positions. Diagram drawn by Meg Smith.

By pressing the button on the wall according to the activity, lights in the meeting room can support people to work effectively and emotionally delighted. Scenes provided: whiteboard focus, F2F collaboration, blue boost, warm boost, A/V, and off/on/auto.

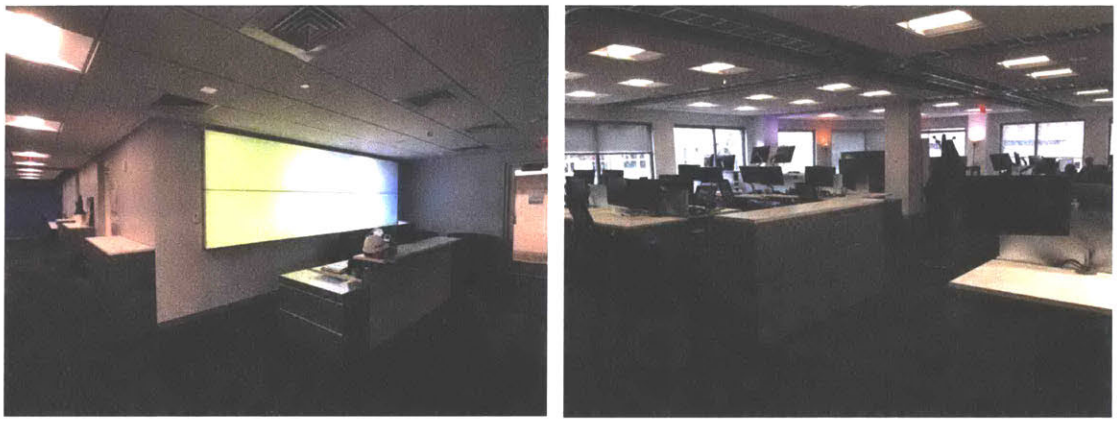
Another ongoing project is applying Philips Hue to the healthcare industry, such as in the hospital or healthcare center. As bedridden patients, patients' family members, and healthcare providers, who stay a long time indoors, will easily lose their perceptivity of time. Philips Hue simulates natural light which create both physical and psychological impacts that contribute to patients' recovery.

Simulation of natural light by Philips Hue for a health care space.

To provide a human-centered lighting experience, research on demographics, such as age, sexual orientation and identity, ethnicity, race, gender, and physical abilities and qualities are still ongoing. According to Meg, how the light should behave base on individual characteristic is an interesting topic that they are still working on. Examples like how light should be designed according to different user's personality, what is the difference between improving the efficiency for a morning person and a night person, or should the light work against the circadian rhythm or support it are the problems they are trying to answer. Regarding the relationship between lighting and space, there are several things they are focusing on:

- Wellness: How can the workplace support people's health and well-being?
- Adaptability: How can spaces adapt to people, not vice versa?
- Connectivity: How can spaces increase mobility, collaboration, and strong social ties?

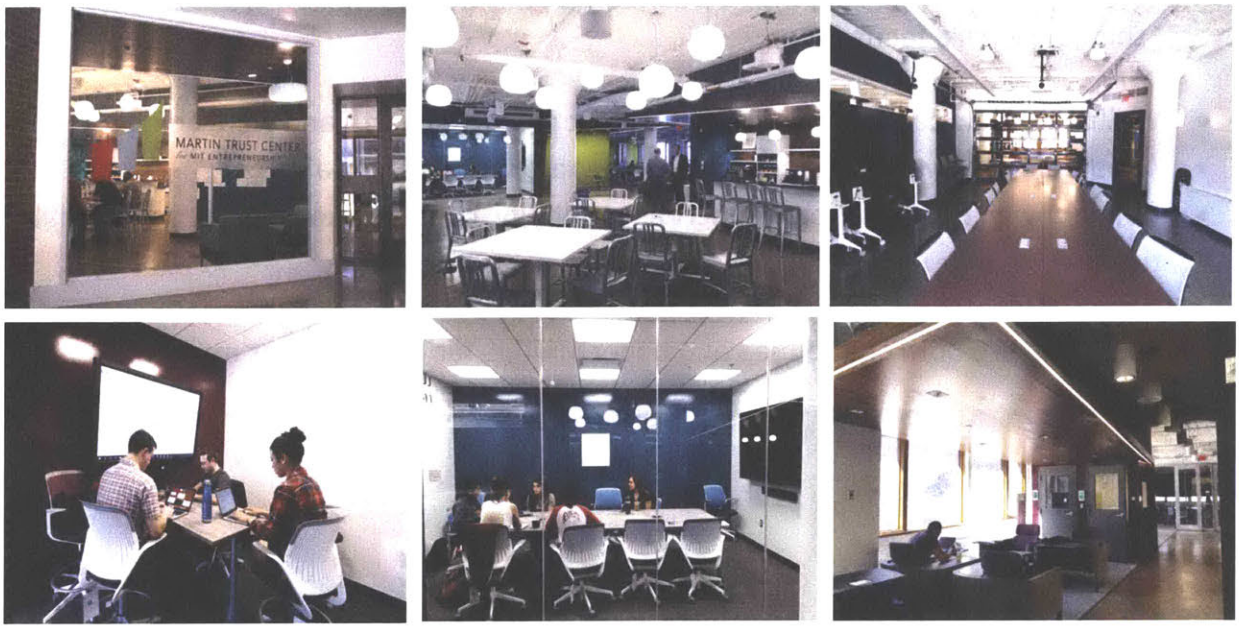
These questions are both challenges and opportunities for us to further explore.



Other products powered by Philips Lighting

5.3.2. Users Observation

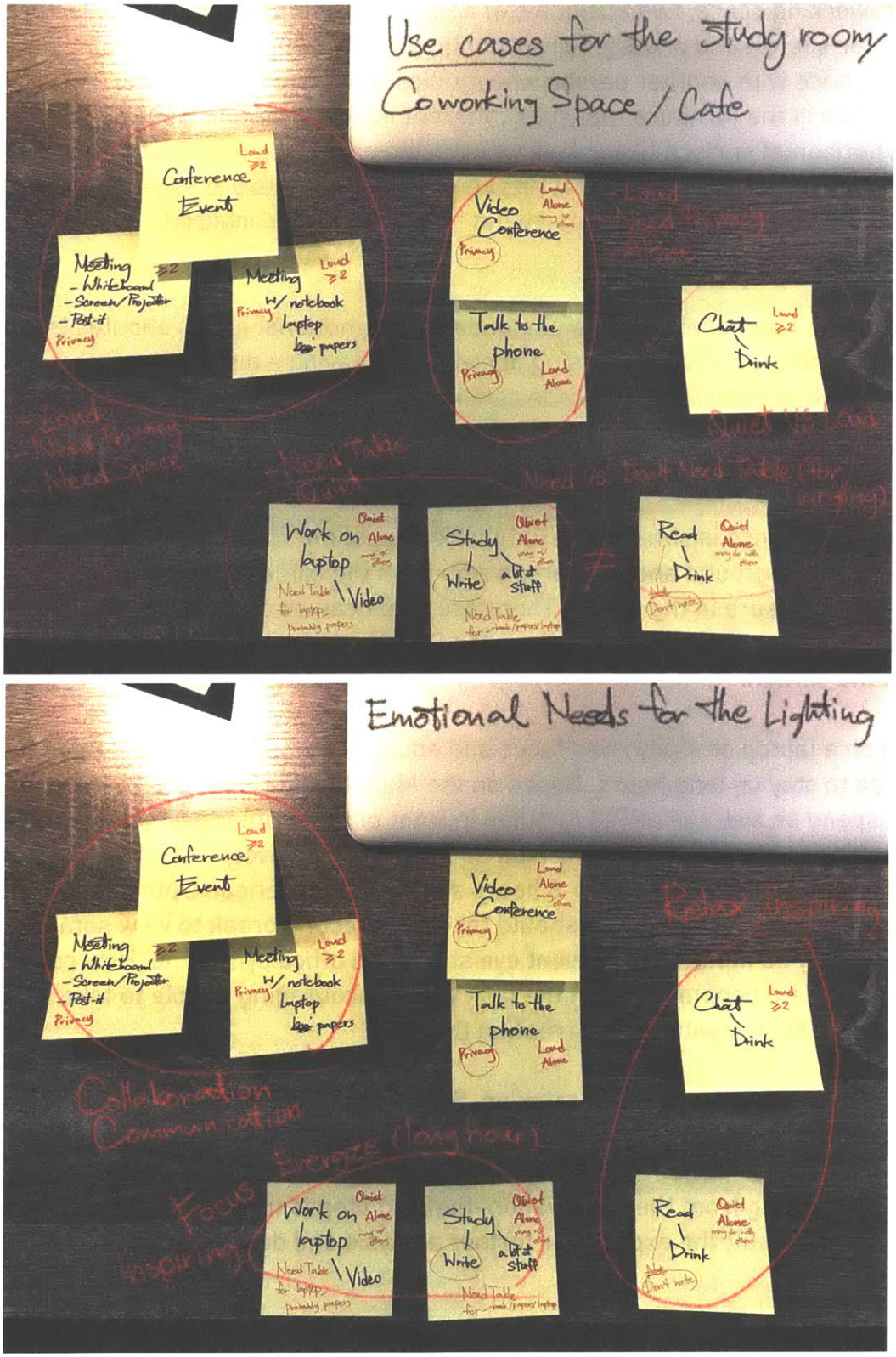
To understand the user behavior in co-working space, we started with the observation of people's behaviors and activities, the environments and their interactions with lighting (Hanington & Martin, 2012). The spot we choose to observe people is Martin Trust Center, a co-working space at Massachusetts Institute of Technology (MIT), to understand different needs of people who use that space.



Martin Trust Center at MIT

From observation, we could categorize eight different activities as follows:

1. Doing paperwork;
2. Working on the laptop;
3. Reading from a book or smart device;
4. Presentation;
5. Using a whiteboard;
6. Using Post-Its;
7. Discussion in the meeting;
8. Having a video call.



Analysis from the observation

In the co-working space, two attributes of activity are commonly used to allocate space; the need for silence and privacy. For example, a person who has a video call, if share the same space with another person who studies, will disturb each other. Another consideration is the furniture that suits different needs. A person working on a laptop needs a horizontal surface like a desk while using post-its in the meeting need either horizontal or vertical surface. Recognize these requirements are essential as we know which activities need to be separated before diving into personalized lighting for each one of them.

Apart from the functional needs, some underlying emotional needs should also be addressed. Using a whiteboard, using post-its, and having a discussion at the meeting are activities that encourage communication and collaboration, so the illumination should light up participants equally to encourage openness and trust. It should also help people focus on the presenter who is the center of attention if needed.

The video conference is similar: the luminaire should not create too much contrast between the background and the person who is on the camera, as it will create unbalanced exposure in the frame. Therefore, trust can be created in this way. Also, similar to the case when people work on the laptop, the luminaire should not create glare on the screen.

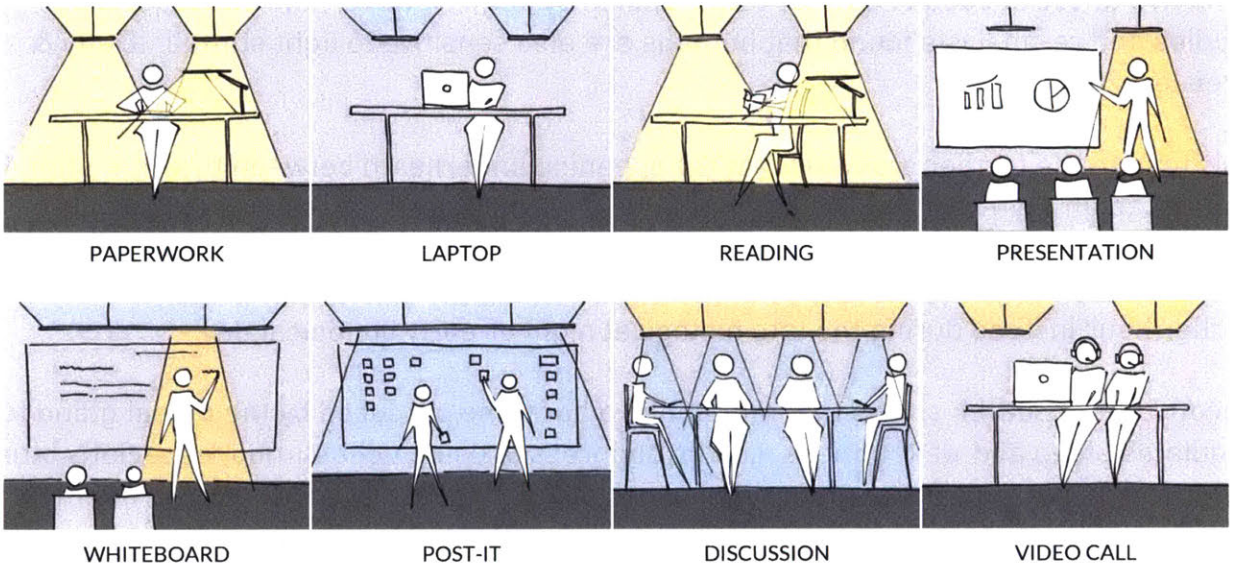
Working on a laptop or study need focus and energy – sometimes people need the motivation to stay up long hours. Based on the Mary Meeker's report (2014), people in the U.S. spend an average of 103 minutes in front of a computer every day. However, other professionals who rely on working on a laptop intensively like programmers are usually in front of the screen for 4-8 hours a day. Also, American Optometric Association suggests that people should take a 20-second break to view something 20 feet away every 20 minutes to prevent eye strain and office syndrome. How could we motivate and help people focus on the task while encouraging people to take short breaks along the way without interrupting the flow?

Reading, however, is more about relaxing. Sometimes almost to the point where people utilize this time to reflect and internalization on themselves.

Base on our finding from the observation, the next step is to study the psychological research and consult the experts for further analysis and design the personalized lighting solution.

5.3.3. Light and Activities

Based on our observation at Martin Trust Center at MIT, we summarize activities into eight types: paperwork, working on the laptop, reading, presentation, using the whiteboard, brainstorming with post-its, discussion, and video call.



Eight main activity types in co-working space.

The light scenes are suggested to coordinate with the activity. For instance, the reading light scene should protect reader's eyes without casting the shadow onto the book, and the light above the whiteboard should illuminate the entire board without causing reflection. More details will be discussed in the section of Smart Lighting System design later on.

5.3.4. Light and the Circadian Rhythm

Mankind is the diurnal animal. We wake up to the sunrise and fall asleep during the night. The close relationship with sunlight is well-established that it affects us not only physiologically but at the biological level. To synchronize with the daily day and night cycle of the external environment, human's internal biological clock known as circadian rhythms play a major role in regulating mechanisms and hormones inside our body to match the natural cycle.

Although these rhythms are maintained by the individual organisms, the length is not exactly 24-hours and differs from people to people (Cromie, 1999). That is why it has to

be reset on a daily basis to maintain the synchronization with natural time and have good well-being from sufficient sleep. That process of "resetting" on a daily basis and maintaining synchrony is called entrainment.

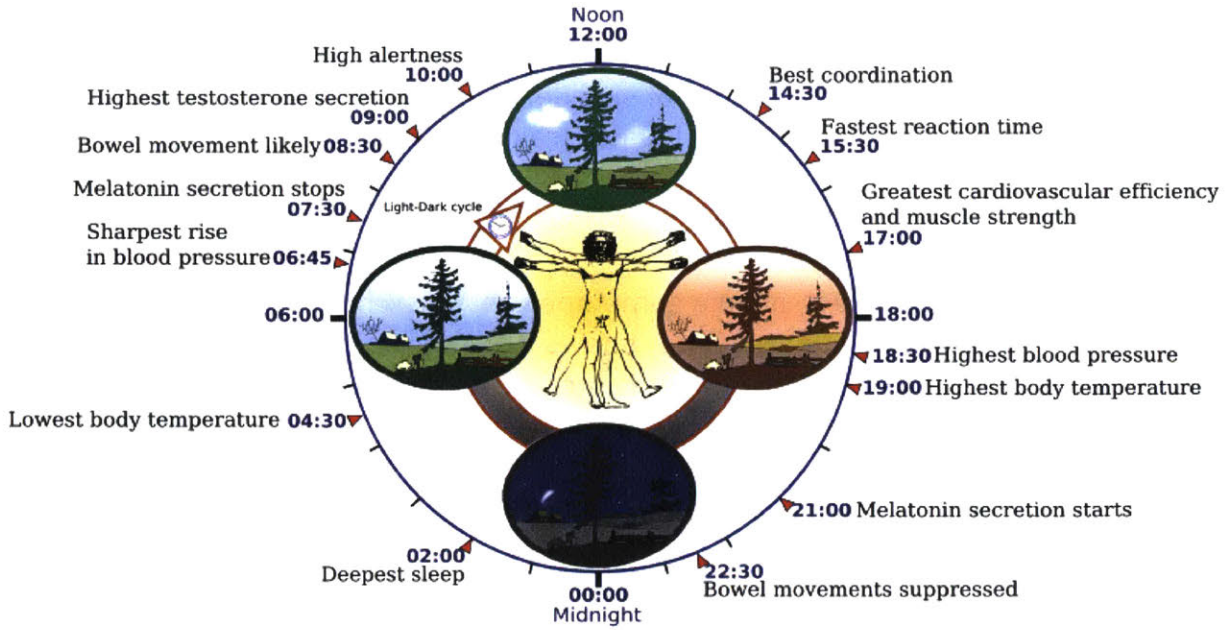
Light exposure is one of the strongest influencers to the circadian rhythm. We used to believe that, unlike other mammals, human relatively insensitive to light and more sensitive to social cues to entrain the circadian system. However, the subsequent studies and re-analysis found that humans are also sensitive to light stimuli. (Duffy & Czeisler, 2009)

This lead to the further study of what is happening underneath between the light stimuli and circadian rhythm. First, we found that when people are exposed to light stimuli during the late biological day or early biological night, the stimulus will make the circadian rhythm shift to a later hour. While in the opposite, the rhythm will shift to an earlier hour instead during the late biological night or early biological day.

Second, the research shows that melatonin, a hormone produced by the pineal gland to regulates sleep and wakefulness, can be suppressed using light stimuli, especially blue light. That is because is Ganglion cells, which aid with temporal regulation, is the most sensitive to the blueish light. (Clark and Brennan, 2016)

Furthermore, the length of light exposure, intensity, and the wavelength of light are all influence entrainment. Such as the longer your exposure to the light, the greater the effect, or the brighter light is more effective than dim light.

The basic strategy for lighting design mostly suggests that the luminaire should imitate natural daylight as closely as possible to prevent possible disruption or desynchronization between the biological clock and natural time. Also, knowing that human's biological clock is not exactly 24 hours (the majority of the population has around 24.3 hours of the biological clock on average) (Cromie, 1999), the proper light stimulus received in the early morning will advance the phrase (or in other words, shorten our biological cycle), making us more alert during the day and better synchronize with the natural time which is shorter than our biological clock. In the opposite, exposing to the light stimuli during the night will shift the phrase to an earlier hour, therefore postpone our bedtime and desynchronize the entrainment (as it makes the circadian clock, which is already longer than the natural cycle, even longer). This could lead to shorter sleep time, fatigue, and lack of focus on the following day. Therefore, providing blue light or warm light, bright light or dim light at the strategic times could help entrain the circadian rhythm and improve well-being.



Overview of Circadian Clock in humans that depicts a typical pattern of someone who rises early in morning, each lunch around noon, and go to bet at 10 P.M., However, the rhythms can be affected by other factors such as meal times or stress (Clark, 2013)

5.3.5. Light and Weather

Different weather condition directly affects the amount direct and indirect sunlight during daytime. On a certain location, whenever the Sun is above the local horizon, the illuminance from the sunlight at noon could vary from 120,000 lux at the day with the brightest sunlight to even less than 1 lux in the extremely cloudy day.

Regarding the functionality, the daylight plays a huge role in illuminating the indoor space through windows and skylights. Typical buildings are designed to have the windows, allowing sunlight into the building accompanied by artificial lights for sufficient luminance. This solution helps save energy and prevent the adverse effects of over-illumination by artificial light. Also, there is a commercialized technology called daylight harvesting which allows the artificial lights to dim based on the presence of daylight automatically (Papamichael, Graeber, Page, & Siminovitch, 2010).

On the biological level, the variations of daylight level from different weather also influence the circadian rhythm as the light is widely known as the stimuli and the melatonin suppressor. For instance, the lack of sunlight during winter induces people to sleep longer and more difficult to wake up because of the lack of natural light to suppress melatonin and no clear distinction between daytime and nighttime. Furthermore, the lack of daylight on a gloomy day could lead to mood disorder called

seasonal affective disorder (SAD.) This mental disorder exhibits the depressive symptoms such as having low energy, lack of focus, withdrawal from social interaction or even feel hopelessness and thoughts of suicide. There are studies show that the treatment of light therapy could be an effective treatment for SAD. The patient sitting at a prescribed distance in front of the lightbox for 30-60 minutes seems to get relieved from SAD by the effect of light. (Avery, Kizer, Bolte, & Hellekson, 2001)

Apart from the biological effect, people sometimes get a psychological-emotional impact on different quality of light. A study shows if all objects and surfaces in a room receive equal emphasis from light without contrast. Over time, the lack of contrast causes people to feel listless and depressed as it is similar to the quality that a cloudy, overcast day produces. On the contrary, proper bright highlights and crisp shadows induce people to feel more alert, energetic, and positive just like a sunny day (Day, 2003).

These discoveries could help us develop a strategy for the lighting to compensate the absence of daylight from different seasonal or weather changes and help increase the quality of life.

Illuminance	Example
120,000 lux	Brightest sunlight
111,000 lux	Bright sunlight
20,000 lux	Shade illuminated by entire clear blue sky, midday
1,000 - 2,000 lux	Typical overcast day, midday
400 lux	Sunrise or sunset on a clear day (ambient illumination)
<200 lux	Extreme of thickest storm clouds, midday
40 lux	Fully overcast, sunset/sunrise
<1 lux	Extreme of thickest storm clouds, sunset/rise

Daylight Intensity in Different Conditions (Wikipedia, 2018)

Illuminance	Example
<1 lux	Moonlight, clear night sky
0.25 lux	A full Moon, clear night sky
0.01 lux	A quarter Moon, clear night sky
0.002 lux	Starlight, clear moonless night sky, including airglow
0.0002 lux	Starlight, clear moonless night sky, excluding airglow
0.00014 lux	Venus at brightness, clear night sky
0.0001 lux	Starlight, overcast moonless night sky

Nighttime Illuminance for Comparison (Wikipedia, 2018)

5.3.6. Light and Work Styles

As we focus on the personalized lighting in the co-working space, we attempt to explore beyond time and the weather – the relationship between light and psychological work-related impacts. But first, it is essential to know who are we designing for. What is their behavior looks like? Are they working from 9 to 5, performing different tasks in several tiny time slots manner, or focusing on one task for long hours?

Many researchers are still trying to understand the psychological effects of lighting on cognitive performance and gender effect. In 1995, Igor Knez experimented on subjects by asking them to perform various cognitive tasks under different lighting condition and do self-report on their mood. Still, the underlying mechanisms for the effects are still unclear. (Knez, 1995) Another study attempted to recognize the different subgroups with a similar need of light within the group based on gender, Burell's personality test (BT), and the visual comfort test (VCT). The result indicated that gender is not seen as a reason for building up the subgroups with the similar need for light. BT and VCT, however, are possible to be used as the way of constructing subgroups. Nevertheless, as stated in the report, this type of study should be questioned. Both self-assessed tests are subjective and the results can be influenced by unaddressed external or internal triggers of different kinds (Säter, 2011).

Next, we explored different psychological patterns on how people approach their work. Deloitte, a consulting firm, developed a framework called Business Chemistry that identifies four primary patterns of behaviors in the diverse today's organization setting: Pioneers who seek possibilities and spark energy and imagination, Guardians who like a challenge and generate momentum, Drivers who crave stability and bring order and rigor, and Integrators who desire connection an bring teams together. (The New Science of Team Chemistry, 2017) Although the assessment only focuses on people's traits and how to form a common ground that brings the team together, it serves as the starting point that raises an interesting question – how can we help to create an open environment that connects diverse people and also respect their privacy in the workplace through lighting?

Another interesting concept about how different types of workers psychologically see their schedule is Maker vs. Manager, originally described in a 2009 essay from Paul Graham, a co-founder of Y Combinator (Graham, 2009). The makers, not necessarily mean people who tinker but any workers who create things of any kinds: writers, programmers, designers, etc.

For the managers. Their schedule is embodied in the traditional appointment book, with each day cut into small intervals. Their day is usually spent in the meeting, organizing, and making decisions. On the contrary, maker's schedule is made up of long blocks of time for deep focus required tasks. Breaking the day into multiple tiny slots would be equivalent to doing nothing. As Paul said, "you can't write or program well in units of an hour, that's barely enough time to get started." The underline is that the cost of interruption, especially scheduling the meeting, cost terribly more to maker's schedule than manager's. (Graham.2009) So how can we support these different working styles and minimize interruptions among each other who work in the same space is going to be an interesting challenge.

5.4. Smart Lighting System

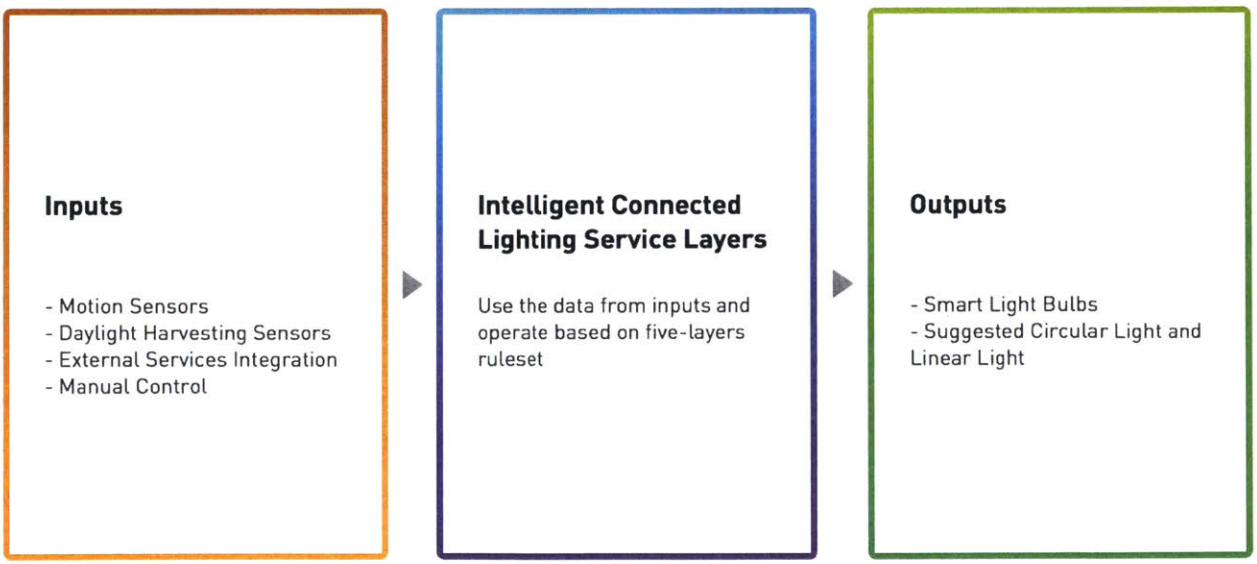
Public workplaces like co-working spaces are extremely difficult to light well. The occupants are diverse with different agendas. Some have a group meeting while other sitting next to the strangers, working on their computer. To make sure that space is perfectly-lit for everyone, we imagine a smart lighting system that acts like a living organism, adapts the light settings based on how space is used, and support the biological and psychological well-being of occupants. But first, we need to define needs as well as the limitation.

5.4.1. Addressing Needs

1. The light helps to entrain the circadian rhythm;
2. The light lifts up the mood and compensate for the absence of daylight due to the weather;
3. The light provides sufficient luminance for various activities in the co-working space;
4. The light helps save energy for the power efficiency;
5. The light is easy to control if needed;
6. The light gives occupants an appropriated level of manual control;
7. The light settings do not create tension between people who may have different needs;
8. The light creates the positive task-related psychological effect.

5.4.2. System Architecture

To provide personalized lighting experience that addresses needs we have mentioned. The system needs to collect contextual data from sensors, integrated service, and manual control to change the lighting settings based on the context automatically.



5.4.2.1. Inputs

To provide personalized lighting experience that addresses needs we have mentioned. The system needs to collect contextual data from sensors, integrated service, and manual control to change the lighting settings based on the context automatically.

- Motion sensors to detect the occupancy
- Daylight harvesting sensors
- External service integration like the room reservation system or the wireless presentation system
- Manual control such as switches, mobile app, and voice control (i.e. Alexa, Google Home)

5.4.2.2. Intelligent Connected Lighting Service Layer

With the stream of various inputs passing to the Intelligent Connected Lighting Service Layer, we can recognize the context and follow the programmable ruleset that dictates how the lighting should behave as referred to chapter 5.4.3. Strategy For The Space Allocation and 5.4.4. Ruleset for the Light Settings. This will allow the system to change 'light scene' automatically without the manual control. The scene is referred to the different light settings with a distinct level of brightness, color temperature, and other parameters.

Light scenes designed for different activities from Philips Hue, a smart light bulb that offers functionality for users to change 'scene' through a mobile application. Additionally, the product allows third-party integration through Philips API which allows the Intelligent Connected Lighting Service Layers to use Philips Hue as the luminaire, or in other words, the output in our system.

5.4.2.3. Output

The LED lamp is commonly used for illuminating indoor spaces nowadays because of the long lifespan and power efficiency. As of 2016, LEDs use less than 10% of the energy an incandescent lamp requires. Moreover, many products in the market like Philips Hue also allow the brightness control, color temperature control, and hue control wirelessly through either a mobile app or API. This opens up great possibilities for the smart lighting application. Still, the next evolution we see requires additional control over the direction and diffusion of the light source as we will discuss in chapter 5.3. Light Appearance Design.

5.4.3. Strategy for the Space Allocation

To manage the luminaires inside the space where individuals perform different tasks and have different needs of light, the Intelligent Connect Lighting Service needs a way of thinking, or ruleset, to know how to change the light settings based on situations.

However, before jumping into light settings, the observation suggests the separation of space based on the need for silence and privacy to avoid tension and make sure that the fundamental needs of each activity are met. Imagine trying to concentrate on the paperwork and someone talk very loud nearby, or hesitate to discuss something openly in the open space and need some privacy. These are the examples of the tension happening in the open space that better be solved by the space design rather than the lighting design. Therefore, we started by analyzing 8 activities from 5.1.3. Light and Activities based on the need for silence and privacy.

Activities	Need for Silence	Need for Privacy
Paperwork	Yes	No
Laptop	Yes	No
Reading	Yes	No
Presentation	No	Yes
Whiteboard	No	Yes
Post-It	No	Yes
Discussion	No	Yes
Video Call	No	Yes

The result suggests categorizing activities into two distinct groups with their own allocated space; The open space for doing paperwork, working on the laptop, reading, and the private room for having a presentation, using a whiteboard, brainstorm with post-its, having a discussion, having a video call. The separation of incompatible activities to the different allocated space also make it easier to develop the lighting solution that serves everyone's needs.

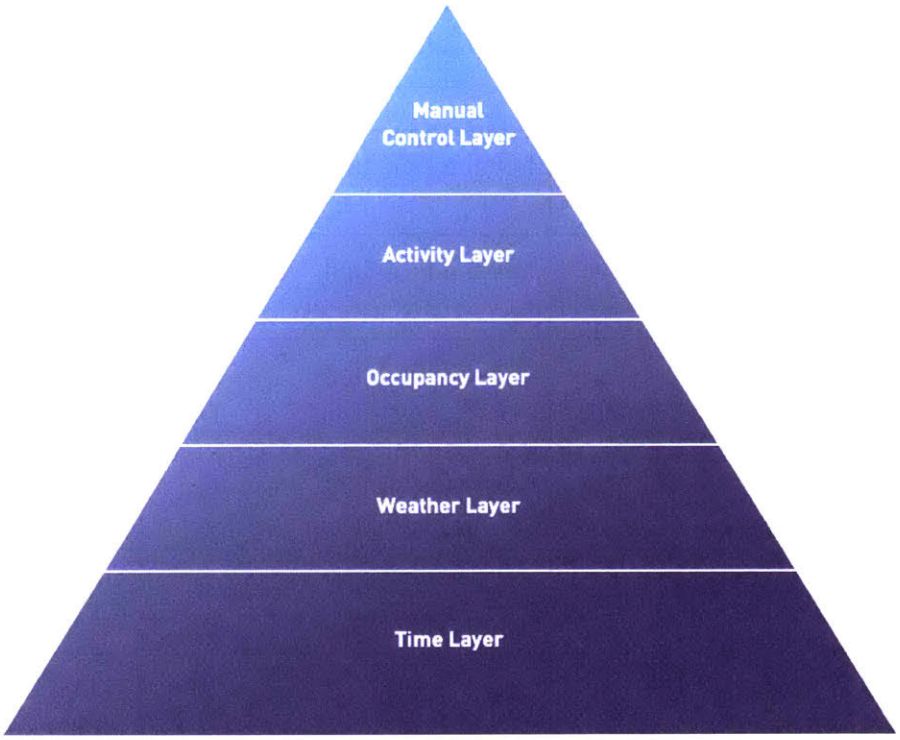
Group 1 – Open Workspace	Group 2 – Private Room
People need silence to concentrate on their tasks but do not need a private space.	A group of people needs privacy for conversation and meeting.
• Paperwork • Laptop • Reading	• Presentation • Whiteboard • Post-It • Discussion • Video Call

Another discussion we had with Philips Lighting also involve what level of control should be given to the users. What will happen if someone wants to dim the light while another wants bright light? This issue has long been a difficult question for designers, not only light designers but the architects who design space itself. To solve this tension, a consensus, as a form of decision-making concluding when all participants reach an agreement, come into play. We consider the different levels of consensus from occupants in each space. In the shared space like Group 1, most occupants do not come from the same group or organization, so it is difficult to change the light settings with common agreement from everyone. Therefore, we suggest providing an only low level of the manual control and make sure that the lighting is "normalized." We define this space as having a low level of consensus. Contrary, the private room where people inside come from the same group with shared agenda. It is extremely easy to make a decision together. Therefore, this place has a high level of consensus, and we could allow more control over the light for the occupants.

Group 1 – Open Workspace	Group 2 – Private Room
Low Level of Consensus	***High Level of Consensus***
A shared space where different groups of people work in the same place, so there is no consensus on how the light settings should be. The light settings should be normalized automatically for the common needs, and the level of manual control should be low.	A space occupied by a group of people with the same agenda and agreement. A high level of manual control for the light is acceptable.

5.4.4. Ruleset for the Light Settings

First, we categorize inputs to the light settings into five levels. The system will determine from the bottom level and move upward. The higher level will always have the priority and will override any parameter that conflict with the lower level. For instance, if Time as the bottom layer dictate the setting for light luminance to be at 500 lux at 9:00 AM. However, because it is a cloudy day with less daylight than usual, the Weather, as the upper layer, override the luminance settings from time layer with 612 lux.



The 5-layers structure developed by us will support the system to manage the complexity and help serve the user needs.

5.4.4.1. Time Layer

To help human body entrain to the circadian rhythm, the time layer serves as the default settings at the bottom of the pyramid in the ruleset. This level aims to create the positive biological effect on the occupants' well-being by changing the luminance and color temperature based on time of the day. With the help of weather web service API, time and timezone will be pulled to determine the scenario as follows:

	Exact Time (can vary based on the season)	Light Intensity (can be adjusted as appropriate)	Color Temperature
Early Morning	5:01 AM - 9:00 AM	Level 3 (500 lux)	3000 - 4500 K (Warm Light)
Late Morning	9:01 AM - 12:00 AM	Level 4 (750 lux)	4000 - 6000 K (Daylight White)
Noon	12:01 AM - 1:00 PM	Level 4 (750 lux)	4000 - 6000 K (Daylight White)
Early Afternoon	1:01 PM - 3:00 PM	Level 3 (500 lux)	3000 - 5000 K (Cool Light)
Late Afternoon	3:01 PM - 6:00 PM	Level 2 (250 lux)	3000 - 4000 K (Warm Light)
Evening	6:01 PM - 8:30 PM	Level 1 (150 lux)	3000 - 2400 K (Very Warm Light)
Late Night	8:31 PM - 5:00 AM	Level 1 (150 lux)	2400 -2000 K (Very Warm Light)

Recommended light intensity values based on "Determination of Illuminance Categories" in Mark S. Rea, ed., The IESNA Lighting Handbook: Reference & Application, 9th ed. (New York: Illuminating Engineering Society of North America, 2000).

5.4.4.2. Weather Layer

Weather affects the level and color temperature of daylight directly which then influence the circadian rhythm and mood of people in the workplace. To compensate for the differences, the weather layer adjusts the values of light intensity and color temperature settings by adding the "modifier" to parameters based on the data from weather web service API like Dark Sky API and daylight harvesting sensors.

	Weather	Daylight Intensity	Level of Energy and Alertness	Modifier
Group 1 – High Energy Day	Sunny Day	High (10,752 lux)	High	1
	Clear Day	High (10,752 lux)	High	1
Group 2 – Medium Energy Day	Partly Cloudy Day	Medium (1,075 lux)	Medium	1.15
	Cloudy Day	Medium (1,075 lux)	Medium	1.15
Group 3 – Low Energy Day	Snow	Low (107 lux)	Low	1.25
	Sleet	Low (107 lux)	Low	1.25
	Fog	Low (107 lux)	Low	1.25
	Rain	Low (107 lux)	Low	1.25

Reference for daylight intensity (Illuminance - Recommended Light Level, 2003)

Example Scenario:

On a rainy day at 9:00 AM. Although the Time layer set the luminance as 500 lux with color temperature at 3,000 K. The Weather layer then override the light intensity by 25% (1.25). As a result, the luminance is set to 625 lux. This will help compensate to the absence of daylight in the rainy day and induce the alertness to the occupants.

5.4.4.3. Occupancy Layer

The goal for the occupancy layer is for energy efficiency and ease of use. With the motion sensors spread across the area, the system detects the first occupant's arrival to activate the passive mode. This will illuminate space, allow people to navigate, and prevent the risk of accidents. However, when people grab a seat and occupy the area, the luminaires will transition to the active level and brighten up the area. The system also gets the data from optional external service like the room reservation system and automatically change to the passive mode when the reserved time come, serving as the cue for the occupants. As the last occupant left, the light turns off, saving energy by

20%-60% in most cases. (Galasiu, A.D.; Newsham, G.R.; Suvagau, C.; Sander, D.M., 2017)

Mode	Modifier	Conditions
Off	0.0	When no occupants in the space
Passive	0.6	The first occupant enter the area or the room is reserved
Active	1.0	The space is occupied by the occupant

5.2.4.4. Activities Layer

Different activity has different needs for lighting. In the open workspace, the default light settings, when the motion sensor detects an occupant at the desk, is the Paperwork scene (similar to Reading) which illuminate the area and the horizontal surface for people to start working right away. However, the light will automatically transition to the Laptop scene whenever the occupant plugs the computer into the power supply (or choose the laptop scene option at the portal pop-up window when connecting to the provided public wifi.) This will create a seamless personalized lighting experience based on the user's activity. The occupant, nevertheless, can manually override the scene if wanted as discussed in chapter 5.2.4.5. Manual Control Layer.

For the private room, the default light settings will be the Discussion scene which the light is equally distributed within the room. This instantly creates an open collaborative environment as the group step into the room. However, when the motion sensor above the board (or whiteboard) detects the presence, the light transitions to Post-It or Whiteboard, allowing the occupants to shift focus to the board and get ready to brainstorm. The system, however, shifts to the Presentation scene when the HDMI or the wireless presentation system is connected. As a result, the light dims down just one part of the room where the wall is projected while leaves sufficient illumination for taking notes at another part of the room. Lastly, for the Video Call scene, the system will detect when the video conference system like the microphone and camera system is connected. The lights are diffused to prevent hash ambient light. Also, the light sources that are visible in the camera will be turned off to prevent glare.

Group	Activity	Direction	Diffusion	Brightness	Color
Group 1 – Open Workspace	Paperwork	The light is casted from the back to avoid reflecting back to the eyes directly	Direct	N/A	N/A
	Laptop	The casted light must not visible on the screen reflection or in the eyesight when looking at the screen	Indirect	Dim by 10% from default	N/A
	Reading	The light is casted from the back to avoid reflecting directly to the eyes	Direct	N/A	N/A
Group 2 – Private Room	Presenting	N/A	Indirect	Dim light by 80% at the projected side of the room, and 10% on the others	N/A
	Whiteboard	N/A	Indirect	The light above the whiteboard is lit, triggered by the motion sensor on top of the board	Override the color of the light located above whiteboard to cool white light (5500 K)
	Post-It	N/A	Indirect	The light above the board is lit, triggered by the motion sensor on top of the board	Override the light above board to cool white light (5500 K)
	Discussion	N/A	Indirect	The lights are equally distributed in the room	N/A
	Video Call	The light point to the seat but is diffused to prevent hash light. Also make sure that there's no light source appear on the screen	Indirect	N/A	Natural Warm White (3200 K)

(N/A means the Activities Layer will not override that parameter. Consequently, the light settings will use the value as stated from the lower layer.)

5.4.4.5. Manual Control Layer

Although the previously mentioned four layers are designed to work automatically, there will come the time when the users may want to adjust the light settings manually. The Manual Control layer has the highest priority and can override other layers when used.

Although we do not want the individual to manually adjust the light settings in the Open Workspace, we could still provide the switch just in case it is needed. The Private Room, however, is more suitable for manual control as the level of consensus is high. The voice control could also be installed as an optional way to control the light easily.

Finally, the ruleset and permission control can be adjusted if needed by the admin control application.

List of Manual Control:

- Physical Switch
- Voice Controlled Assistant (i.e. Alexa, Google Home)
- Web/Mobile App for Admin Control

With the combination of five layers from the ruleset, the Intelligent Connected Lighting Service Layer will control the luminaires based on inputs, providing the personalized lighting experience that serves people needs.

5.4.5. Example Scenarios

Our provided system architecture and ruleset serves as the foundation for the next generation smart lighting system. Still, further details need to be sorted out for the real implementation, such as the technology stack, the default parameters which may differ from place to place, or the implication that may occur in the different space layout.

To illustrate how the system works. Here is the example scenario demonstrating how the lighting system will behave:

It is 9:30 AM until John, a web developer, arrives at WeWork Boston co-working space that equipped with the Intelligent Connected Lighting System.

As he walks pass through the corridor, the lights with the luminance at 500 lux and warm white color as directed by Time layer transition from 60% to 100% brightness as they become active.

Now, he walks into the Open Workspace as the lights in the room brighten up. He sits in one of the desks where the motion sensor detects his presence and tell a Circular Light that located above his desk to activate the Reading scene as the default. John spends around 15 minutes writing his daily to-do list on a post-it and sticks to his desk. Then, he pulls out his Macbook and plugs to the power outlet. The system then automatically detects and tells the Circular Light to change into Laptop scene for appropriate light intensity and avoid creating glare or cause any discomfort.

Time goes by and it is already 1:15 PM. The light color changes to cool light to boost energy and alertness of the occupants. However, as it begins to rain outside, the Weather layer adds the modifier by increase the light intensity by 25% to compensate for the absence of daylight.

Now it is time for the meeting; John joins his team, Lin and Tim, and walks into the Private Room as it is already lit 60% because they have booked the room earlier. The lights then brighten up to 100% and activate the Discussion scene when they sit around the meeting table and start talking about the product strategy. Tim then connects to the wireless presentation system to show his presentation slide with the projector. The light system detects the connection and change to Presentation scene where the light at the projected wall is dimmed. The presentation goes well and everyone agrees with the team direction. The light settings transitions back to Discussion scene, brighten up the entire room as Tim stop the connection with the system.

As the direction is set, it is not long until the team decides to start brainstorming on the whiteboard. The motion sensor nearby detects the activity and tell the system to change into the Whiteboard scene where the luminaire above the whiteboard is lit with cool white light. This helps everyone to focus on the board as the color is distinct from other lights. The color also has the psychological and biological positive effect on the focus and alertness.

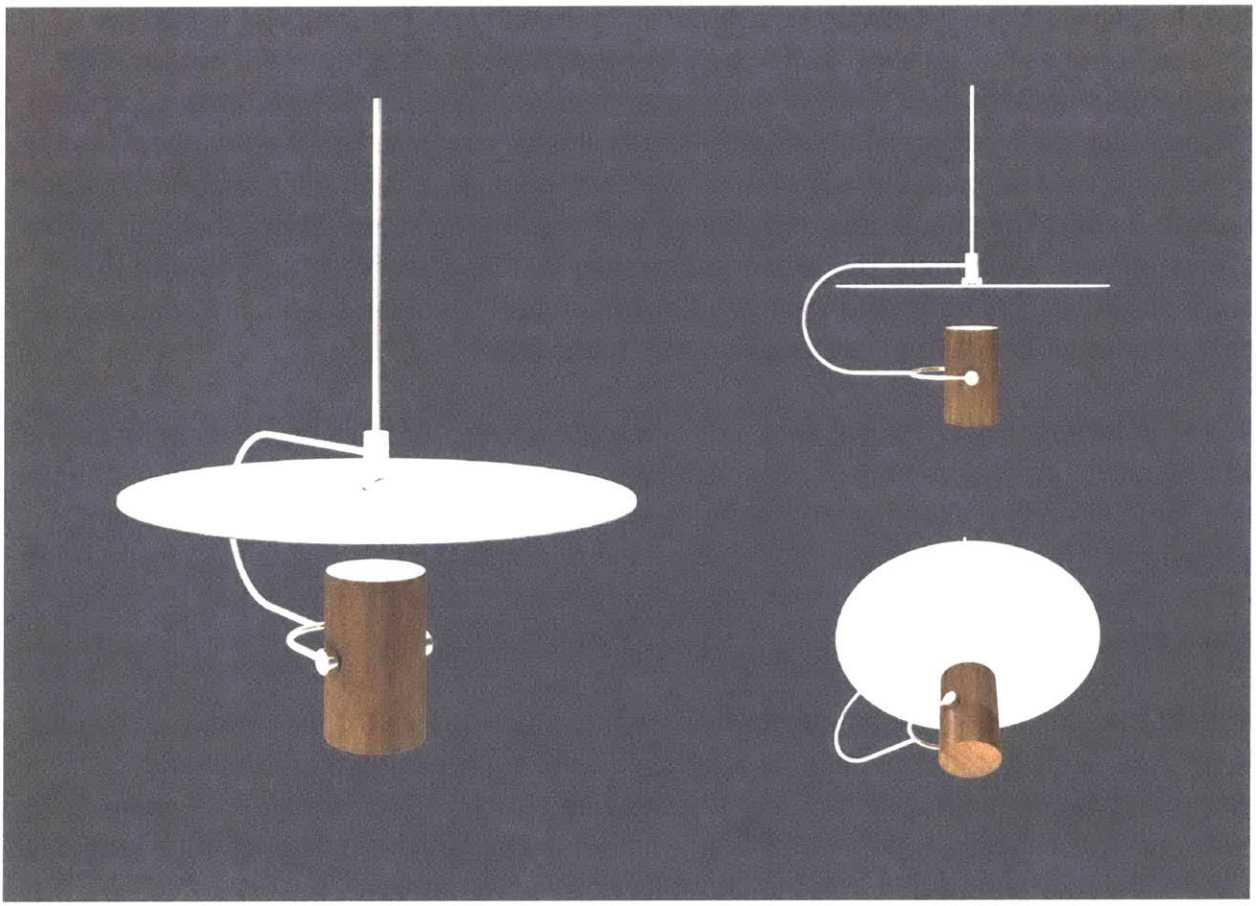
At 6:30 PM, the ambient light slowly dim down to Level 1 (150 lux) with very warm color to provide sufficient illuminance for work, yet avoid suppressing melatonin and disrupting the circadian rhythm. The team decides to call off for today. They make tremendous progress and the smart lighting helps support them throughout a long day. They know they need a good rest to continue fighting tomorrow.

5.5. Luminaires Design

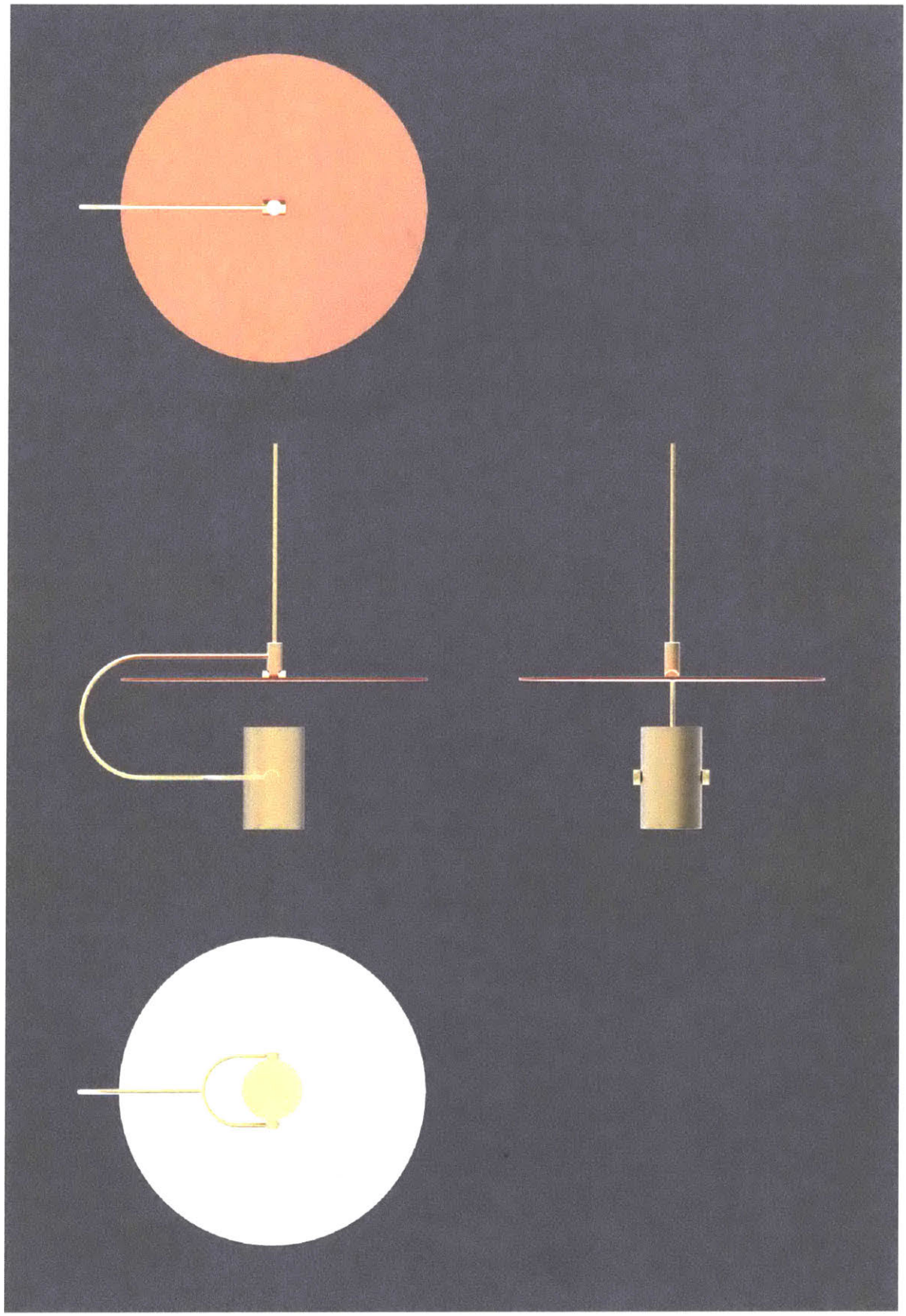
A holistic light experience design for co-working space does not merely rely on the light source. The form of the lamp, the installation location, the interior design, daylight, and even the architectural structure do matter. In this section, we will focus on the developing the luminaire appearance design that supports the light scene and adds more flexibility to the system.

5.5.1. Circular Light

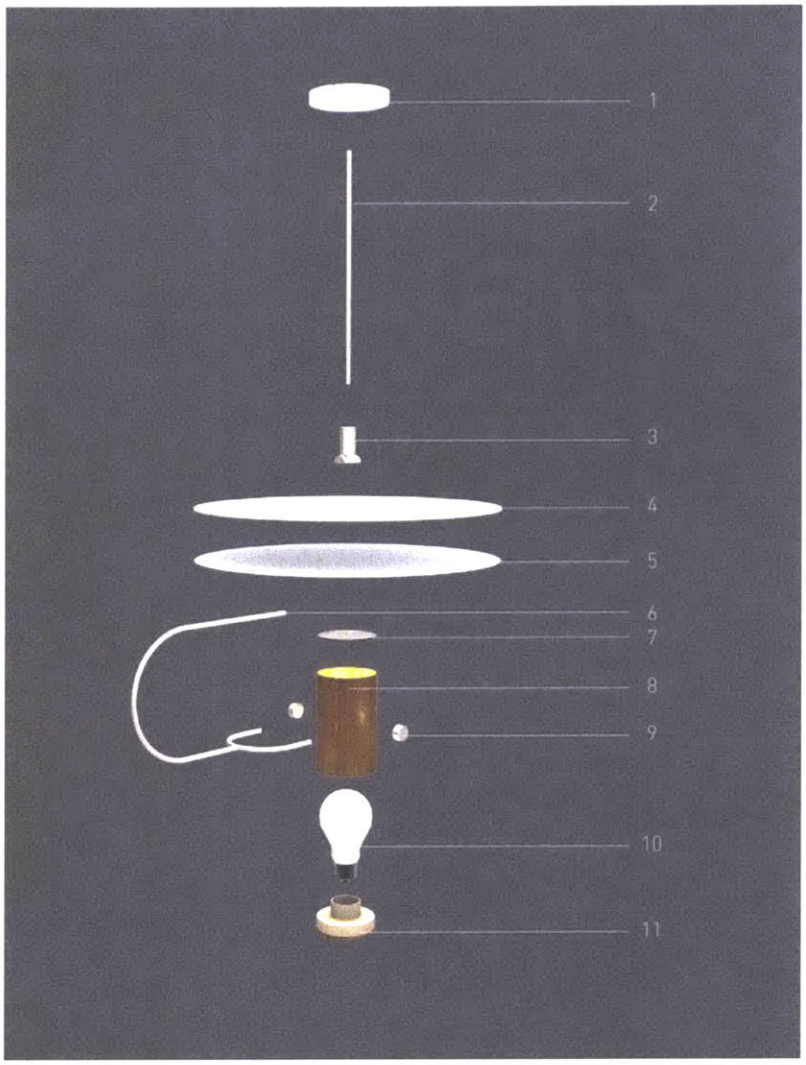
The Circular Light designed by us is for operating with the horizontal work surface, including paperwork, working with the laptop, reading, having a group discussion, and brainstorming in the meeting room. In this design, Philips Hue E26 bulb is used as the light source in the Circular Light. With a high adjustability of light angle and distribution, together with the Intelligent Connected Lighting System and sensor technology, the Circular Light provides personalized lighting for people working on various tasks.



Perspective view



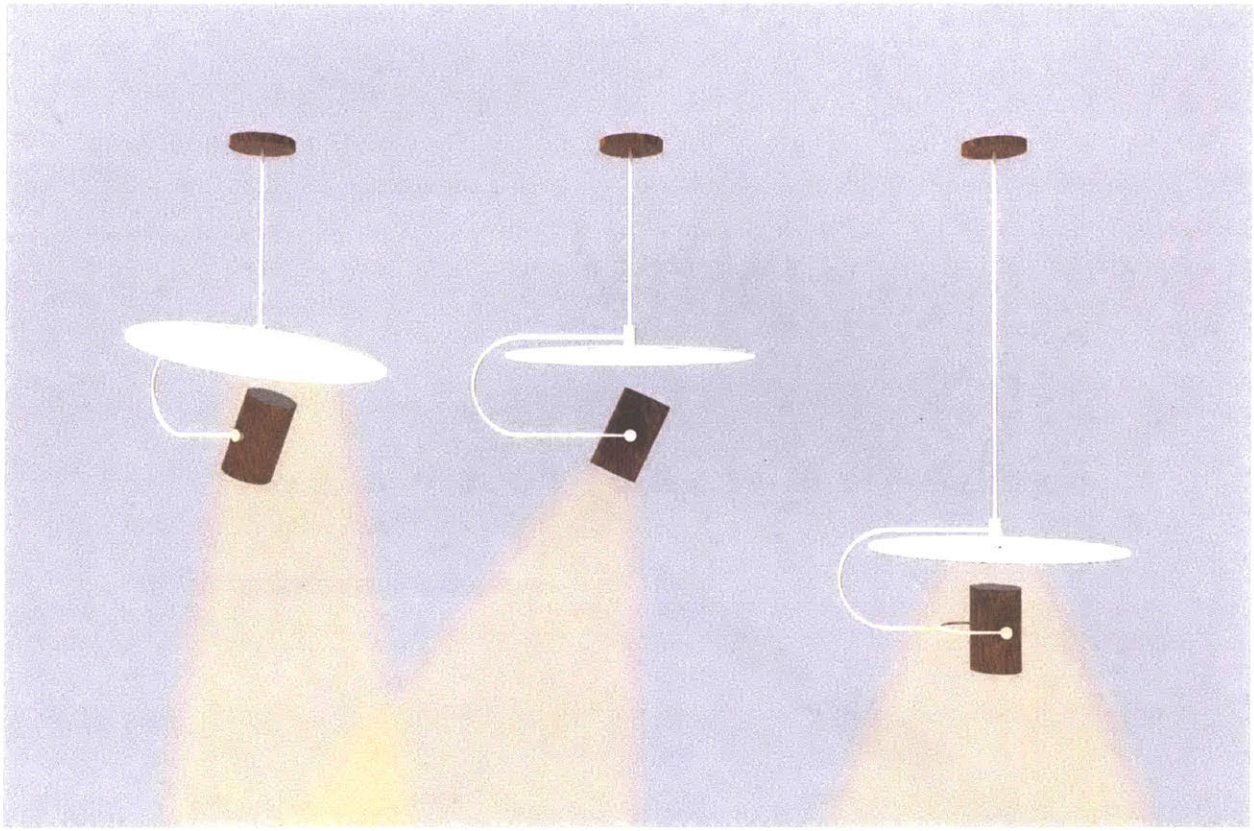
Four-view



Explosive view

1. Ceiling base
2. Telescopic pole (heave)
3. Joint a (yaw + roll)
4. Plate
5. Semi-specular reflection coating
6. Holder
7. Translucent lid
8. Tube
9. Joint b (pitch)
10. Philips Hue bulb E26
11. Tube base

To fit in different styles of co-working space interior design, the form of the Circular Light is minimalistic, aiming at supporting necessary functions and add an elegant decoration to the scene. The figure above shows the structure of the Circular Light. The height of the light can be heaved by (2) telescopic pole together with (1) ceiling base according to users' demand. With (3) joint a of yaw and roll, and (9) joint b of pitch, the light can be adjusted in 6 degrees of freedom. Diffuse light is provided when the (7) translucent lid faces upwards, which allow the light beam to reach the (5) semi-specular reflection coating on the (4) plate before spreading towards users. When there is a requirement of direct focused light, the (8) tube can be rotated to have the (7) translucent lid faces downwards. All the mechanical adjustments can be made automatically based on the data from pre-programmed light behaviors and sensors by the mechanisms in the (3)(9) joints and (1) ceiling base (motors and wires are not presented in this explosive view).

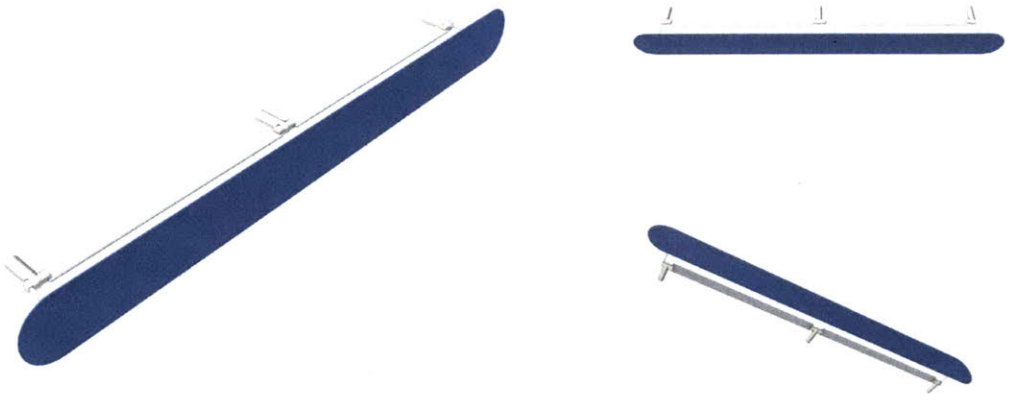


From left to right: Diffuse light of different angles adapted with the rotatable plate and tube; Focused light with the tube downwards; Adjustable height.

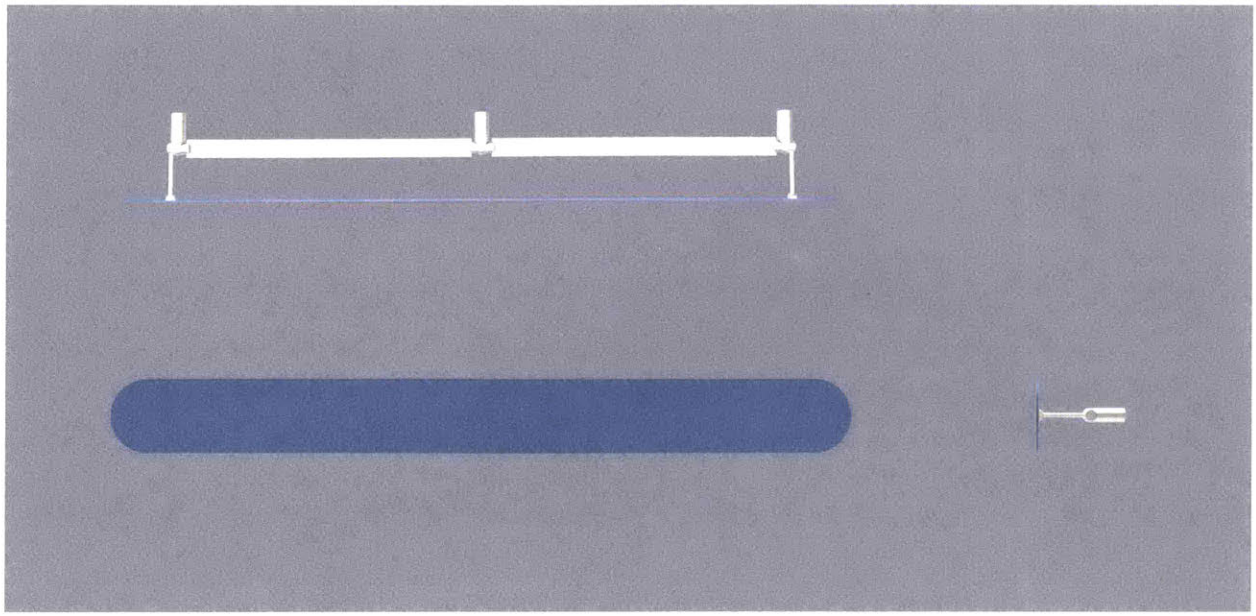
Apart from the lighting technology, we consider users' emotion as a crucial factor in overall design. The appearance is designed to feel light. The combination of wood texture and white color adds an atmosphere of Zen to the space. Colors of the plate, tube, and ceiling base can be changed based on the co-working space interior design. The reflective plate, which looks like an umbrella, acting the role of guardian for users' health. The light tube, held by the holder, spreads energy and inspiration towards the ones seating under the light. Beyond illumination, the light performs as a care provider, taking care of every individual in their daily life.

5.5.2. Linear Light

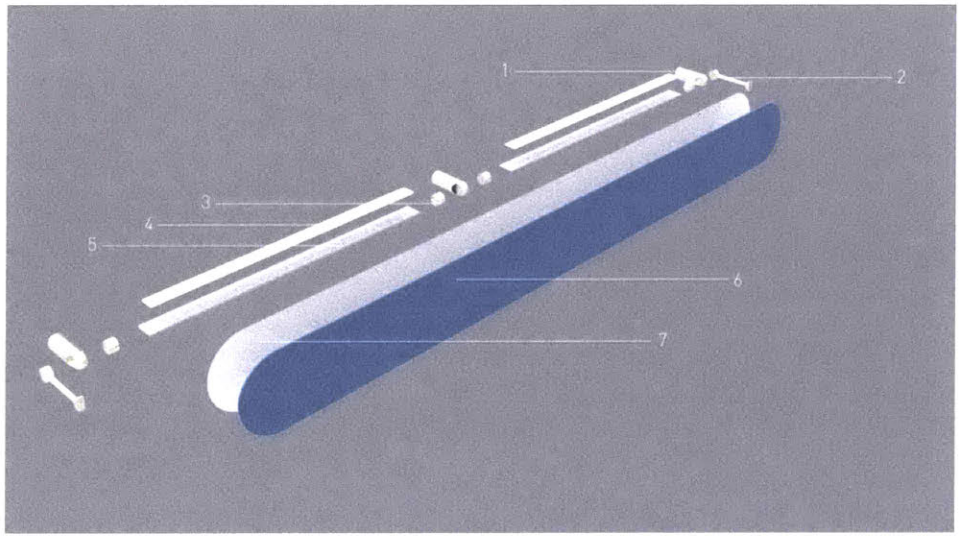
The Linear Light designed by us is for the tasks involving with the vertical surface, including the presentation with the projected screen, writing on the whiteboard, and brainstorming with post-it notes. Two Philips Hue LED strips are used as the light source in the Linear Light. Similar to the Circular Light, the Linear Light has the high adjustability of light angle and distribution, adding flexibility to the system.



Perspective view



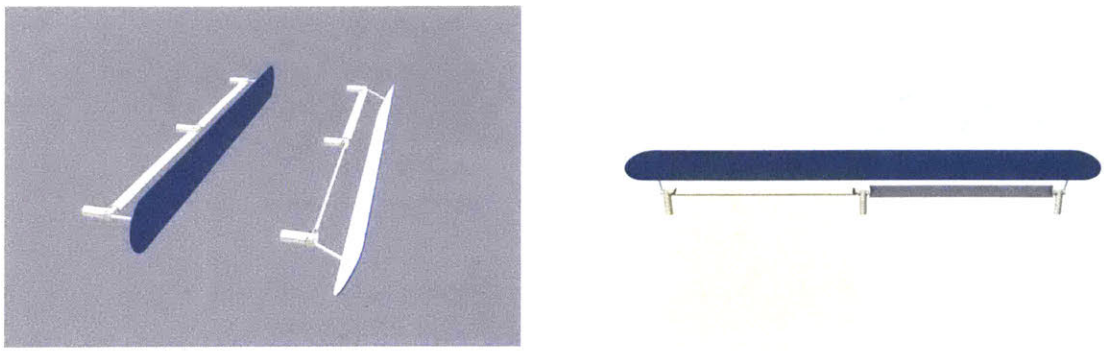
Three-view



Explosive view

1. Holder
2. Joint a
3. Joint b
4. Philip Hue LED Strip
5. Bar
6. Plate
7. Semi-specular reflective coating

The pitchy design with reduced industrial feeling fits different environment and meets the functional needs. With two (2) joint A on both ends of the (6) plate, the angle of the plate can be adjusted according to users' need. The angle of (4) LED strips are also adjustable by rotating the (5) bar with (3) joint B on the inner side of the (1) holders. Two LED strips can be adjusted individually to provide either diffuse light or focused light downwards or upwards.



Change angle of plate and LED, diffuse and focused, individual LED direction and color

The color of the plate and the length of Linear Light can be customized base on the size of the screen, whiteboard, and the interior design in the meeting room. The skateboard shape reminds people to relax and let the inspiring ideas flow.

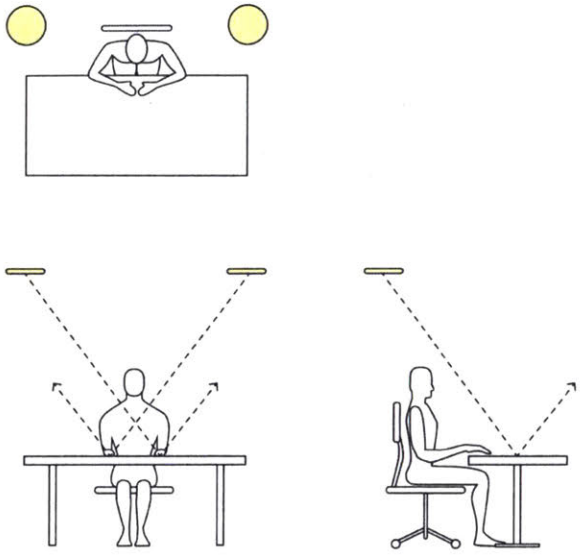
Installed on the wall above the screen or whiteboard, the Linear Light can not only prevent reflections on the surface and protect people's eye, but also adjusts the light distribution according to activities. For instance, when present with a slide, the light needs to be dimmed to avoid causing the reflection and increase the contrast. At the same time, the presenter needs to be highlighted. The Linear Light is designed to that end, to provide a healthier lighting environment for the activity with the vertical working surface in the meeting room.

5.6. Application and Installation

According to Interior Lighting for Designers by Gordon Day (2003), psychological-emotional impact on people in an interior space can be created by light distribution. People who work in the space, receiving equal emphasis from the light on all objects and surfaces will lead to the loss of contrast, which causes people to feel listless and depressed. Brightness contrast can be established by creating light patterns and shade-by selecting specific surface and objects to receive lighting emphasis while leaving others in comparative darkness. Foreground and background are developed by the emphasis. To create the emphasis, each work surface needs to be assigned an individual light source.

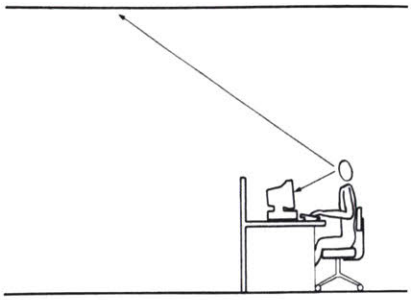
For a good working experience on the desktop with lighting, glare and reflected glare need to be avoided. Rather than too much light, glare is caused by light coming from the wrong direction. For paperwork and reading which require a horizontal working surface, according to Gordon Day (2003), potential approaches of veiling reflections can be avoided by reducing glossiness of work surface, adding diffuse transmitting material to increase the diffusion of the light source, and locating lighting equipment outside the

reflected field of view. With the Circular Light, our suggested light location relative to task surface for paperwork and reading is shown in the figure below. Light locating above and slightly behind the user can prevent the reflected glare towards the user and also reduce the overlaying shadow.

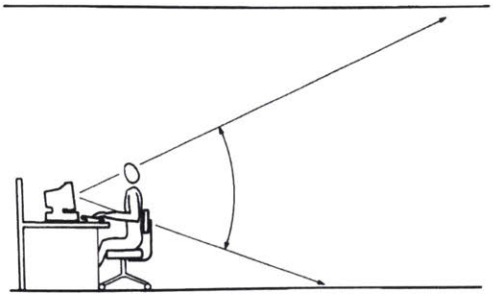


Suggested proper desk lighting to avoid reflected glare to the eyes

For glossy vertical work surfaces: Video Display Terminals (VDTs), such as laptop, glare and reflected glare can also be avoided by installing the light at the proper location. The figure below shows the area of the ceiling that is visible when looking at a computer screen. To avoid glare, the light needs to be installed other than this area. For the reflected glare happens on the screen, as the normal range for reflection line-of-sight angles in a VDT is 65° to 110° from vertical, the light should be installed outside of this area as well.

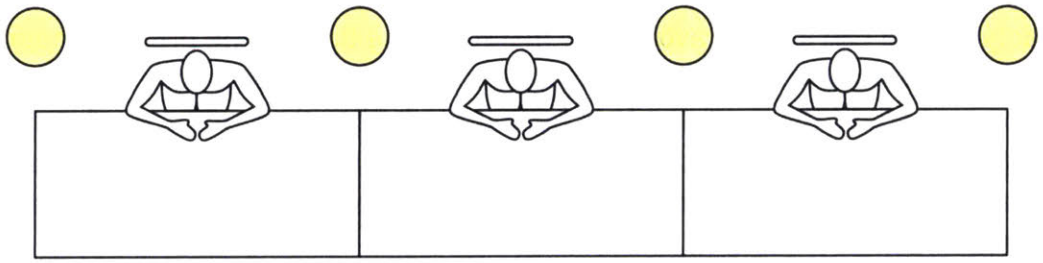


A large area of the ceiling that is visible in the field of view when looking at a Video Display Terminal (VDT) (Day, 2003)



Normal range for reflected line-of-sight angles in a VDT (65° to 110° from vertical) (Day, 2003)

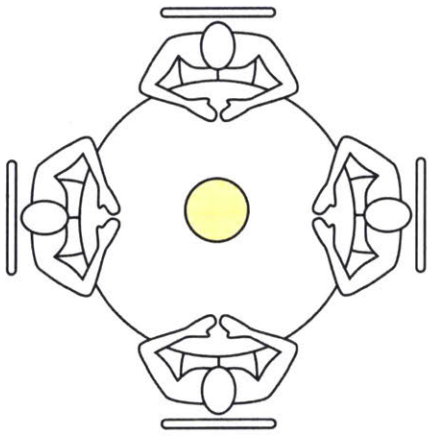
When designing the co-working space, the floor plan, the desks arrangement, and where to install the lights should be considered together. In the open working space, each work surface needs to be accompanied by at least one light source. It is possible for one light source to be shared by strategically designing the desks arrangement or for energy saving purpose. The figure below presents a paradigm how the distribution of light sources corresponds to multiple work surfaces.



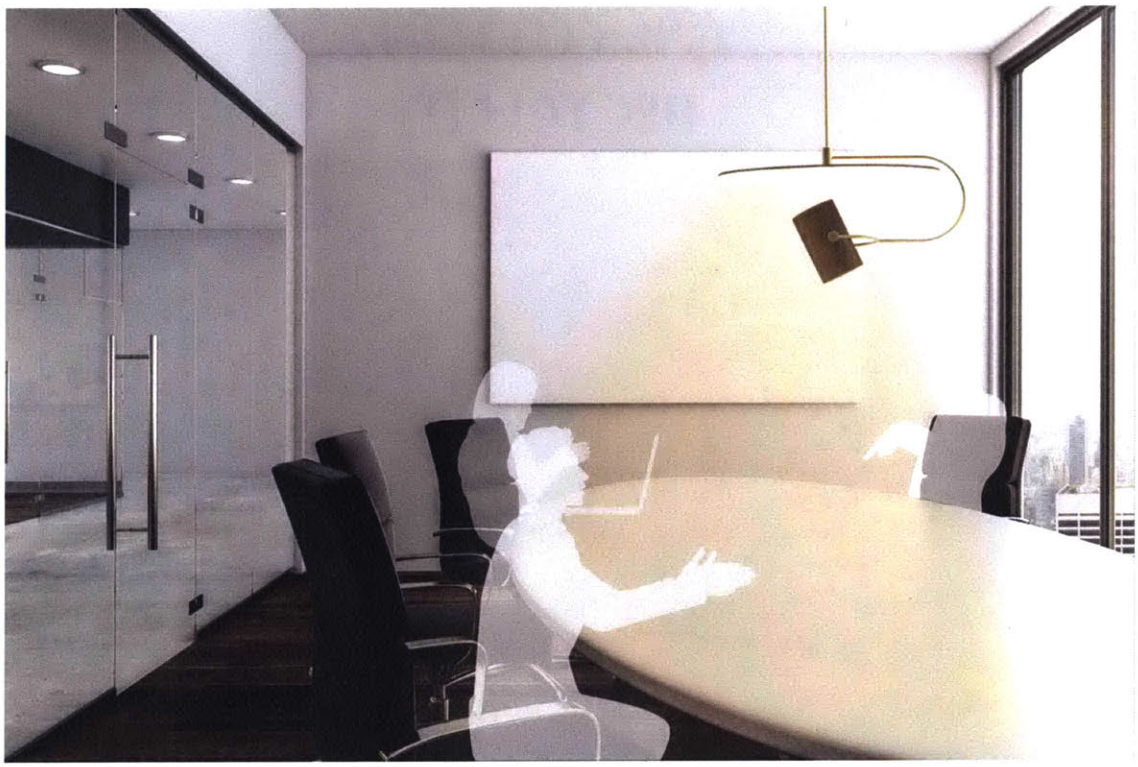
Suggested installing location of the Circular Lights relative to task stations in the open space

Rendering of light installation in the open space

The Circular Light can be used to illuminate a horizontal group work surface such as the table for group discussion. The object to be discussed can be highlighted with the diffused light by placing it at the center of the table. It is also possible to cast directional light on the person who is speaking. Still, whether this function is necessary (or should be implemented) is still need the discussion, as people might less likely to prefer constantly changing light during the discussion. When the table is used for individual work, directional light can also support the activities.

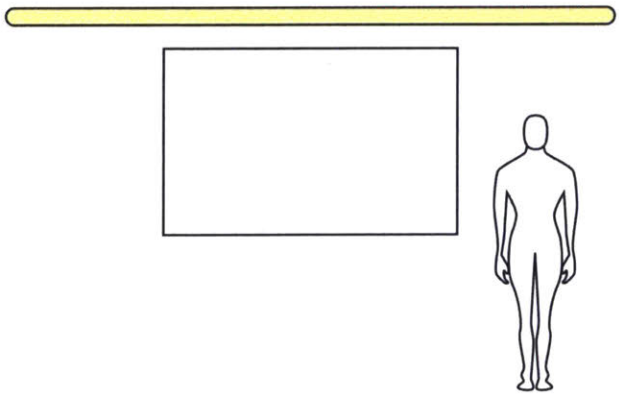


Suggested installing location of the Circular Light for a group work surface

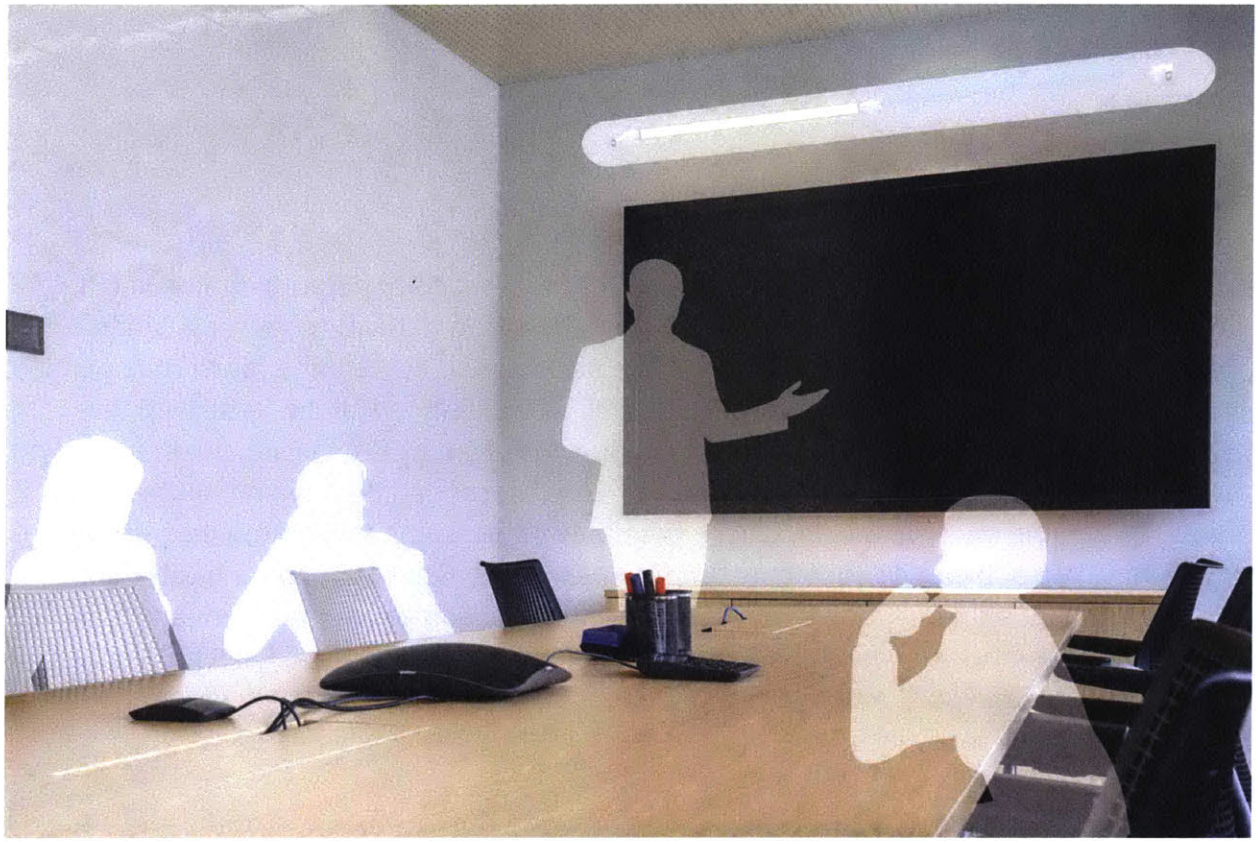


Rendering of light installation in the group workspace

Vertical work surface such as the screen and whiteboard is illuminated from the wall above. The Linear Light is designed for this purpose. The length of the light can be customized base on the width of the surface or the interior design. The Linear Light can light up the presenter without creating reflections on the screen. Both direct and indirect light can be developed at the same time.



Suggested installation for the Linear Light installation at the vertical work surface



Rendering of light installation in the meeting room when a person is having a presentation

Chapter 6
Conclusion

6.1. Conclusion

The rapid urbanization causes more than half of the world's population to live in cities since 2008. Challenges such as overpopulation, depleting natural resources, aging infrastructure, and unsafe neighborhoods are pushing the cities to be more than a place for dwelling, but a care provider. Aiming at 2035, according to Philips' research, five primary features with four sub-features will be addressed by the caring cities: Identity and self, where the cities will help support citizens' personal identity and be their true selves; Belonging and sociability, where the cities help people to become part of the community; Attractiveness and opportunity, where the cities help people fulfill their aspirations; Inclusion and mobility, where the cities recognize everyone equally, and even empathic to those beyond their own border; Safety and balance, where the cities support people's physical and mental well-being and co-create valuable solutions for an empathic intelligent city.

As an indispensable part of cities, light was born with the introduction of the city and is gradually transforming its role beyond illumination. In the futuristic caring cities, light communicates valuable information and shapes the desirable urban experience. Base on the case study, six roles of light has been extracted: Time travel, a universal foundation and symbol throughout history and religions; Guide, navigation and indicator in the ancient voyage and modern city infrastructure; Carrier, message conveyer in myth, architectural, cultural and political context; Catalyst, an interaction and emotion stimulator; Enhancer, a city infrastructure and people performance promoter; Affect, a physical and psychological well-being provider.

Aiming at providing daily care to people's well-being through lighting in public sector, secondary research on the current social pressure situation and primary research on people's opinions towards a balanced lifestyle were conducted. The latter includes conducting the interview, developing personas and generates user needs list, which yields to the design concepts generation. The concepts are then screened by the concept scoring method and go through design iteration. As a result, the final problem statement is made. Base on this, we develop the personalized lighting design concepts in nine different scenes across the city, including the photon therapy station on the airplane, the mobile indicator for carpool, the performance enhancer in the gym, the emotional carer in hotel, the efficiency accelerator in co-working space, a refreshing

mirror in public restroom, the entertaining floor tiles on square, the augmented dining experience in restaurants, and the recreation assistant in bar.

Focusing on designing the co-working space out of the nine scenes, we visited the office of Philips Lighting and observed activities happened in the co-working space. Eight common activities, including paperwork, working on laptop, reading, having a presentation, writing on the whiteboard, brainstorming with post-its, having a group discussion, and doing the video call, are key experiences that the design concept targets at. Study on the relationship between light and the circadian rhythm, weather conditions, and different work styles suggest that we need the system with a programmable ruleset to manage this complexity. We suggest five hierarchical levels: time, weather, occupancy, activities, and manual control, with the ascending order from low to high priority, to dictate how the lighting will behave based on the occupants.

Together with light scenes, two lamp designs, the Circular Light, and the Linear Light, are developed for the horizontal and vertical work surface. The design provides an adjustable option between diffuse light and direct light, with the flexibility to change direction according to the environment and occupants' activities. To design the lighting in the co-working space, we suggest installing the Circular Light above and slightly behind each work surface to avoid glare and reflected glare, and increase the contrast between foreground and background; for the group working space, the Circular Light can be applied to illuminated the table, and the Linear Light is designed to be installed above the vertical work surface to create integrated lighting solution. To make the experience seamless, we suggest utilizing the combination of automation like motion sensor to detect the occupancy, integration with other systems or applications like the wireless presentation system to change the preset that suit with the current activity, and providing the appropriate level of manual control in particular space for ease of use.

Artificial light has been existing through the ages accompanied by the development of modern cities, which has become an essential element that might not second to the importance of air and water. Not only confined to lighten up the darkness, but the light also has significant impacts on people, which the latter might not be realized. To improve people's well-being, nuance adjustment on the light might yield huge differences such as creating positive emotion, increasing work efficiency, improving sleeping quality, which should be supported by the intelligent caring city to make a better place for everyone.

6.2. Discussion

The thesis has discussed various features of future caring cities and roles of light. Nine scenarios of lighting experience in future cities have been designed, yet not every detail has been fully discussed due to the limitation of space. A detailed study on possibilities of future caring cities can refer to the publication of Philips Lighting Research - Future of cities: Scenarios that show how people may experience cities in 2035, and the report - Empathic Smart City: the human side of the smart city. Detailed foundational research on six roles of lighting can refer to Connected Lighting for Caring City, the report we co-authored with the research team at MIT Design Lab. Regarding the nine scenarios, there are already similar design concepts come out for some of them, yet not many of them have been extensively applied. Possible reasons might vary from cases to cases, such as high cost, limitation from public policy, the premature replacement for aging infrastructure, and so forth. To make these design more applicable, more detailed plans need to be discussed in the future study. Here we hope to raise cities planners and public venues owners' awareness for possible improvement that the connected lighting design can make to work towards a more intelligent and caring city.

For the connected lighting designed for co-working space, we have focused on the exploration of possible impacts from environment and people themselves, and how the light can prevent the cause for negative emotion and develop a better user experience as well as well-being. According to the leading lighting technology provider, Philips Lighting, most of the existing human-centered personalized solution designed for working space is time and activities based, many of them are manually controlled. Yet, how the light should behave in a 'true' personalized way, that response to every individual's characteristic is still under discussion. Our provided system architecture and ruleset serves as the foundation for the next generation smart lighting system. Still, further details need to be sorted out for the real implementation, such as the technology stack, the default settings and appropriated parameters which may differ from place to place, or the implication that may occur in different space layout.

The concept design of two lamps, the Circular Light, and the Linear Light, are theoretically designed base on our study of interior lighting. Here we point out the possibility but have not addressed on the materials, mechanical structure, and the entire control system. As the design targets at 2035, technologies have not mature today might be viable in the future design. More risk can be taken as long as the trend of the developing technology is optimistic and serves a user-centered purpose. In addition, further user testing and several iterations might need before the design is ready for manufacturing.

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Appendix

A. Caring City Interviews Digest by MIT Design Lab

"It's about place-making and making a city that pro- vides space for people to interact and go out and b in a space that they care about."

"I think of a community where there is comfort and warmth all around; A spirit of growth and people listening to one another"

"it takes seriously the demands of democracy. It's equally welcoming to people regardless of background. It takes welcoming one step further, it fosters development, through economic programs, health, driving change in an equitable manner that is people focused."

"Community centers, things/policies that help a wide group of people. Street lights for safety, aesthetic and fosters people coming together."

"When I think of the caring city, I think about the place where residents feel safe"

"The thing that come to the top of my mind when talking about the inclusiveness in the city is having an open community space, almost like when students gather around in common area at the campus, and spending time with each other and relax."

"The city is clean, neat, and well organized. From the infrastructure, I feel being cared for."

"People feel safe in the city."

"I think cities tend to form around identities, and that could be a neat thing to experience and be a part of.

I believe this could help you find your place in the world, and also know where people' places are."

"People contribute to the city in return, like infrastructure, animals and so forth."

"I moved to different cities in the different times in my life because there will be something new offered by that place, whether different people, experience, or culture."

"I feel I'm part of the city when I travel back and see students and professors walking around, and eager to start a conversation. The topics and conversations flow around the city, which I'm interested in."

"Human-centered city: everybody feels welcomed regardless the age, gender, race, and origin." "I feel being included in the city by attending and learning from the events held almost every week, which is an echo of my personality"

"Friday night after work, the first thing that come to my mind is what's going on around the city tonight. And it's very advantageous to be a part of the city that

facilitates these community spaces/events/concerts not only during the day but the night."

"Everybody has enough flexibility to move around."

"Care starts with supports."

"be comfortable, and live in the space where they can be themselves"

"And they know they are being taking care of."

B. Millennials' Expectations an Urban Transformation by MIT Design Lab

The Networked City: connect people, places and things for services and experiences in the city to work seamlessly.

The Sustainable City: create opportunities for Millennials to integrate sustainable behavior in their daily lives.

The Communicative City: create communication channels to speak with Millennials on platforms they're comfortable with and focus on fostering a two-way dialogue.

The Active City: create opportunities for Millennials to form bottom-up communities related to health and wellbeing in the city.

The DIY City: create opportunities for Millennials to hack, design, and appropriate from the bottom-up.

The Equitable City: create systems that allow people from diverse social, and economic.

C. Future of Cities Scenarios by Philips

Fablab: citizens can help solve big city issues. People take ownership to realize infrastructure and experience without waiting or against the intentions of the authorities.

Resort: when digital systems fail, cities can retake control from companies. People are guided and facilitated in their choices regarding work and daily lifestyle.

Sandbox: the city gives up control, trusting its own population and letting people shape the environment for themselves. Authorities motivate and support citizens to realize solutions to improve communities and experiences.

Campsite: citizens are unengaged with their city. New pastimes and education take precedence. As different places offer different benefits in both the physical and virtual worlds, people adopt new lifestyles with unexpected consequences.

D. Empathic Smart City by Philips

Personal Identity: An Empathic Smart City supports each individual in exploring and expressing their personal identity. One is stimulated to find one's place and identity within the city.

Neighborhood Identity: In an Empathic Smart City, the people who visit, live, work or consume in a specific neighborhood de ne its identity, in conjunction with what the area physically offers.

City Identity: An Empathic Smart City has a deep relationship with the people who visit, live, work or consume in the city because these people connect with the unique set of attributes and values that de ne and characterize the city.

Citizen Co-creation: An Empathic Smart City constantly takes the pulse of the people living in the city, so that it can offer what is needed in both the short and long term. The city gauges the true sentiment of its citizens and engages people to be closely connected, to enable co-creation.

Hospitable City: in an Empathic Smart City, everyone feels at home and feels like they belong, even in a continually changing environment. People with different back- grounds and stories have all found their place and are tolerant of others.

Social City: an Empathic Smart City, people know where and how to connect with like minded people or interests, across the city. People step out of their own neighbor- hood or tourist hotspots to areas where they can nd the mental, social, physical stimuli they are seeking

Flexible City: an Empathic Smart City energizes its citizens by offering spontaneous, sometimes unexpected and surprising events and experiences. It offers a break from the usual routine and activities.

City as a Platform: in an Empathic Smart City, the physical world and the digital world are morphed into one and allow the creation of new, locally relevant (business or social) initiatives. It stimulates would- be entrepreneurs and invites new social initiatives to happen.

Community Feel: an Empathic Smart City supports people to actively and passively participate, creating a strong sense of community. It creates less anonymity, more trust, and makes the city more permeable.

Planning heart and Soul: an Empathic Smart City involves its citizens in urban planning and gentrification projects to make sure the essence of the neighbor- hood remains. Any new urban renewal project is perceived as an improvement by the people who live or work there, or visit.

Aspirational City: an Empathic Smart City fits personal needs and aspirations and gives people the confidence they can find what they are looking for - for their future or for their family's future (e.g. education, career opportunities, personal development, healthcare, culture etc.)

City as a Lab: an Empathic Smart City functions as an incubator for Smart City innovations, acting as an open lab to allow large-scale learning to improve the city.

Inclusive City: in an Empathic Smart City, barriers to participating in daily life have been lowered, so that everyone can equally take part in society without being hindered. These barriers could have a social, physical, economic, or other origin.

Urban Habitat: in an Empathic Smart City people, animals and plants co-exist as one eco-system. Bio-diversity plays an essential role in urban quality of life and the provision of eco-system services.

Safe City: in an Empathic Smart City, people feel safe and are reassured the city works with them to stay safe - both on the street as well as at home. The city ecosystem works to counteract new vulnerabilities in a changing society.

Need to Wind Down: an Empathic Smart City understands there is a balance between being 'ever present' and knowing when to not intrude. People need a chance to pause, relax, reflect and unwind, to re- energize and release stress.

Edges of City: an Empathic Smart City doesn't stop at the city's borders, but embraces the fringes of the city and those who live and work there.

Flow of the City: in an Empathic Smart City, people and means of transportation are in constant flow.

Health City: an Empathic Smart City fosters a healthy life(style). People are not always aware of - potentially dangerous - health risks.

City Foundation: in an Empathic Smart City, the utilities that keep the city running are well protected and maintained. A city needs 'fuel' to function: clean water, gas, waste disposal, electricity, etc.

E. Ideal Balanced Lifestyle Interviews Digest

Interviewee A:

Male, 18-year-old, studying in US, freshman majors in Mechanical Engineering and Design

Q: Do you think you are living with a balanced life now?
A: Yes, during weekday, go to class, study, do exercise 1-2 hours. Weekend, do laundry, buy grocery. Feel busy when there is design deadline, paper deadline, and exam. Brain dead when stuck on generating great idea. Just go sleep to pause a bit
Q: How do you think you life before undergrad?
A: Basically study everyday. The definition of a balanced life is less intense study. During holiday usually travel to different places to wind down.
Q: Do you think your parents have a balanced lifestyle?
A: Mom (professor of industrial design) is busy, but she seems enjoy her busy life. Go to grandma's during weekend. Travel during vacation; Dad (professor of engineering education) is not having a balanced life. Get busier after my high school, maybe due to pressure of my tuition, works harder to make more money. Has been sick twice last year, and each time last for weeks.

Interviewee B

Male, 22-year-old, studying in Hong Kong and doing research in US, senior major in Physics

Q: How is your life in Hong Kong?
A: OK for first two years. Busy started from junior, due to application to US PhD. Accumulating experience like research and paper. Feel extremely painful while preparing for TOFEL and GRE, spent long time but no improvement on scores
Q: How is your life in Harvard research?
A: Have been nowhere, never been to China town. Cooking and go to good restaurant is the only enjoyable thing right now, when stuck on research late at night.

Interviewee C

Male, 32-year-old, studying in US, MBA from Mechanical Engineering background, will work in Amazon this year

Q: What is your definition of balanced life?
A: Balanced life: work, family, hobby
Q: Are you living with a balanced life?
A: Doing well on work, good on family, not many on hobby. Reading, live music, are hobbies, taking classes like coding classes are also hobbies, not doing well on hobby. Maybe can do better by improve efficiency and prioritize things.

Q: What do you usually do to wind down、
A: To refresh mind: go sw else like mountains, universities, cafe, live music
Q: How can you get the info and if the city support you to have a balanced life？
A: Easier to explore within the city cuz if no time to go too far. Usually get info from friends in different classes. Lots of existing web but not everyone fit personal interest

Interviewee D

Female, 25-year-old, studying in US, master student major in IDM

Q: What is your definition of balanced life?
A: Happy, not feel unrest of threatened. Material and spiritual satisfied. If study whole day with happy mood, it can be called as balanced life as well.
Q: Ways to relax?
A: Depends on status. When studying, go to restaurant or somewhere interesting. When working, with more money, will go for trip to relax. Go to beach to enjoy sunshine when summer. Relaxation in different cities: Boston: Yelp, hang out with friends in bar or restaurant, go for night view, go to new places base on FB events or recommendation from friends, online shopping; Worcester: nature, go fishing, go hiking, go skiing; Guangzhou: Karaoke with friends, shopping
Q: How do you think your life so far?
A: Living in a balanced life, in right places, do right things, feel happiness; A tipical day: weekdays: go to classes during the day, do homework at night, meet boyfriend during weekend, have dinner tgt; have middle pressure
Q: Tools to help you to relax
A: Like current social medias such as FB, Yelp, much better than before. Groupon, discount nearby, e.g. mini golf, tree climbing.
Q: How to support people to live a balanced life as a city?
A: Improve transportation to support people go outside; Free museum info, improve people's motivation to relax. The youth can easily get info by web, should do more promotion to family who seldom get info from social media

Interviewee E

Male, 24-year-old, studying in US, master student major in Electronic Engineering

Q: What is your definition of balanced life?
A: Balance between work and relaxation, interested and uninterested things, easy and hard things, exercise and relax, spiritual intense and relax, positive and negative.
Q: How do you think your life so far?
A: Mostly satisfied, trying to be more balance. Study, do exercise, relaxation. Do exercise 6 times a week when not busy. Over relaxation is not balanced.
Q: What do you do to relax?

A: When busy in study, finish the task makes me relax. Relaxation means to whatever I want to do. Play games, reading, watch a movie, lie down, board game. Seldom go outside casue no idea what to do. Glad to join if somebody has a good proposal.

Interviewee F

Male, 61-year-old, living in China, Designer

Q: What is your definition of balanced life?
A: Life of regularity, effectiveness, healthy. Enjoy the work I'm doing, have more production, go beyond myself and keep the abilities. Get up at 6.30am, working during the day, swim at noon, go walking after dinner, paint or write book in the evening, read book before sleep, go sleep at 11.30 pm. Go to museum, zoo, or other scenic spot during weekend. Travel to other cities for business trip, or with family. Keep life in a regular pace, don't like over relaxation. Prefer to go the place I familiar with, like museum with different exhibitions around the year. Feel time is valuable at this age. Don't want to waste time to go somewhere far and unfamiliar with. Away from social media and digital product

Interviewee G

Female, 56, living in China, health physician

Q: What is your definition of balanced life?
A: Don't work overtime or in the weekend. Live in a healthy life, with health diet, regular exercise, keep optimistic. Always have time to travel to different places. Get up at 6.30am, working during the day, nap at noon, go walking after dinner, watch TV/video/play games in the evening, sleep at around 1pm. Curious about new things and want to try. Get tired of going to same places all the time. Know new places from social media or recommendation from friends. Hope to have someone go to new places with me cause my husband likes same place and my daughter is studying abroad. Take the opportunity of business trip to travel in other cities.

Interviewee H

Male, 26, living in Thailand, UX designer

Mick is working as a UX designer in one of the software house company. He's an introvert, shy, and think of everything in a very logical way.

He starts his work at 9:00 AM and works until 18:00 PM. His home is very near his workplace. It's just 10-15 minutes apart by walking. So even sometimes, he comes home to have lunch and go back to work.

I asked him about the activities that make him relax. He answered with two things: workout and reading.

For the workout, he usually runs and does weight-training. He tries to do it every day in the morning and after work. He doesn't often go and hang out with a friend because it's just tricky to find the time that works with his (close) friends.

For jogging or running, he always jogs (alone) in the park very near his home and workplace. When I asked about if he jogs alone, he replied with that maybe it would be fun to have a group that you can go and exercise together. But it's just that he can do at his own time if he does alone. That's why he usually go alone.

For reading, he tries to allocate the time before bed to read books. He's interested in books about design, self-improvement, and management.

I noticed that, although reading good books and working out make him happy, but the drive that makes him do these activities regularly is the need to feel like he achieves something; He tries so hard to keep these 2 activities like the daily habit, and he also motivated by the self-improvement that happens to his body and his mind. When I reassured about this, he confirmed that it's true.

He wore Apple Watch on the day we met, so I asked. He said he wears it as the activity tracker. He doesn't care about the notification feature on the watch (he only turned the notification on for email, phone call, and SMS), just the activity tracking (he bought many activity trackers before, but end up with the Apple Watch because of the seamless integration) and the fashion purpose.

He sees the social media as the evil thing sometimes. So, although he regularly uses it unintentionally, when he's fatigue or use it purposefully to share his knowledge or the idea. He frequently feels guilty for spending time in the social media. He mostly uses Facebook and Instagram. He also enjoys watching good series on Netflix and watching manga. However, he even tries to restrict the time spending on it.

I asked about what services he subscribes to. He named just a few: Netflix, Internet and mobile plans, and the fitness.

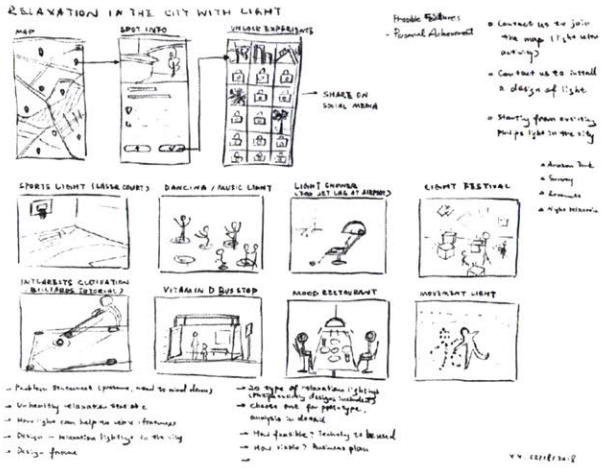
He then revealed that he enjoys being a foodie. He only focuses on finding a good hamburger, rib, steak, and ramen restaurants. I frequently saw his food photo posts though. He then talked a lot about this kind of foods. To him, it's almost like foods are the sport or something that he wants to achieve. For instance, from time to time, he will come up with the goal to eat all top 100 hamburgers in Bangkok. And when he succeeds, he will feel proud of it.

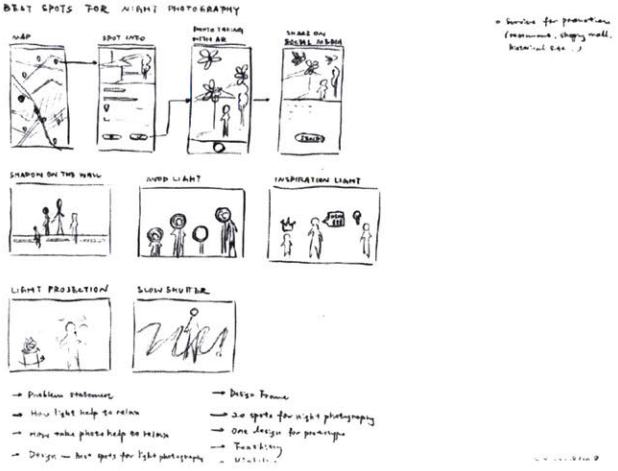
Whatever he do (or try to do), he is very critical if it's the thing that he wants as the part of his personality. Apple watch, less social media, fashion, foodies, books, jogging and weight training – they are the things that make him feel like he's smart, logical, efficient, and achiever.

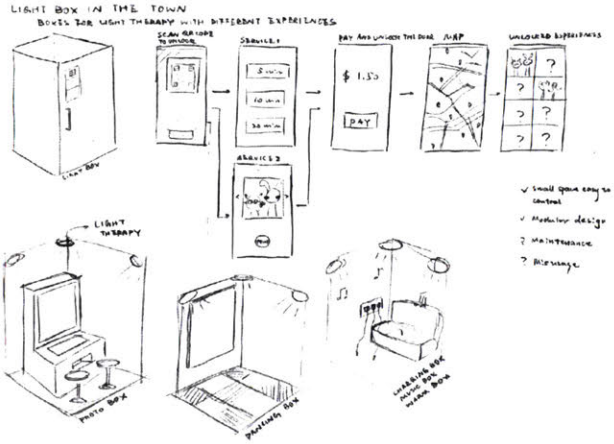
He loves Zara fashion brand. He tries to control his spend each month with the app. But most of the time, it can't help.

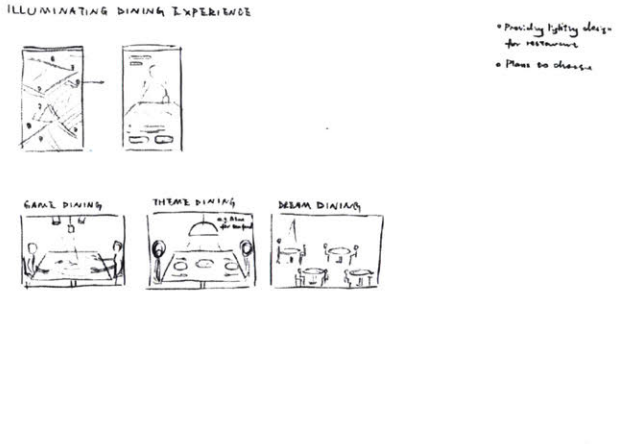
He regularly tracks his sleeping using the Apple watch and the app. He also tries to do the meditation with the help of the app called Headspace. Although he recently stops it, he still thinking and forcing himself to go back doing it. Sometimes he also tries to notice what and how activities during the day affect his sleeping quality using the tracking app.

F. Concept Ideation Sketches

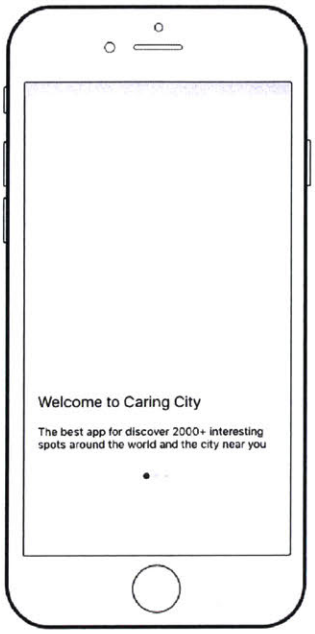


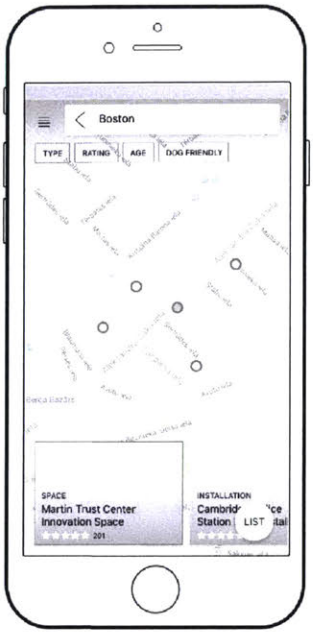


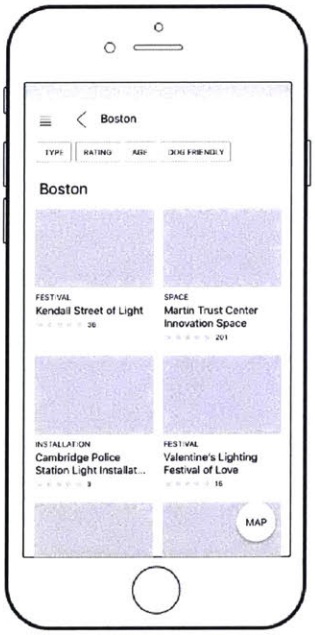


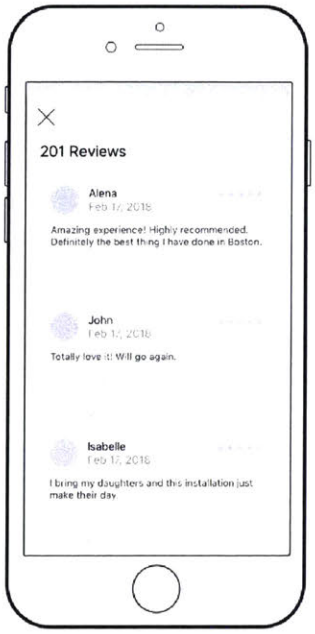


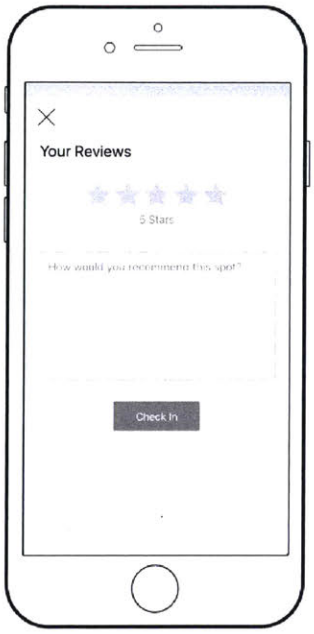
G. UI Prototype for User Testing

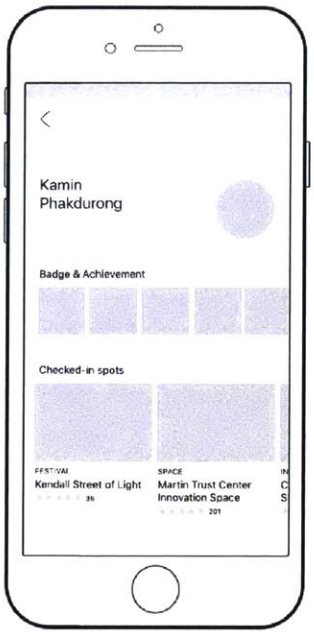


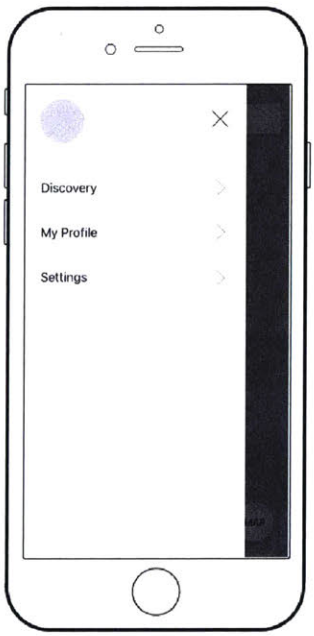




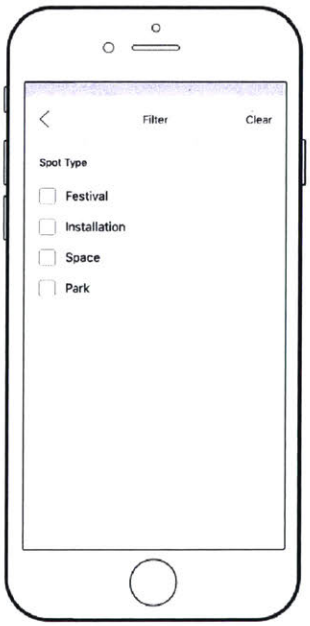

201 Reviews
Alena
Feb 12, 2018
Amazing experience! Highly recommended. Definitely the best thing I have done in Boston.
John
Feb 12, 2018
Totally love it! Will go again.
Isabelle
Feb 12, 2018
I bring my daughters and this installation just make their day.


Your Reviews
5 Stars
How would you recommend this spot?
Check In


Kamin
Phakdurong
Badge & Achievement
Checked-in spots
FESTIVAL
Kendall Street of Light
SPACE
Martin Trust Center
Innovation Space

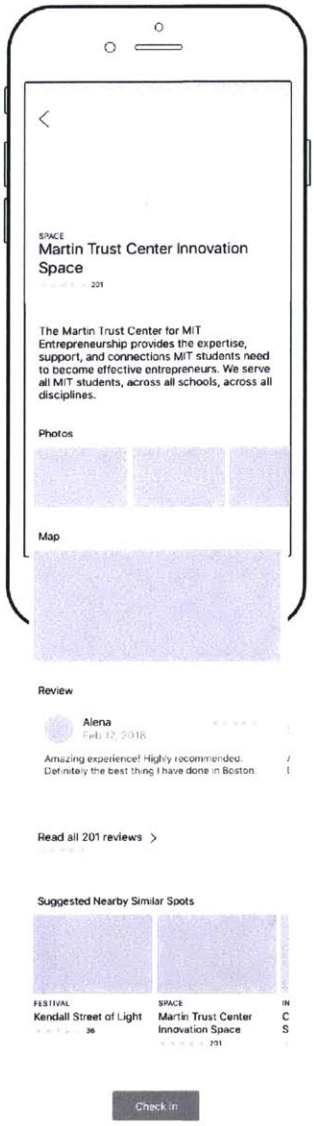

Discovery
My Profile
Settings


Search city
Nearby
Boston
New York
Chicago


Filter
Clear
Spot Type
Festival
Installation
Space
Park


Settings
Notifications
Terms of Service
Log out


TYPE
RATING
AGE
DOG FRIENDLY
DISCOVER SPOTS
BOSTON
Our favorite selected spots nearby you
Categories
Spots for relaxation
Our favorite selected spots for relaxation
FESTIVAL
Kendall Street of Light
SPACE
Martin Trust Center Innovation Space
Spots for music
Our favorite selected spots for music
MAP

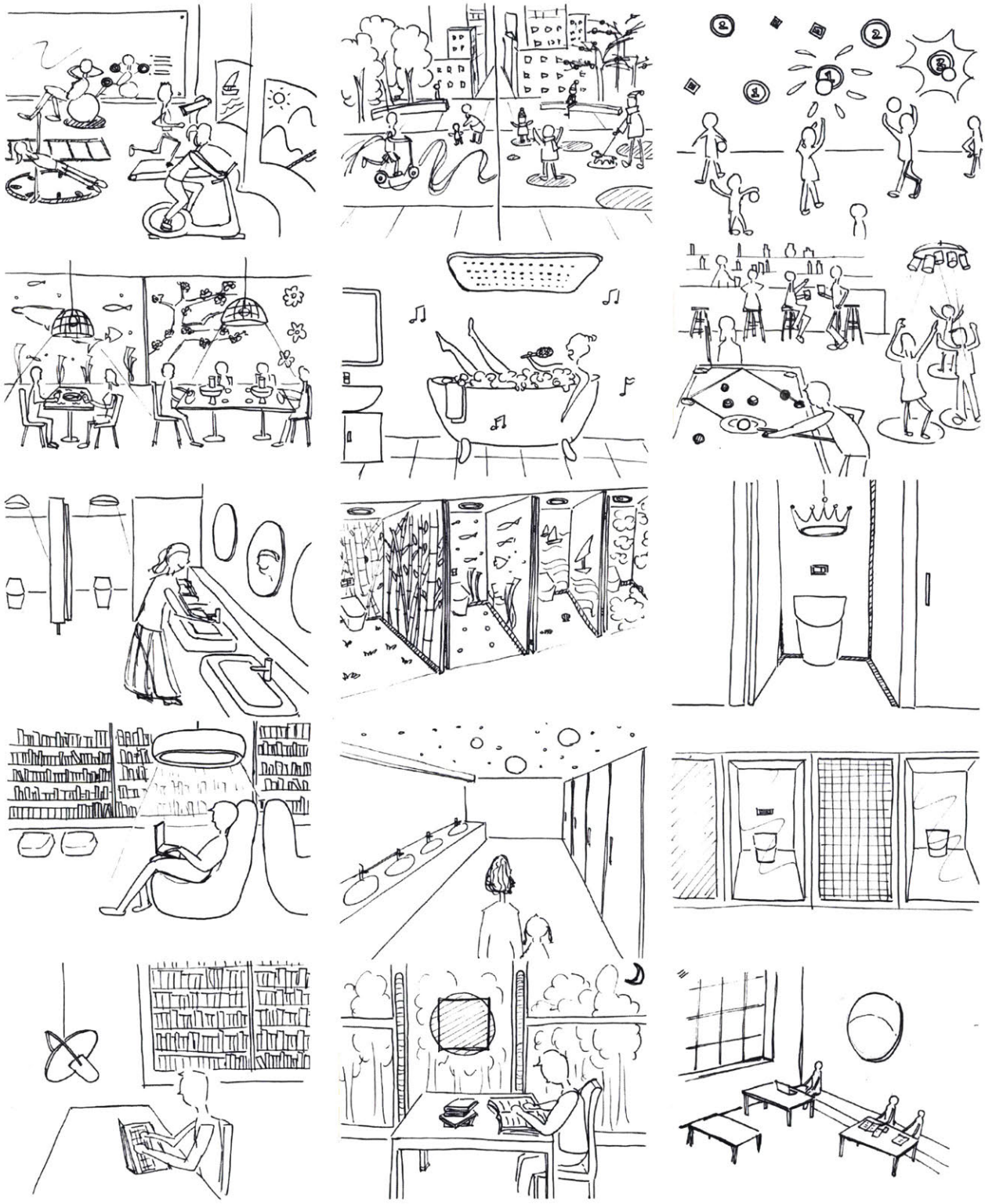

SPACE
Martin Trust Center Innovation Space
The Martin Trust Center for MIT Entrepreneurship provides the expertise, support, and connections MIT students need to become effective entrepreneurs. We serve all MIT students, across all schools, across all disciplines.
Photos
Map
Review
Alena
Amazing experience! Highly recommended. Definitely the best thing I have done in Boston.
Read all 201 reviews
Suggested Nearby Similar Spots
FESTIVAL
Kendall Street of Light
SPACE
Martin Trust Center Innovation Space
Check In

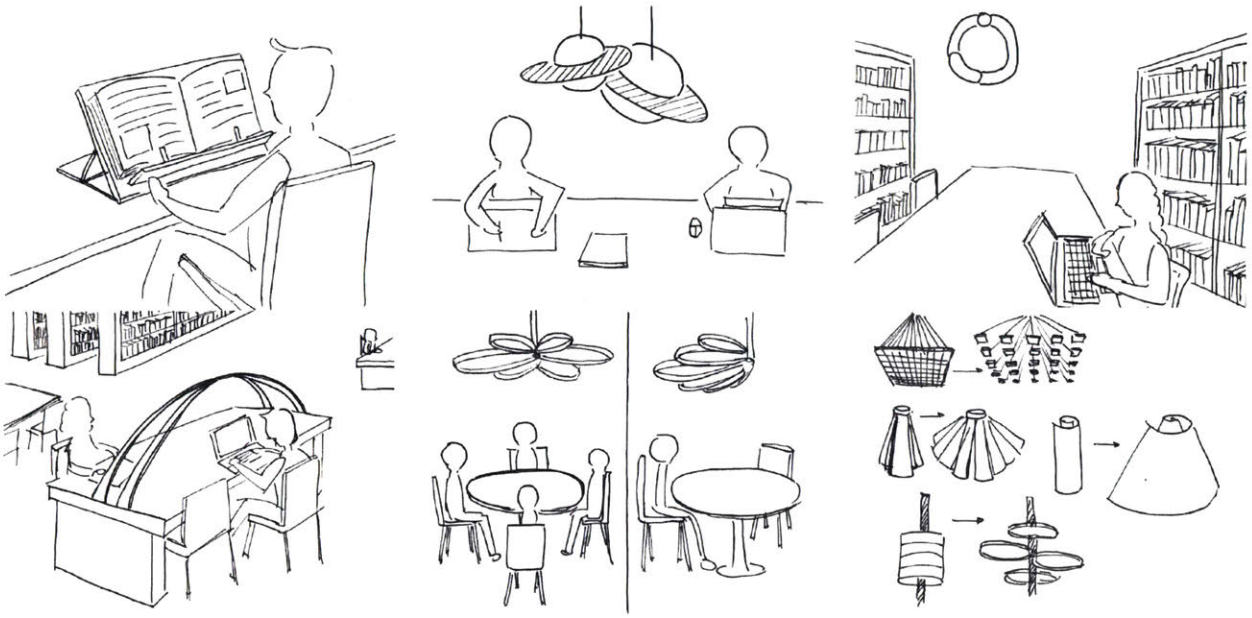
H. UI User Testing Feedbacks

User	Comment
1	The purpose of the app is not clear
Female	Confused about the filter "Age"
	The check in purpose is not clear
	The check in button should be more standing out
	The spot info page is good
	What kind of input can the user puts in the search bar?
	There should be a sign on the installation tells you what to do
	Do I need to check out? (use the term "Unlock?")
	Notification should be like 2-3 hours after, not longer than that or I'll forget
	Pro:
	Explore Boston
	Google map only show the building, not the installation
	User usually get the information from the social media
	Cons:
	Why do we need to check in?
	How does the team get that contents about the installation?
	Age Filter -> Kids friendly. What should be on the filters
2	What does it mean by check in
Male	I love the map and only want to go to the location nearby (that's because I'm not an outdoor person)
	Love that the review only show one review first, and allow the user to view more reviews
	I will normally just stay at home and don't want to go too far

User	Comment
3	Why I'm already in Boston.
Female	What do we use to catagorize places in the categories
	What's the difference from Google Map
	Why do I need to check in?
	What is the light installation means?
	She just put the stars but no comments on the review page
	We should be clear about the motivation why people should download the app
	She showed one example from Foamlab in NYC
	She doesn't care about the achievement, but may be she will if there's a friend using with her
	One of the motivation for her to download the app is the coupon
	She purposes the idea about the game that users can interact with the installation at the same and compete with one another (like tapping competition)
	She also think of the bell in Europe where it will ring only at the certain time and people will wait for it
4	Why need to download
Female	On the welcome screen, we should show the example of the places and what it's all about
	What do we use to catagorize places in the categories
	What does the light installation means?
	She couldn't find the check in button
	Why do I need to check in?
	In the spot info page, is this information about the installation or the location that the installation that is inside
	She's not a big fan of collecting the achievement
	She doesn't use the social media that much
	She has a lot of problem about the fidelity of the prototype

I. Personalized Lighting Experience in the Future City Concept Sketches





J. Light Appearance Design Concept Sketches