University of Wismar

Faculty of Architecture and Design

Master-Thesis

Lighting Interior Landscapes Inaccessible to Daylight

Beleuchtung Innenraum Landschaften unzugänglich für Tageslicht

Thesis prepared for the degree of

Master of Arts

Submitted by:	Hussain Burhani
	Born : 02nd October 1980
	Master Architectural Lighting and Design Management
First Mentor:	Prof. Dr.-Ing. Marcus Hackel
Second Mentor:	Prof. Dr. Amardeep Mohanlal Dugar

Mumbai, 5th September 2018

STATUTORY DECLARATION

I declare that I have developed and written the enclosed Master Thesis completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. The Master Thesis was not used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

Hussain Burhani

Mumbai, 5th September 2018

Foreword

Having spent all my life in a super busy metropolitan city like Mumbai makes me value the presence of greens around me the most. Cramped for space and trying to create more and more infrastructure the city has given away all the green spaces that existed all the years. I still remember as a child going to play cricket with friends at a place that had huge open grounds, grass and trees. This particular place is today known as Bandra-Kurla Complex (BKC) which is the business hub of Mumbai with the world largest corporates having their offices in this location. Today if you want to play you need to enrol at a club where you have specified open spaces to play and go around. This is the case with most of the large cities around the world. I personally believe that it is extremely important to create a proper balance of the ecosystem by having access to enough nature around us for your body and mind.

The idea of being able to grow plants with artificial lights struck me a few years back when I first heard the concept of being able to grow food with artificial electric lights. Having been involved in the lighting industry this make me think and ponder how this could not only solve the world food problem but also solve the major problem of lack of green spaces around you in indoor spaces. If you visit a city like Mumbai where people barely find space to live you will notice a very common sight, everyone trying to grow plants in whatever space they find outside their house, spaces that are generally not usable. This primarily includes house balcony, building terraces and most common is the window ledge (metal grill) where people try and place pots to grow small plants. It goes to prove how much people wants plants and nature to be part of their life even in a small possible way despite the space restrictions.

When I attended PLDC conference last November and heard Kathryn Gustafson where she explained how everyone expected them to place plants everywhere but she was not able to make that possible since there was no appropriate lighting solutions available. This made me think to take this up and try to perform real life experiments to see how plants could survive and grow under artificial lighting. Now growing plants using artificial lights is an established concept by emulating the spectrum of the sun but the challenge was to ensure that the artificial lighting provided for plants blends with the overall indoor space because if we are to place plants in indoor spaces it is very important that it belongs there as part of the space. If the lighting system placed for plants in indoors does not blend with the overall architecture then it defeats the whole purpose of having plants in the space in the first place.

The intent of this thesis and experiment is to try and come up with a solution which gives us the flexibility to place plants in indoor spaces without any accessible daylight and make them survive using lighting spectrums that are suitable for architectural uses.

Acknowledgments

I would like to take this opportunity to thank everyone involved in the past two and half years over the period of my Masters course at Wismar. Starting with my colleagues at office who convinced me to undertake this course specially at a time when I had to do this along with managing the work. A special thanks to my entire family, my wife Kejal and son Arsh who have always stood by my decisions and helped me get through, this would not have been possible without you guys. It has been a wonderful learning experience and I would like to thank all the professors who have helped us learn over the course in many different ways. Its important to thank all the course co-ordinators who have helped us manage everything specially since it is a foreign university. Lastly but most importantly all my classmates and friends who have helped me throughout the course, it was a real pleasure working with everyone.

Moving onto this thesis I want to start by thanking both my mentors Prof. Dr.-Ing Marcus Hackel and Prof. Dr. Amardeep Dugar who helped me start and complete this research.

Prof. Dr. Hackel has always been there to help in every possible situation and I would really like to thank him for his sheer dedication in teaching us throughout the course. He has always made us push the limits and find innovative ways to learn and come up with new ideas. His experience and teachings would go a long way in our careers and lives.

Dr. Amardeep whom I met and acquainted during the course of this thesis research has been instrumental in helping me go through this entire research process. His commitment towards this thesis has been outstanding and I would like to sincerely thank him for all the efforts that he put in this research and the time he has spent in getting this completed. He has been kind to travel all the way to Mumbai to physically inspect the experiment sites not once but twice over the course of this thesis study.

I would also like to thank all the people involved in this research including the office staff and residents of the experiment sites, the staff from the nursery where we got our plants, the horticulturists who helped us understand the basics and the agency who helped us complete one of the installations. Without their support this would have not been possible. I would specially like to thank all my office colleagues who have supported me in an extremely positive way to try and achieve the desired results.

Abstract

Plants and trees are a part of nature that are connected to humans just the way we are connected to the sun and the sky. It is impossible to image our lives without plants and trees in it. It forms a core part of our biological existence where we need food to eat and survive and oxygen to breathe and exist. Yet with this profound knowledge of truth there is still a decay in existence of plants in our lives in urban architectural spaces. On one hand we cannot stop from being indoor both due to climatic conditions and also due to the way the world is developing where we are tuned to work and live in closed spaces whether it be apartments, offices, schools or hospitals. The issue this research tries to address is how we can improve the availability and presence of plants and trees in such indoor spaces by installing the right lighting which would also blend with the overall space and design. Its a proven fact that plants can grow with artificial lighting but we cannot have purple color lights in a hospital or an office or a school or in a living room. Thus its important to understand whether we can maintain plants by use of artificial light color that is commonly used in such spaces which is between 3000k to 4000k.

The thesis is part desk research and part experiment. The first part tries to evaluate the data available with regards to growing plants with artificial lights starting with the benefits of having plants in indoor spaces. The research also looks at case studies where such installations are commissioned and being operated successfully. The next part of the research is setting up two live experiments with different conditions, locations, people and light colors. This was done in order to test the theory in actual conditions and see the results. The idea was to install lighting which suits the space with regards to color, form, intensity and duration but at the same time works well for the existence and growth of the plants.

In both the cases, one being an office installation and other being a residential installation, the users were interviewed before and after the installation in order to understand and learn from their behavioral response. In case of the residence the plants have been growing well with artificial lights and it has now become a permanent installation since the users so not want it removed. In case of the office as well the plants survived well in both 3000k and 4000k, where the users want the plants to stay in their office space and not let them go. This proves the need for plants in indoor spaces and that they can be grown by including them as part of the overall lighting design scheme.

A lot needs to be done in this field in order to make this a common and wide phenomenon. Awareness about this has to be increased, an effort on the part of the project and design team has to be made to have this as a priority with its known benefits. A deeper research and study needs to be conducted in order to come up certain models and standards that can be easily used by the design community in specific and others in general since study of plants is restricted to biology and horticulture. This research intends to be a small starting point in that direction.

Table of Contents

Chapter – 1: Introduction

1.1. Lighting and Plants in Interior Spaces

Light and plants are natural phenomenon having an extremely important and inherent role in our lives. They form a part of human existence and directly relate to our well being. For any space lighting is considered to be the soul since the best of material or designs would be inaccessible or undervalued without the use of light. Lighting creates or changes moods, increases or decreases efficiency, even changes perception, influences decision-making process. Likewise plants or greens in a space affects mood, changes perception, impacts efficiency and influences decision-making. Thus lighting and plants both are integral components of any given space.

All designers including architects, interior, landscape as well as lighting designers prefer greenery in interior spaces as they try to incorporate plants as part of their overall design scheme. There are architects who create jungles while lighting designers eagerly highlight these jungles. Any project such as hotels, malls, office buildings, residential towers or even small offices, restaurants and individual houses, designers try to incorporate plants and trees within interior spaces. Given below are a few project examples that depict the move towards incorporating greens as part of the structure and overall space. Instead of adding green within spaces like in the past, these designs add spaces within the greens.

Colony and Summer Pavilion, Singapore - Tony Chi & Associates + Nipek Lighting Design Collective. Image courtesy: www.nipek.jp

Bosco Verticale, Italy - Stefano Boeri. Image courtesy : www.stefanoboeriarchitetti.net

Park Royal Hotel, Singapore - WOHA Architects. Image courtesy : www.woha.net

1.1.1. The Problem

The shift towards incorporating plants and trees in our surroundings has primarily been determined by the availability of natural daylight. This is due to the popular and common belief that daylight is required to grow and maintain plants and trees. Thus majority of the installation of plants and trees are planned in and around the availability of daylight. Skylight atriums, open ceilings, windows, doors, wall openings and other such mediums are used to ensure the growth of plants and trees within interior spaces. Although this shift has created new methods for daylight design, it has also caused a great limitation to adding plants within interior spaces. Consequently, the use of plants and trees in interior spaces is only determined by the availability of daylight. Thus restricting the possibility of incorporating plants in areas inaccessible to daylight.

But is it really the case that plants cannot be grown in interior spaces inaccessible to daylight? Considering today's modern technological advances one can safely conclude that this is definitely not the case. Considerable amount of research has already been done on growing plants and vegetables with electric lighting. (Russian botanist Andrei Famintsyn was the first to use electric lighting for growing plants (1868)). There are several established grow farms that boast superior quality of produce achieved with the use of electric lighting (Aero Farms, Newark, USA). Major lighting manufacturers around the world now offer standard luminaires commonly known as grow lights for the production of vegetables and plants. Subsequent chapters of this thesis will describe in detail the different types of grow lights and how they assist in plant growth.

With such established electric lighting systems for growing plants, why are landscape designers or lighting designers unable to cultivate plants in interior spaces inaccessible to daylight? This research has identified two primary reasons. The first reason is that these lighting systems are focused only on increasing the growth, quality and intensity of vegetation produced as they are typically used for farming. The requirements for growing plants are completely different from the requirements for architectural lighting environments. Consequently, the luminaires used for growing plants are unsuitable both aesthetically and technically for architectural lighting applications. The second reason is that field of architectural lighting which is derived principally from fields of architecture and engineering seems different from grow lighting which is derived principally from biology, agriculture and horticulture. While both these field on the onset appear too different, has led to lighting designers not exploring the possibility of designing lighting for both architectural and grow applications.


vs.


Architectural lighting vs. Lighting for plants. Image courtesy : www.ihg.com, www.nasa.gov


1.1.2. The Aim

This provides a unique opportunity to explore design techniques that tries to bridge this gap between two scientifically complex subjects of botany and lighting design. This thesis aims to provide a detailed and simplistic study of using electric lighting to maintain and grow plants within the overall framework of an architecturally lighted interior scheme. This implies that the luminaires used for growing plants should be such that it seamlessly blends with the overall interior design without being conspicuous. The idea is to maintain the overall design scheme and not force lights into the design scheme solely for the purpose of growing plants. This also implies that the lighting used to grow and maintain plants in an indoor environment should not have inappropriate colour spectrums or over-lit illumination levels that do not match the overall design scheme of the space. Therefore the aim is to blend the luminaires as well as the lighting effect used for growing plants with the overall architecture and interior design of a given interior space.

1.2. Background

The benefits of using plants in indoor spaces are many and have been known to human race for a very long time. People directly relate plants to nature and well-being. Indoor plants play an important role in interior design. They bring in a living element that is portable, growing, and ever changing, for a fraction of the cost of a new wall or architectural element. They provide function and form while looking beautiful. They can change the ambiance and feel of a space. They add colour to complement any decor. They enhance the design without interfering with other important design elements. Indoor plants enhance the atmosphere and image of public and private spaces. From building lobbies to individual offices, to homes, they bring forth the freshness of outdoors, boosting morale and productivity of employees and visitors alike in a commercial or any other type of building.

1.2.1. Interior + Landscaping = Interiorscaping

Interiorscaping is the practice of designing, arranging and caring for living plants in typically enclosed environments. Interiorscaping is an appropriate term because indoor environments contain plains, angles and horizons that are softened, accentuated or altered by the addition of plants thereby landscaping the interiors. Similar to outdoor landscapes, interiorscaping provides spaces with colour, sculptural elements, focal points and an overall pleasant environment. Interiorscaping is enhancing the indoor environment by making it aesthetically pleasing and perceptually stimulating. Plants not only provide natural health benefits but also play an important role in projecting certain quality for the building or a space.

1.2.2. Design Benefits

PLANTS AS FOCAL POINTS - An indoor plant can act as a focal point, drawing people through the space and towards a specific destination. This can be done in several ways. Large specimen plants can be used alone to draw attention due to their size. Specimen plants are usually 12 to 14 feet tall or more. Plants with unusual forms act as living sculptures and are often used as a focal point. For example, plants with interesting twists and bends in its trunks can be pruned into topiary shapes. Plants with bright colours can be used as focal points, either alone or in masses. A bed of brightly coloured plants draws attention during the holiday season. Vibrantly coloured plants with their yellow, red, and orange foliage are natural focal points, while neon-green and lime-green plants attract the eye from a distance and stand out against solid-green foliage plants. Plants can help to direct the flow of foot traffic in a space and can be used to establish a walkway. Plants also affect how fast people will move along that walkway. When several different kinds of plants in a variety of shapes and sizes line a walkway, people tend to walk more slowly. There's plenty for them to see and they are drawn to look at each plant along the way. If the walkway is curved instead of straight, they'll slow down even more. If identical plants are used in a straight row, people are apt to walk quickly. There's not much to see or capture their attention after the first plant or two. This can be helpful in areas where the designer wants people to move through quickly, such as the waiting line in a movie theatre or in a busy lobby.

A row of identical aglaonemas lines a busy hallway, encouraging people to move quickly so the area doesn't become congested. Image courtesy: Phillips Interior Plants & Displays

PLANTS CAN FRAME OR SCREEN A VIEW - A plant can act as a picture frame, drawing attention to an object or destination. The usual way to frame such a focal point is by using a symmetrical arrangement of plants on both sides. For example, two identical palms, one on either side, of the directory in an office-building lobby will frame the directory and attract the attention of visitors. Similarly, plants can be used to frame a plaque, a doorway, an elevator, a staircase, an entrance, or even a significant piece of artwork, drawing attention and directing foot traffic to the area. A pair of plants can frame a spectacular view from a window or doorway, drawing people's attention outside the indoor space and visually into the outdoor space. Plants can also block a view that is less than desirable. In an atrium garden, they can hide the mechanics of a fountain, while in a restaurant, they can conceal the water station, or screen off a private dining room from the main dining floor. Plants can be used as drapes to shroud an ugly outdoor view without substantially decreasing the amount of daylight, maintaining the ambiance and feeling of spaciousness while obscuring the view of that ugly parking garage roof.

Snake plants mark the entryway to each cubicle, while adding color and interest to a gray interior.
Image courtesy: Heroman Services Plant Company

PLANTS CREATE VISUAL DEPTH AND DELINEATE SPACES - Large spaces, such as building lobbies and shopping malls, can seem intimidating and uninviting. People can feel exposed in big, empty spaces, especially in unfamiliar surroundings. Introducing plants can interrupt that space, creating visual depth and breaking the space into smaller, cosier, more appealing areas. Plants can act as room dividers, creating smaller, more intimate spaces within a building lobby where people can meet and review their notes prior to attending a business meeting. Plants can also be used as portable walls, creating collaboration spaces in an open-concept office without walls. Most plants in individual pots can be moved as the needs of the tenants and visitors change, something most walls cannot do.

PLANTS VISUALLY LOWER CEILINGS - Tall ceilings can also be daunting and make a visitor feel small and vulnerable. Introducing tall plants with a canopy of foliage into such a setting creates a "false ceiling" by visually lowering the space overhead. Tall, well-spaced ficus trees can turn a large lobby or shopping mall into an inviting indoor garden space. For example, introducing a 15-foot-tall tree in a space with 50-foot ceilings can visually bring the ceiling down to a more manageable 12- to 15-foot height. The heavier the canopy of foliage, the greater the reduction in perceived overhead space.

Tall palm trees and shorter tree ferns effectively bring the visual ceiling of this space down to a more comfortable level in two stages. Image courtesy: Kathy Fediw

PLANTS CHANGE THE ACOUSTICS AND MUFFLE SOUND **-** Plants help to reduce the amount of noise without altering the overall design of the space in several ways. The next time you're in a noisy restaurant, look around the space. You'll see a lot of hard surfaces—walls, floors, windows, and furniture—without much cloth or padding to muffle the sound. Any noises reverberate and bounce back and forth, reaching into the corners. People talk louder in order to be heard, and the sound levels rise even more. Research has shown that indoor plants are effective in absorbing sound at higher frequencies (which are more annoying than lower-frequency sounds), especially in rooms with a lot of hard surfaces and very little upholstery or cloth. In addition, the bark mulch on the soil surface was also found to absorb sound. Plants with many small leaves, such as ficus trees, tend to scatter sounds as opposed to absorbing sounds, making the interior space less noisy and more inviting.

PLANTS ADD COLOR AND INTEREST **-** Plants can add splashes and dashes of colour to an otherwise monotone setting. We think of plants, as being green, yet there are many shades of green. Leaves can vary from deep green to olive green, blue-green, silver-green, or neon-lime green, to name a few possibilities. Leaves can be variegated white, silver, yellow, red, purple, or orange, or even have markings in multiple colours. Vibrant-coloured plants stand out while darker shades of green or deep maroon recede, adding depth and acting as a background in plant groupings. Juxtaposing plants of different shades adds more allure and visual appeal in masses of plants.

The vivid colours of the plants stand out along the edges of the planting, while the darker foliage in the back recedes, creating depth. Image courtesy: Mimosa Interior Landscape

1.2.3. Human & Environmental Benefits

PLANTS REDUCE STRESS, INCREASE WELL-BEING AND PRODUCTIVITY **-** Plants affect our overall sense of well-being. They help to provide feelings of pleasure, calm, and relief from "attention fatigue" and create a restorative environment (Shibata and Suzuki 2002). Designers take advantage of this benefit by using plants in break rooms and restaurants in office buildings and hospitals. Visual contact with nature reduces the fatigue associated with intense concentration. Plants can help to replenish the attention system so people can refocus quickly after short "nature" breaks (R. Kaplan and S. Kaplan 1990, S. Kaplan 1995). In another study, college students under stress from an exam felt more positive and had less fear and anger when they had a view of plants (Ulrich 1979). Plants can also improve our productivity, an important benefit in the workplace. One study showed that people working in a room with plants completed a series of computerized tasks 12 per cent faster than those working in the same room without plants (Lohr et al. 1996).

Placing plants inside actual workspaces providing a relaxed environment. Image courtesy: Ambius

PLANTS CLEAN THE AIR AND CONTRIBUTE TO A HEALTHY ENVIRONMENT **-** Plants provide a wealth of health and well-being benefits to those who work, live, and visit the indoor built environment. Over the years, scientists and researchers have proven what we've known all along—plants make us feel better. Plants remove harmful volatile organic compounds (VOCs) such as formaldehyde and benzene from the air, converting VOCs into harmless compounds that plants then use for food. Bill Wolverton, former research scientist at the U.S. National Aeronautics and Space Administration (NASA), was among the first to study this process. Researchers have found that the potted-plant microcosm (the plant, its root system, soil microbes, and soil medium) is able to reduce by at least 70 percent all high-concentration, air-borne VOCs within 24 hours, sometimes completely eliminating these VOCs (Wood et al. 2006).

Plants have also been shown to reduce levels of carbon monoxide from indoor air by 90 per cent (Tarran et al. 2007). Even at minute concentrations, carbon monoxide can affect attention, focus, and overall health, and can be fatal when in larger concentrations. Besides eliminating harmful VOCs from the air, plants benefit our health and well being in many other ways. When plants are in an office space, the occupants experience 40 per cent fewer coughs, 30 per cent fewer sore throats and dryness in the throat, 30 per cent fewer headaches, a 25-percent reduction in dry skin irritations, and a 20-percent reduction in fatigue (Fjeld et al. 1998). In similar research studies, sick leave absences were reduced by an incredible 60 per cent in offices with plants (Fjeld 2002). Other research studies have shown that when people are working in a windowless room with plants, they have lower blood pressure and feel more attentive than those working in the same room without plants (Lohr et al. 1996). Potted plants stabilize humidity and temperature, creating a more comfortable and healthy environment (Costa and James 1999). In fact, plants stabilize the humidity levels indoor to between 30 and 60 per cent, the comfort level for people (Lohr and Pearson-Mims 2000). Without plants the humidity levels in many buildings would be an arid 20 per cent. Lohr and Pearson-Mims also proved that potted plants reduce dust levels.

A planter of cast-iron plants adds just the right amount of modernism to a contemporary lobby. Image courtesy: Interior Plantscapes

1.2.4. Economic Benefits

PLANTS IMPROVE ECONOMIC AND PERCEIVED VALUE **-** Research has shown that when plants are present in a shopping area, people perceive that the value of the merchandise being sold is greater, compared to the same merchandise in an area without plants. In one study, consumers were willing to spend a conservative 12 per cent more for products in an environment with trees (Wolf 2002). People also tend to linger longer and buy more merchandise in shopping areas where plants are present. Many shopping malls and boutique shops take advantage of this effect to increase sales. Plants add a sense of luxury and prestige to a space. People subconsciously associate tropical plants with success, and feel more confident while working and dealing with companies that have plants in their built environment. Ferns, palms, and flowering plants are especially effective in creating a luxurious ambiance. These plants are often used in the finest hotels, restaurants, and high-end luxury homes. Most successful corporate headquarters and prestigious office buildings have indoor plants. Having and maintaining plants in a space or building generally increases the overall perception of the upkeep of the space or building thereby enhancing the overall value of the building in terms of valuation.

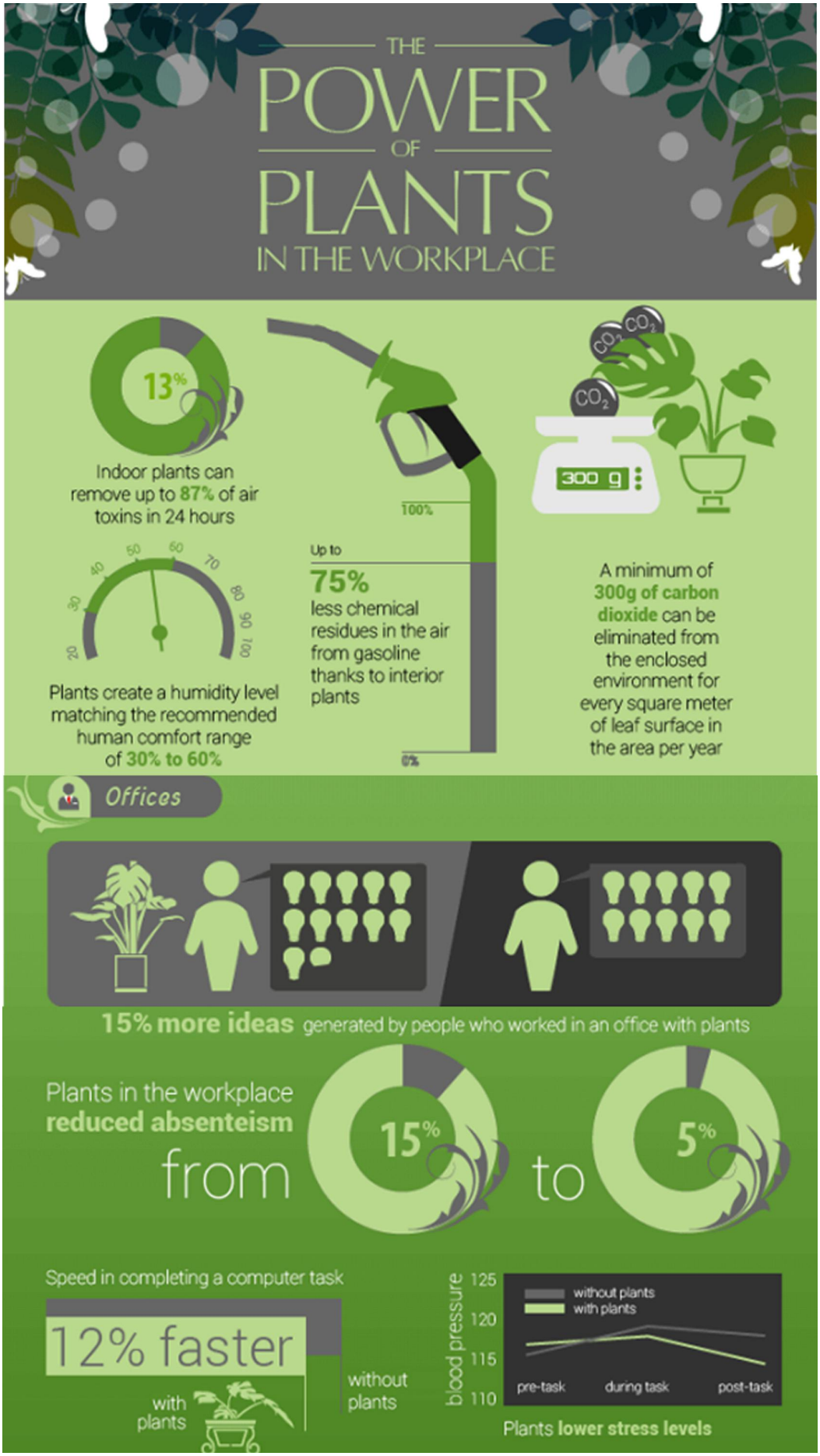
Having plants and trees in corporate lobbies directly reflects on the company's image in the industry. Image courtesy: NY Times Building

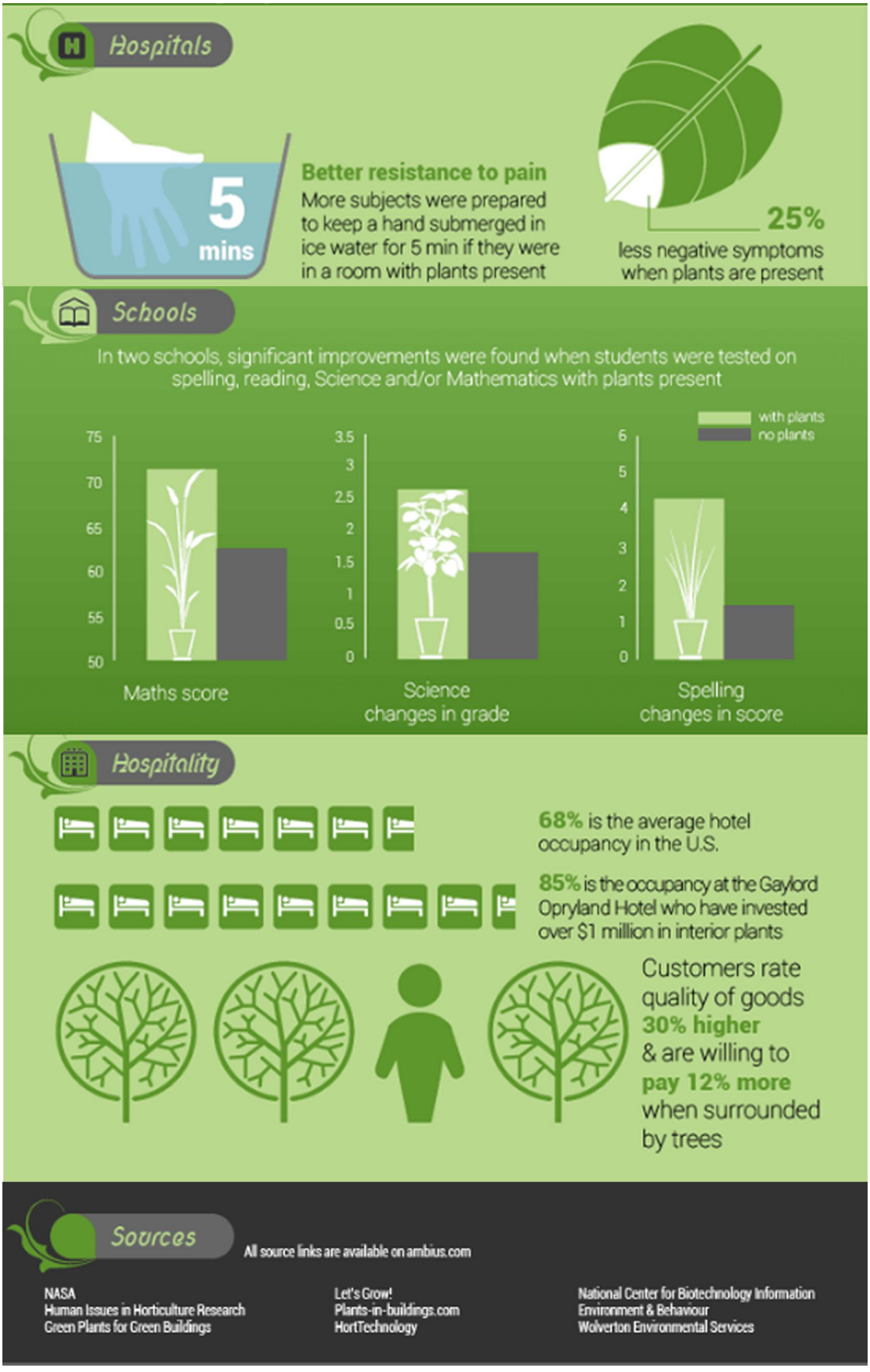
LEED CERTIFICATION FOR BUILDINGS **-** Interiorscapes have an integral role in green building design. University research has proven that plants improve indoor air quality, increase worker productivity, boost morale and provide a sense of tranquility. Plants can contribute to a buildings ranking from US Green Building Council's Leadership in Energy and Environmental Design (LEED) certification. Depending on level of certification, LEED buildings tend to use less energy, less water, have more natural light, are built from environmentally friendly materials and are more comfortable to work in. Plants and interior landscapes can contribute to LEED certification points in the following categories:

Innovation in design
Indoor air-quality
Indoor chemical and pollutant source control
Water efficiency

Mega-structures designed by globally renowned architects involve plants and trees as part of their green design. Image: Vincent Callebaut The Gate Megatree

PLANTS REDUCE ENERGY COSTS **-** Plants release moisture into the air through the process of transpiration, which is when moisture evaporates from the leaves. This can both cool and warm a room, ironically enough. According to the University of Vermont Extension, when plants release moisture into the air in a warm room, it can reduce the temperature by as much as 10 degrees. On the other hand, according to a US News article titled "10 Ways to Save on Energy Costs This Winter," a cool but humid room feels warmer because the moist air holds heat better. So in the winter, set your thermostat a bit lower and use plants to get the air nice and humid.


THE
POWER
OF
PLANTS
IN THE WORKPLACE
13%
Indoor plants can remove up to 87% of air toxins in 24 hours
100%
Up to
75%
less chemical residues in the air from gasoline thanks to interior plants
0%
CO_2
CO_2
CO_2
300 g
A minimum of 300g of carbon dioxide can be eliminated from the enclosed environment for every square meter of leaf surface in the area per year
20
30
40
50
60
70
80
90
100
Plants create a humidity level matching the recommended human comfort range of 30% to 60%
Offices
15% more ideas generated by people who worked in an office with plants
Plants in the workplace reduced absenteism
from
15%
to
5%
Speed in completing a computer task
12% faster
with plants
without plants
blood pressure
125
120
115
110
without plants
with plants
pre-task
during task
post-task
Plants lower stress levels


Hospitals
5 mins
Better resistance to pain
More subjects were prepared to keep a hand submerged in ice water for 5 min if they were in a room with plants present
25%
less negative symptoms when plants are present
Schools
In two schools, significant improvements were found when students were tested on spelling, reading, Science and/or Mathematics with plants present
with plants
no plants
75
70
65
60
55
50
Maths score
3.5
3
2.5
2
1.5
1
0.5
0
Science changes in grade
6
5
4
3
2
1
0
Spelling changes in score
Hospitality
68% is the average hotel occupancy in the U.S.
85% is the occupancy at the Gaylord Opryland Hotel who have invested over $1 million in interior plants
Customers rate quality of goods 30% higher & are willing to pay 12% more when surrounded by trees
Sources
All source links are available on ambius.com
NASA
Human Issues in Horticulture Research
Green Plants for Green Buildings
Let's Grow!
Plants-in-buildings.com
HortTechnology
National Center for Biotechnology Information
Environment & Behaviour
Wolverton Environmental Services

1.3. Methodology

The core intent of this thesis is divided into multiple steps in order to try and bridge the subjects of lighting design, architecture, landscaping and horticulture.
The thought process started during a keynote lecture by renowned landscape architect Kathryn Gustafson at PLDC 2017, which highlighted the restrictions faced while designing interior landscape inaccessible to daylight. It was further highlighted in the same lecture that even lighting designers are unable to provide any concrete solutions.

The first step was to understand the nuances of plants, their varieties, needs, etc. from literature reviews of available documentation on plants from various sources such as books, magazines, journals, websites etc. Several landscape architects and horticulturists were also approached to obtain necessary data and details.

The second step was to understand the necessary conditions required to set up a live experimental setup of plants for testing. This included visits to various plant nurseries to understand the natural conditions required for plant cultivation, which can then be duplicated under experimental conditions. Several plant maintenance agencies that are in charge of the actual installation and maintenance of plants in interior spaces such as commercial buildings, airports, etc. were also approached to understand the practical implications of installing these plants. There was a large difference of opinions between the nurseries and horticulturists, and the plant maintenance agencies about installation and maintenance of plants in interior spaces. On the one hand the nurseries and horticulturists were keen to place lights either in natural daylight or at least close to daylight access. It was difficult for them to believe that these plants could grow without any natural light. On the other hand the maintenance agencies that I spoke to were more convinced that this could work. This was more the case with maintenance workers who managed the Mumbai airport gardens where a lot of these plants are installed in areas completely inaccessible to natural daylight. Their major observation was there has to be a regular upkeep of these plants when they are installed indoors so that they can grow as against natural conditions where plants could grow even without any maintenance or upkeep.

After collection of the necessary information, the third step was to actually design an experimental installation of plants in a space inaccessible to daylight. Apart from designing a plant installation illuminated purely with electric lighting it was also important to ensure that the lighting is aesthetically pleasing and acceptable to people as well as the design of the space. Thus it was decided to have two separate installations for a comprehensive analysis. Installation-1 was designed using potted plants inside an office within the premises of commercial building. Installation-2 was designed as a vertical wall inside a corridor of a residential building. Both experimental installations were inaccessible to any form of daylight. Both installations were monitored on a daily basis so as to observe the changes and document the findings for final analysis and results. The duration allocated for both the installations was two months of growth and maintenance.

As the involvement of human subjects was key to support the aim of this research thesis, the fourth step was a survey. This is done using a survey questionnaire method where people living or working in both these spaces were asked specific questions with respect to plants and their reaction to their effects. Two surveys were conducted; first prior to the experimental setup, and second post completion of the two months with their views was documented in order to get a final analysis. The human subjects involved were people of different age groups, backgrounds, residents, occupants and frequent visitors in order to arrive at comprehensive data analysis. The data was gathered using both qualitative and quantitative methods for a statistical analysis at the end of the experiment.

The fifth and final step was to analyse the results of the findings and arrive at a conclusion in order to find a common solution to the problem stated as the core of this research thesis. This was done by way of analysing the observations and survey data collected about these grow lighting installation and human responses towards these installations.

1.4. Scope and Limitations

The scope of this research thesis is limited only to the maintenance of plants in interior spaces under electric lighting. This thesis does not concern itself with the growth aspect of the plants in terms of their quality of produce and nutritional value. The thesis purely maintains these plants as part of a day-to-day activity and observes their growth under electric lighting.

This research thesis also has its own set of limitations. First is the time and resource constraint as the study was conducted within a span of eight months with very limited knowledge about plant science. Second important limitation to be considered is the conditions of installations. The conditions created for the experiment were semi-ideal conditions, but in reality there could be many external factors that can affect the installation and its performance, which have to be taken into consideration. Other minor limitations include that of space restrictions and the availability of different variety of plants to make a comprehensive installation. As this research thesis aims to successfully install plants in large spaces the idea is to emulate such installations in smaller space with the assumption that it will work just as well in larger spaces if the appropriate lighting conditions are maintained. As there is a great list of indoor plants commonly used by landscape architects for interior installations, this research thesis has tried to include as many varieties as possible but still does not include all of them. Also the quantity of each plant species is limited whereas in an actual large installation their numbers would be much more.

Chapter – 2: Interior Landscapes and Electric Lighting

2.1. Interior Landscape Typologies

Over the years, research has demonstrated the many benefits of interior plants. Hundreds of scientific papers have been published showing how plants can make a major contribution to the health and well being of people, reduce energy costs and increase productivity and profitability. This brings us to the next topic for discussion on the typologies involved in interiorscaping along with elements that are inspired from nature extending to the design. Architects and interior designers incorporate plants in indoor spaces in various ways such as stand-alone small pots on tables or very tall forest-like trees in larger spaces. But as lighting designers, we need to understand the basic typologies commonly used in interiorscaping in order to be able to provide a lighting solution for these plants. Listed below are both the typologies of plants.

2.1.1. Stand alone planter pots

This is the primary and most commonly used type of plant installation and probably the most difficult to tackle with regards to lighting design. These range from small- to medium-size plants and are mounted in various spaces like reception or worktables, passages and corridors, meeting rooms, etc. These could also extend to hanging pots for decorative purposes. Grouped in strategic places, they break the monotony of a space and create an ambient scene. Since these are generally placed ad hoc as an independent unit it becomes very difficult to design lighting around them in order to achieve the desired lux level or color temperature required for these plants, which is discussed in chapters below. Another challenge with regards to providing lights for these planter pots is that they are flexible and can be moved from one place to another. In such cases when you design lights for a particular area keeping in mind these plants, if the plants are moved then it will not serve the purpose.

Independent pots at reception. Image courtesy: www.ambius.com

2.1.2. Vertical garden or green walls

Another common and most popular type of installation is vertical gardens also known as green walls. This is a typical installation where an entire wall in length and height is dressed with plants and greens. Living green walls are panels of plants, grown vertically using hydroponics, on structures that can be either free standing or attached to walls. This is most commonly used in airports, malls, office spaces, lobby walls and even restaurants. With regards to lighting design they are the easiest in terms of designing lighting for their plants. This is primarily because it's a fixed installation and lighting is generally used to highlight this wall as a decor, which in turn also serves as a source of growth for the living plants. Most urban spaces are restricted with horizontal space due to the cost of real estate. Vertical gardens are most suited for such applications since they hardly consume any horizontal space.

Indoor vertical wall in a restaurant. Image courtesy: www.inhabitat.com

2.1.3. Mini forests - cluster of plants and tall trees

This is another classification of interiorscaping typology which is essentially used for larger spaces usually as a central point of attraction, typically found in large hotel or corporate building lobby, atriums, airport terminals and other such large public spaces. These are a combination of small and large plants sometimes even clubbed with a large area of shrubs around it. You can commonly find this in public resting spaces where a mini forest of green is created as a closed area surrounded by seating arrangement. Over the years having a large area dedicated to such an installation has seemingly become common including major airports around the world. Lighting plays a very important role for such type of an installation where it has to be ensured that these plants and trees are maintained and alive. Designing for such an installation requires adequate planning and placement for lights so as to ensure the desired function is achieved.

Lobby at Chamber of Commerce, Ljubljana, Solvenia by Sadar+Vuga. Image courtesy : www.home-designing.com

2.2 Plant Species

Whilst the list of plant species that can be used indoors is huge and requires great deal of horticulture knowledge, we have tried to list down the most commonly known plant species that are regularly used in indoor installations. As our core focus subject is lighting design for plants and not plants we have restricted the list to a small number with the assumption that the experimented rules would apply to other plants as well in general. The following list along with their scientific names has been obtained and derived from nurseries that sell these plants for interiorscaping along with horticulturists and landscape designers. The need for putting down such a list is to provide lighting designers with an overview of plant species. The following is a list of most commonly used indoor plants.

<table>
<tr><th colspan="2">Scindapsus (money plant / devils ivy)</th></tr>
<tr><td>  </td><td>  </td></tr>
<tr><th colspan="2">Aglaonema (chinese evergreen)</th></tr>
<tr><td>  </td><td>  </td></tr>
<tr><th colspan="2">Sansevieria (snake plant)</th></tr>
<tr><td>  </td><td> 
</td></tr>
</table>

Dracena	
	
Zamioculcus	
	
Syngonium	
	
Spathiphyllum	
	

Calathea

Bird Nest

Rhapis Palm

Areca Palm

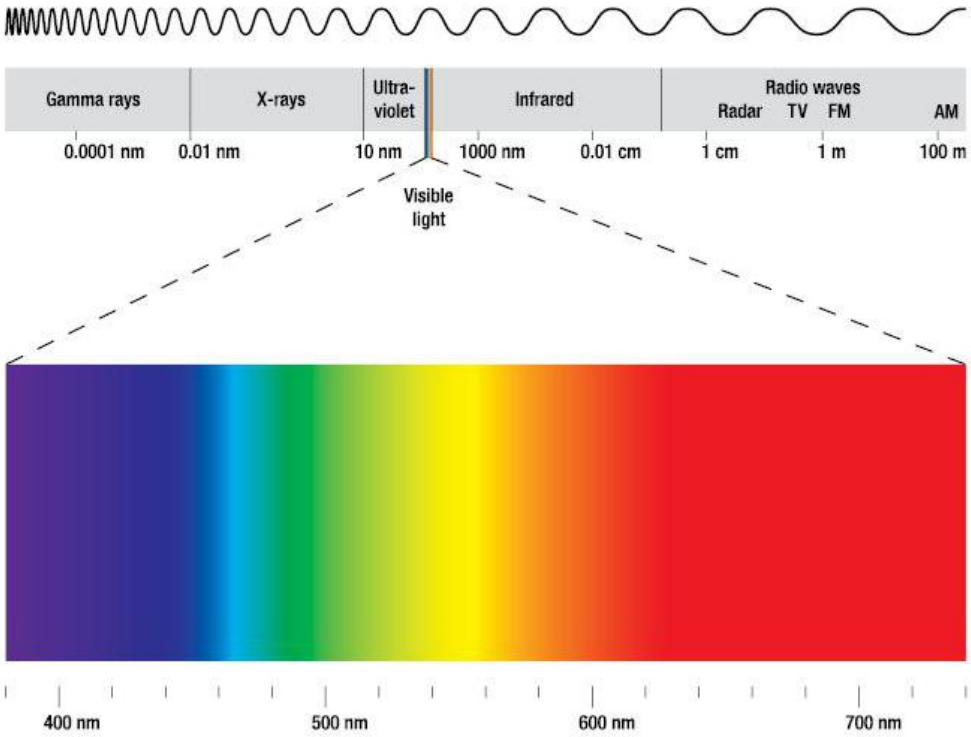
Ficus-Varieties

Fan Palm

2.3. Growing Plants with Electric Lighting

Although this research is restricted to understanding and testing whether plants can grow in artificial lighting using normal spectrums for architectural purposes, it is still extremely important to broadly understand the overall science of growing plants using electric lighting. Growing plants using electric lighting and its research is more than a century old phenomenon, this is commonly known as grow lights or horticulture lighting. This is primarily because growing plants under artificial lights is extremely important for mankind since it helps simulate natural outdoor conditions to grow vegetables in climates where this is not naturally possible. Also studies look at lights to grow vegetables and plants as a medium to solve the global food problem. More companies are involved in research that extend beyond growing vegetables, they are now working towards possibilities of increasing the produce or even increasing the quality of produce using electric lighting.

A grow light or horticulture light is an artificial light source, generally an electric light, designed to stimulate plant growth by emitting a light appropriate for photosynthesis. Grow lights are used in applications where there is either no naturally occurring light, or where supplemental light is required. For example, in the winter months when the available hours of daylight may be insufficient for the desired plant growth, lights are used to extend the time the plants receive light. Grow lights either attempt to provide a light spectrum similar to that of the sun, or to provide a spectrum that is more tailored to the needs of the plants being cultivated. Outdoor conditions are mimicked with varying colour, temperatures and spectral outputs from the grow light, as well as varying the lumen output of the lamps. Depending on the type of plant being cultivated, the stage of cultivation (e.g. the germination/vegetative phase or the flowering/fruiting phase), and the photoperiod required by the plants, specific ranges of spectrum, luminous efficacy and colour temperature are desirable for use with specific plants and time periods. Ever since NASA began experimenting with LEDs for growing plants in the 1980s it is known that different light spectrums have widely varied effects on plants. Some spectrums stimulate vegetative growth and others increase the yield in flowers and fruits. Other spectrums seem to have very little effect in plant growth. Thanks to the variable light spectrum available from LEDs it is easier to understand the relationship between light spectrum and plant growth.

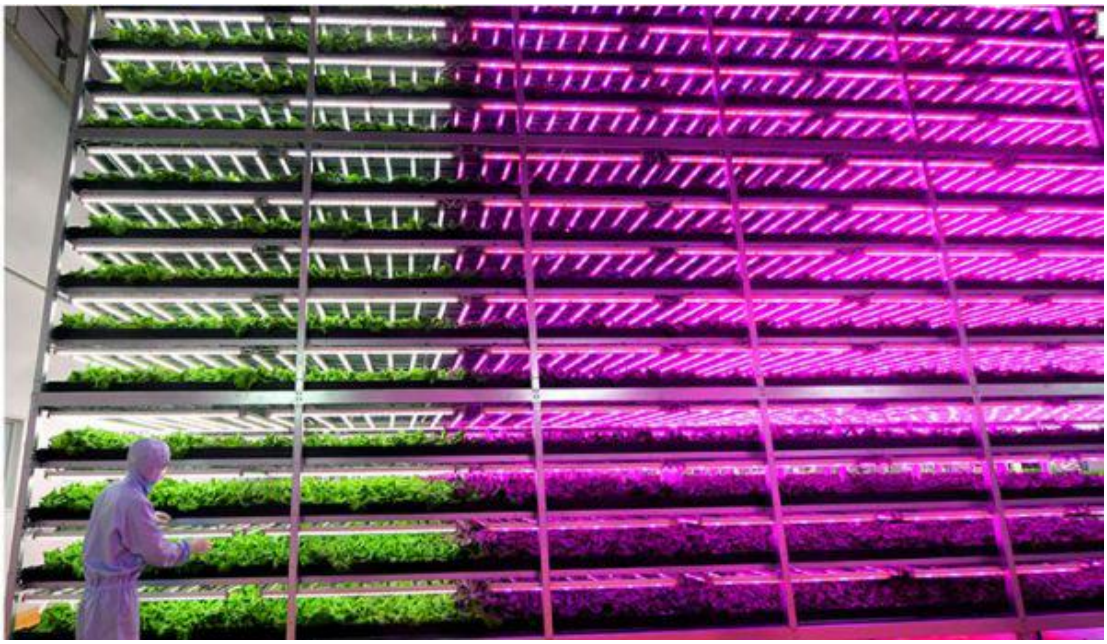


Light spectrum. Image courtesy: www.garderens.com

As seen in below pictures plants and vegetables need different spectrums for their growth and even different spectrums at various stages of growth. This is an area of science, which is being extensively researched by both governments and companies alike worldwide. Depending on the crop being harvested a particular spectrum of lights are used and these are even controlled to change during growth phases.

Red and Blue LEDs being used together for plant growth. Image courtesy: www.uponics.com

White spectrum used for plant growth. Image courtesy: www.inhabitat.com

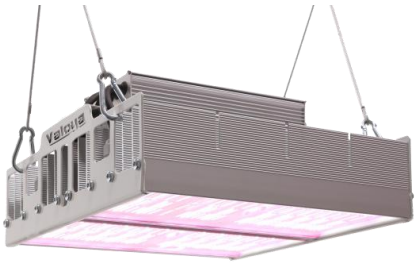


Multiple spectrums being used in the same indoor farm. Image courtesy: www.ge.com

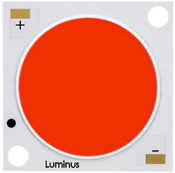
2.4. Companies and products available

With advent of LED and increase in awareness of growing plants with artificial lights more and more manufacturers have started producing light fixtures specifically for the horticulture industry. This has resulted in increased ease of availability and access to such products without having to customise or arrange them. These products are developed in close co-ordination with horticulturists in order to achieve the desired spectrum, intensity and other such technical factors that matter for plant growth.

Right from large lighting manufacturers like Philips, Osram, etc. there are many medium- to small-scale manufacturers focusing specifically on grow lights based mostly in Europe and USA. These include Valoya from Finland, Platinum LED from USA, OpticLED from Canada, Mars Hydro from China to name a few.
The products offered by these manufacturers cover a wide range of offerings. Right from standard and simple home grow light kits to very complex automated control connected light fixtures are made available. These come in form of floodlights, high bays and linear profile mounted light fixtures. Most of these fixtures come with a combination of red, blue and white LED's since they promote plant growth.



Even LED chip manufacturers have started producing LED chips and arrays specifically for horticulture lighting. Leading companies like Cree, Luminus, etc have wide range of LED's listed on their website and part of their standard portfolio.



Purple COB package from Luminus. Image courtesy : www.luminus.com

Chapter – 3: Designing for Human and Plant Requirements

3.1. Design Process

The crux of this thesis is to be able to design for human and plants at the same time and ensure the design is suitable for both. The design process is critical, as the design has to serve dual purpose of catering to the architectural needs of the project or space and also serve the biological needs of plants installed in the project or space. The starting point of the design process is to clearly prioritize the design requirements. In this case, human requirements would precede the plant requirements because the whole concept of introducing plants in interior spaces is to satisfy or enhance human needs and experience.

3.2. Human Design Requirements

As lighting plays a key role in in built environments, the very concept of lighting design starts and ends with people. The primary design factors include human factors, architectural factors and economic factors.

Human factors include those of ergonomics in terms of visibility to enable perception of the space, accessibility to enable identification of activities and tasks, visual amenity to give pleasure to the occupants, contrast and glare control to carefully avert visual fatigue and safety to carefully avert accidents. Human factors also include those of health to enable hormonal regulation that impact sleep and activity, as well as psycho-physiology to simulate the senses and impact moods. Architectural factors include those of form to accurately define the volume and geometry of a space, location to enable people's ability to identify important elements and character of a space. Architectural factors also include those of colour in terms of hue, saturation and value as well as visual motion in terms of rhythm and tempo of luminaires in a space within the field of vision to easily comprehend patterns and dynamics. Economic factors primarily include investment costs in terms of equipment and installation, as well as maintenance and electricity costs.

3.3. Collaborating lighting design for humans and plants

The intent is to arrive at a collaborative lighting design that considers human, architectural, economic factors along with plant factors. While there has to be certain minimum amount of lighting and controls required to facilitate plant growth or maintenance, the idea is to seamlessly integrate it with the overall architectural lighting design scheme without making the lighting for plants conspicuous. This process needs to be incorporated at the time of creating the basic lighting design decisions. For example, one of the most important design decisions with regards to lighting is to consider and plan for daylight. However, in areas where daylight is not possible it becomes important to consider task lighting – which is higher than other general lighting – for both human and plant requirements. Uniform illumination over large areas such as open offices applies for meeting both human and plant requirements. Accentuating vertical surfaces such as entire green walls highlighted with wall-washer work well both architecturally in terms of providing vertical illumination as well as nourishment for plants. The same principles of using automated controls in a lighting design scheme can be applied for lighting plants too as different set of plants require different lighting levels.

Office lighting that provides uniform task illumination for humans as well as plants. Image courtesy: www.inscapeindoor.com

Accentuated wash of a green wall in a restaurant that also provides visual interest for humans. Image courtesy: www.inscapeindoor.com

3.4. Design inspirations

Three case studies provided the major source of inspiration to integrate lighting for architecture and plants. These case studies are real life example of how architectural lighting can be used to grow plants as well as blend with overall interiors of the space. The following section describe these case studies in detail to help understand the role of electric lighting in plant and vegetable growth as well as the implementation of this research. These case studies incorporate lighting for humans and plants as part of the overall lighting design concept provide a compelling reason to experiment and prove that plants can be grown and maintained using only electric lighting.

3.4.1. Pasona Tokyo Headquarters

The Urban Farm at Pasona Tokyo Headquarters is a nine story high, 215,000 square foot corporate office building for a Japanese recruitment company, Pasona Group, located in downtown Tokyo. It is a major renovation project consisting of a double skinned green facade, offices, an auditorium, cafeterias, a rooftop garden and most notably, urban farming facilities integrated within the building. The green space totals over 43,000 square feet including 200 species of fruits, vegetables and rice that are harvested, prepared and served at the cafeterias within the building. It is the largest and most direct “farm-to-table” case study of its kind ever realized inside an office building in the world.

Using both hydroponic and soil based farming, crops and office workers share a common space. For example, tomato vines are suspended above conference tables, lemon and passion fruit trees are used as partitions for meeting spaces, salad leaves are grown inside seminar rooms and bean sprouts are grown under benches. The main lobby also features a rice paddy and a broccoli field. These crops are equipped with fluorescent and LED lamps and an automatic irrigation system. An intelligent climate control monitors humidity, temperature and breeze to balance human comfort during office hours and optimize crop growth during after hours. This maximizes crop yield and annual harvests. Seasonal flowers and orange trees are planted on the balconies between the double skinned facade, partially relying on natural exterior climate to showcase changing of leaves and colours to the exterior facade. All plants are maintained and harvested by Pasona employees with the help of an agricultural specialist.

Facade of the Pasona HQ in Tokyo. Image courtesy: www.konodesigns.com

Grown indoors in a closed agricultural system, the Pasona farm like others of its kind is bacteria-free and pest-free thereby not requiring any pesticides. The 100% organic crops grown in these indoor farms are fed with pesticide-free nutrient mists or a combination of carbon dioxide and fertilizer. The beauty of this development lies partly in its versatility – since it deals in climate-controlled spaces and replicable conditions, a solution of this sort can be deployed anywhere in the world to address food shortages of the present and future. Saving space, indoor vertical farms are also good candidates for local food production in crowded and high-cost urban areas around the globe.

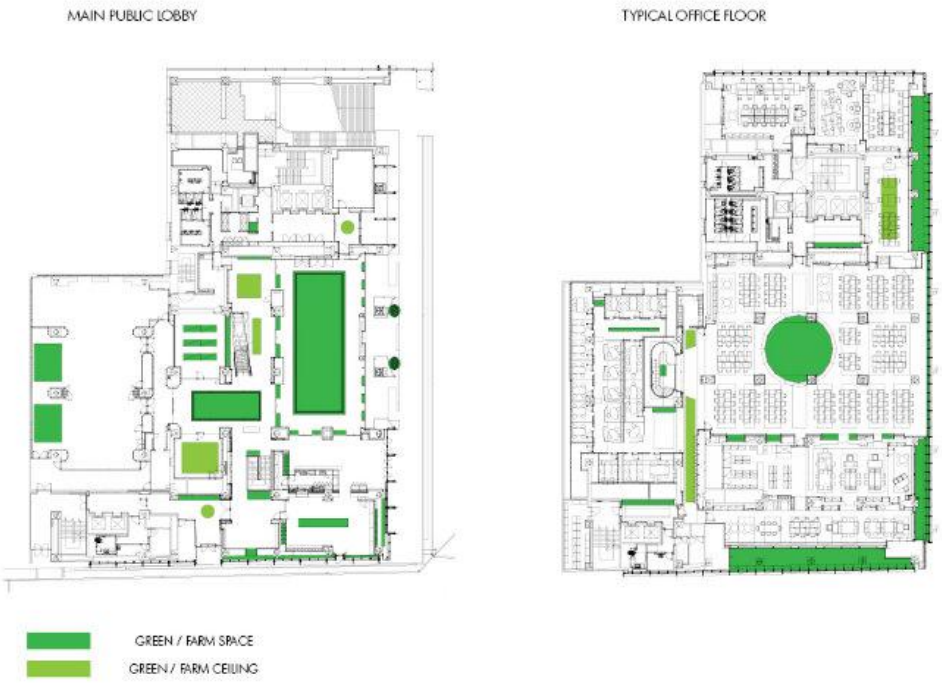
These farms produce 100 times more per square foot than traditional methods using 40% less power, 99% less water usage, and 80% less food waste than traditional agriculture. As self-sustaining urban-based food systems, they also produce fewer food miles and a lower carbon footprint. According to the Japanese Ministry of Economy, Trade, and Industry, Japan currently have about 211 computer-operated plant factories–hydroponic and aeroponic farms growing food in closed environments without the utilization of sunlight.

Rice paddy field inside the lobby of Pasona HQ. Image courtesy: www.konodesigns.com

Office partitions created with plants at the Pasona HQ. Image courtesy: www.konodesigns.com

Meeting Rooms at the Pasona HQ. Image courtesy: www.konodesigns.com

Circulation areas such as floor landings are transformed into plantations at the Pasona HQ. Image courtesy: www.konodesigns.com



Pasona HQ floor plans. Image courtesy: www.konodesigns.com

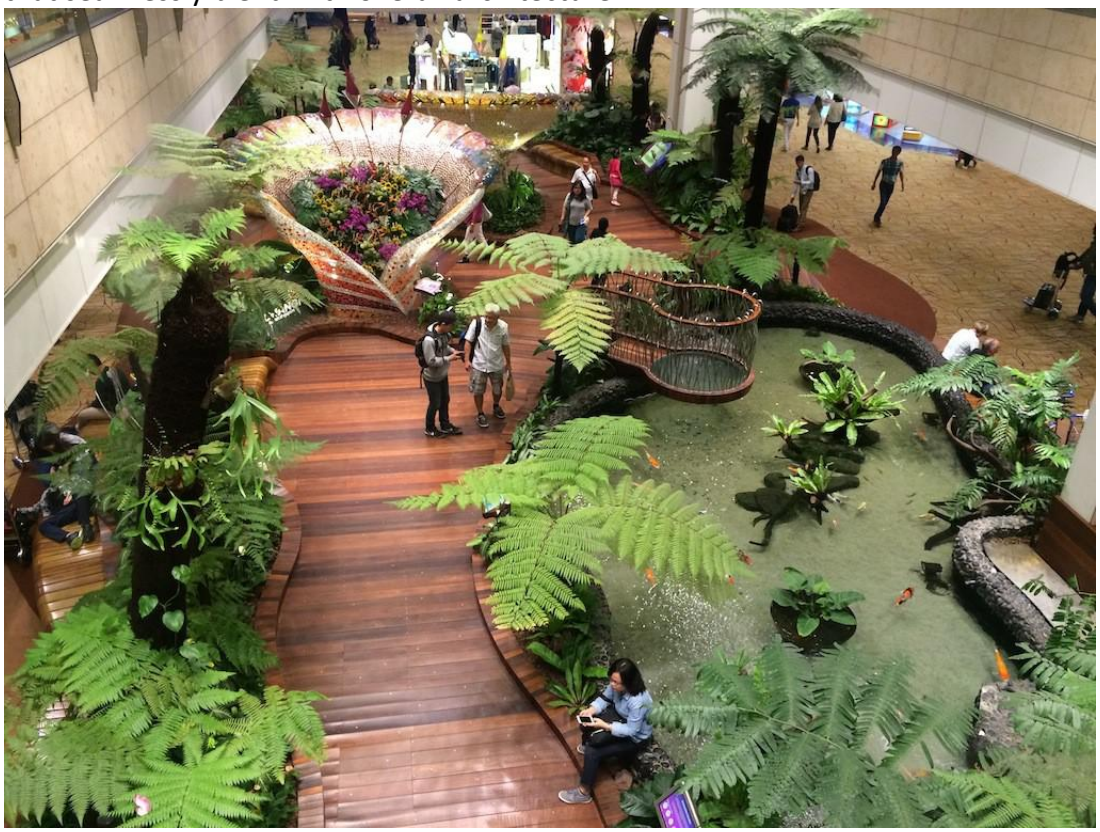
Flower gardens at the Pasona HQ. Image courtesy: www.konodesigns.com

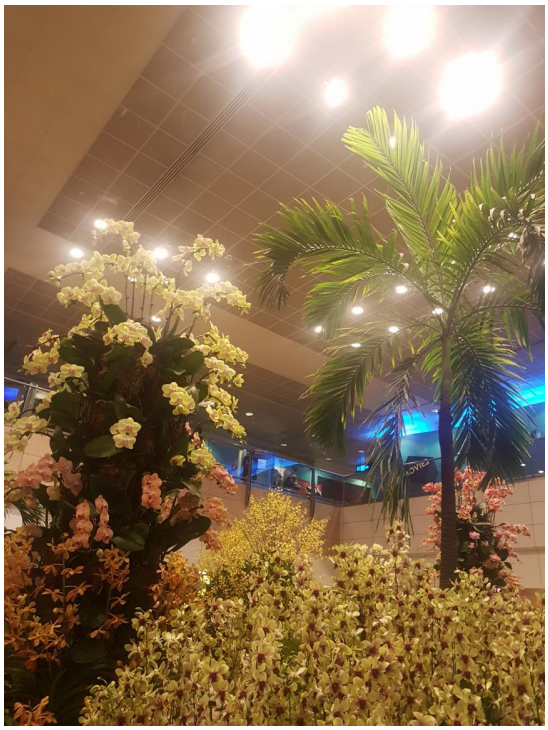
Basement service areas used for growing vegetables grown at the Pasona headquarters. Image courtesy: www.konodesigns.com

Farming under progress at the Pasona headquarters. Image courtesy : www.konodesigns.com

3.4.2. Changi Airport - Singapore

The world's best airport has a horticulture team, a butterfly garden, and 500,000 plants. Changi introduced its first garden in the early 1980s, and over the years it's become rather good at planning and maintaining them. Today it has more than 500,000 plants, and around 250 plant species. It also produces about 3,000 plants a month in its own nursery. The most striking part about this airport is the way plants and trees are used at so many places with electric lighting designed for these plants that seamlessly blend with overall architecture.

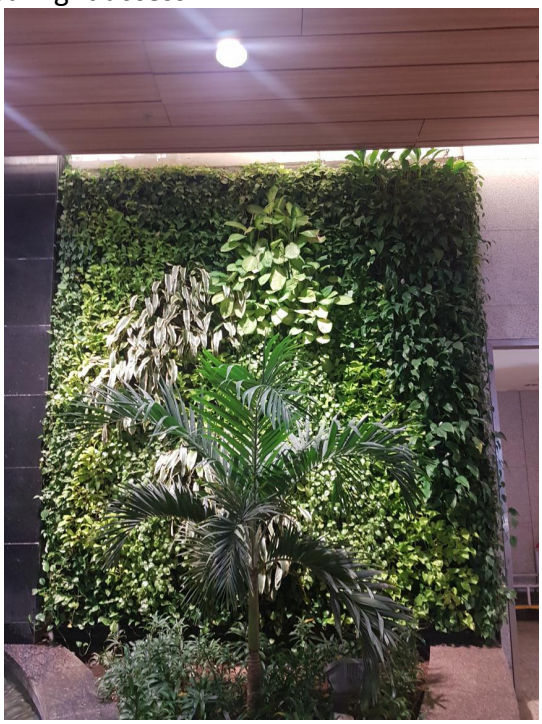


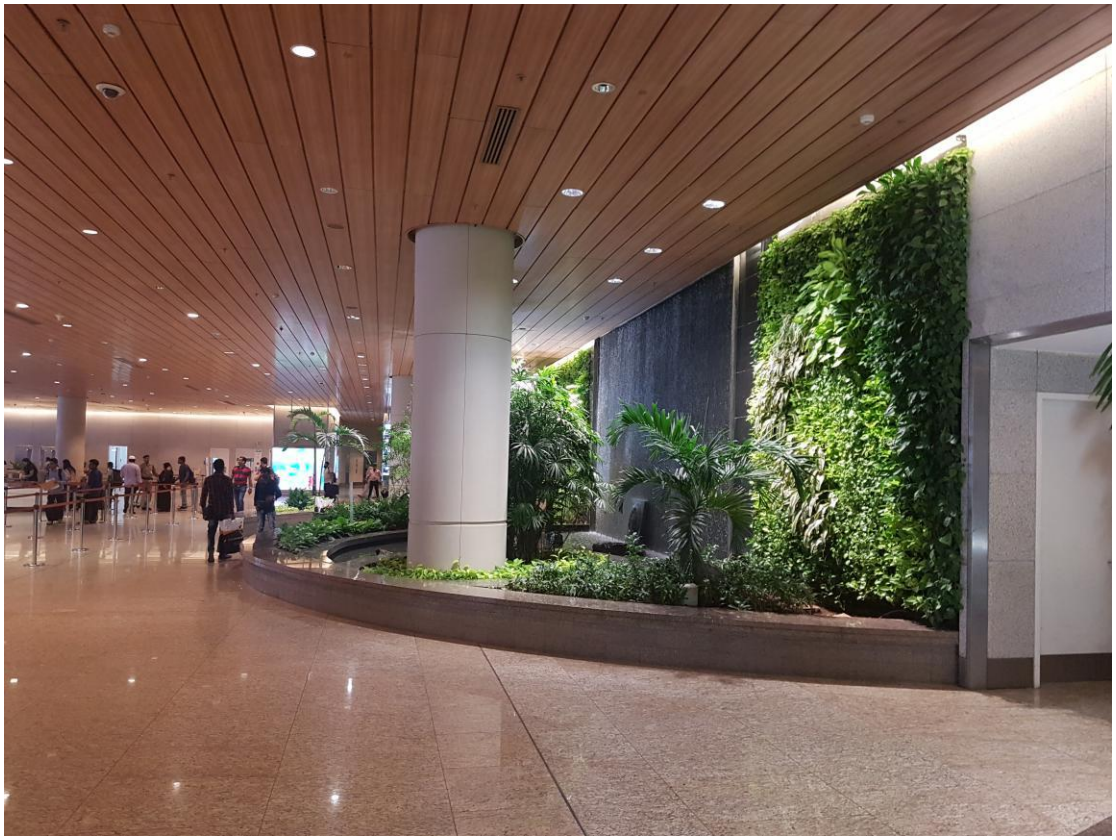


Waiting areas to boarding gates, many open spaces have indoor gardens at Changi Airport

3.4.3. Mumbai International Airport Terminal 2

The newly built Terminal 2 of Mumbai airport is another great example of indoor plant with electric lighting. The GVK Botanical Garden, spread across an area of 90000 sq m in the airport premises has around 77,000 plants and more than 100 species. It has a special team of eight people managing and take care of these gardens on a full time basis. Right from flight gates to baggage collection areas you can find plants and trees everywhere around you in spaces where there is no sunlight access.





Security check areas to baggage belt areas have green gardens at Mumbai Airport

Chapter – 4: Evaluating Designs for Human and Plant Requirements

4.1. Experimental Design

The final phase of this thesis is to experiment and evaluate the practicality of designing lighting installations conducive for both humans and plants. While the design process was critical, it is now imperative to obtain experimental evidence through experimental procedures to support the hypothesis that electric lighting can indeed be designed for both humans and plants in spaces inaccessible to daylight. This can only be tested in a real life situation with actual installation of plants within existing human environments that are inaccessible to daylight. Consequently, the lighting characteristics in terms of intensity, spectrum and duration should be based on the standard usage of the space assuming there are no plants. While the need for special lighting for plants is acknowledged, the idea is to keep the overall illumination as per general design standards. User behaviour towards the installation of plants and the lighting also needs to observed and documented before and after the experimental installations by means of survey questionnaires.

4.1.1. Experimental Design Execution – Site selection

The criteria for selecting the site for the experiments was to ensure their usage by different human subjects in order to study their behaviour towards the installation. Two different locations with two completely different user profiles were selected for conducting two experiments so as to arrive at more comprehensive results. The interior landscape typologies selected for both these experiments were based on the dimensions and usage of the space. The selection and maintenance patterns of plants for these experiments were based on an extensive consultation and discussion with horticulturists and nursery owners. The effort was to try and include a variety of indoor plant for more conclusive results.

However, the sources of plants used in both the experiments were different. In one experiment, the installation was self-designed and executed by procuring plants from different nurseries and luminaires from a lighting manufacturer. While in the other experiment an experienced professional agency was contracted to design and execute the installation by procuring their own plants and equipment including the luminaires. The reason of performing two different installation techniques, one self-done and the other of appointing an agency was twofold. In the self-done installation, the intention was to gain first-hand experience from the process, and the installation by a professional agency was to observe and understand the appropriate procedures of designing and executing such installations. In both experiments, volunteers were approached for the maintenance of the installation on a day-to-day basis, instead of approaching a professional maintenance agency.

4.1.2. Experimental Design Execution – Plants selection

Dr.Vaishali Pawaskar, a leading horticulturist and landscape designer from Mumbai provided a list of plants that are commonly used indoor across all areas whether commercial or residential (listed in Section 2.2). Based on Dr. Pawaskar's recommendation, Tropica Nursery was shortlisted for procuring plants for the experiments. The owner of this nursery, Dr. Ashish Hansoti is a horticulturist who has been contracted to supply and maintain plants at the Mumbai Airport Terminal 2, which also happened to be one of the case studies of this research. A visit to the nursery was made in the 2nd week of June 2019 to check the availability of the shortlisted plants and also to understand the day-to-day procedures involved in maintaining plants with artificial lighting. It was informed that plants can be watered every 8-10 days and fed every 15 days.








The plants at the Tropica Nursery are nurtured in their natural conditions and habitat.







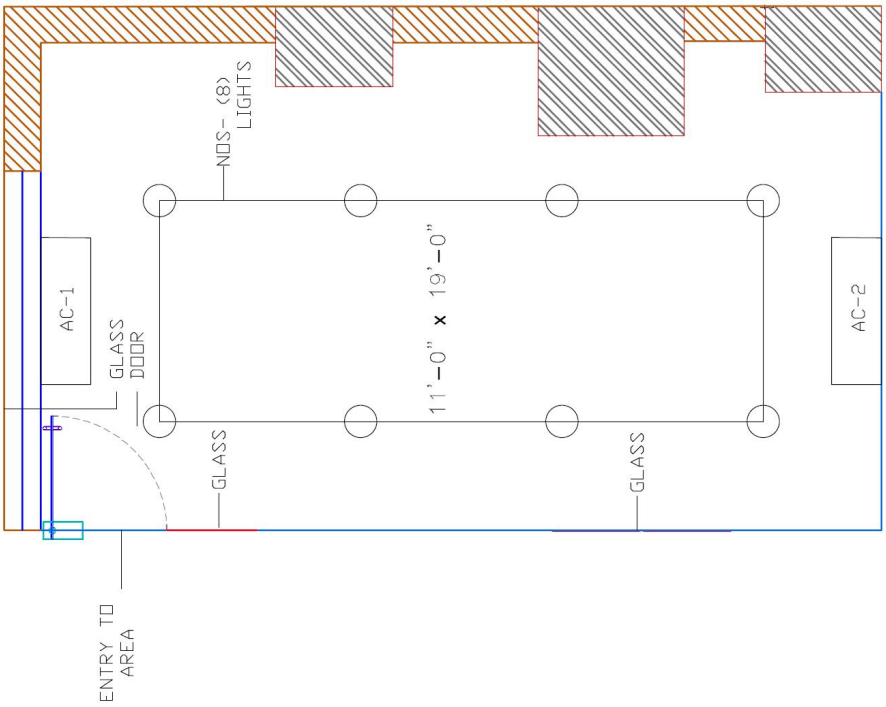
Plants selected for the experiments procured at the nursery

4.2. Experiment-1

The site selected for the first experiment was a multipurpose room in the office of Hazel Lighting. The office itself was within the basement of a commercial building that did not have any access to natural light or ventilation. The room was being used for multiple functions such as making phone calls, conducting meetings, having lunch or just taking a break from work. As the room did not have any plants installed prior to this experiment, it was an ideal location to study and observe the behaviour of subjects before and after the plant installation. For the experiment, all existing furniture in room was removed in order to install potted plants in small clusters resulting in the room no longer being used for its usual multipurpose.

Site Details:
Office Name: Hazel Lighting
Room type: Multipurpose room
Building Name: Boomerang Premises
Location: Mumbai
Site location: Lower Ground Floor
Area: 12ft x 20ft (240sq ft)
Height: 12ft ground to ceiling

Multipurpose room in the office of Hazel Lighting



Multipurpose room plan: Length 19ft x Width 11ft x Height 11ft

4.2.1 . Experiment-1 – Plants Installation Design

The multipurpose room was divided into two parts, where two sets of the same plants were placed and illuminated using two different colour temperatures: 3000K and 4000K. This variation in colour temperature was done to understand whether different colour temperatures have any effect on the life cycles of these plants. The installation was done and completed on 1st of July 2019 with all plants and lights placed in order. It is important to note that this was an enclosed space with no access to natural light or airflow. This space was installed with two air-conditioners, which were used for an hour during the entire day.

Plant Details - In order to get an appropriate result the same species and set of plants were used in both the areas of the room so that there could be a proper comparison and test of results. It was important to position the plants like in any other natural outdoor environment with a mix of small and large plants so as to study the effect of the shadow of bigger plants on the life cycles of smaller plants.

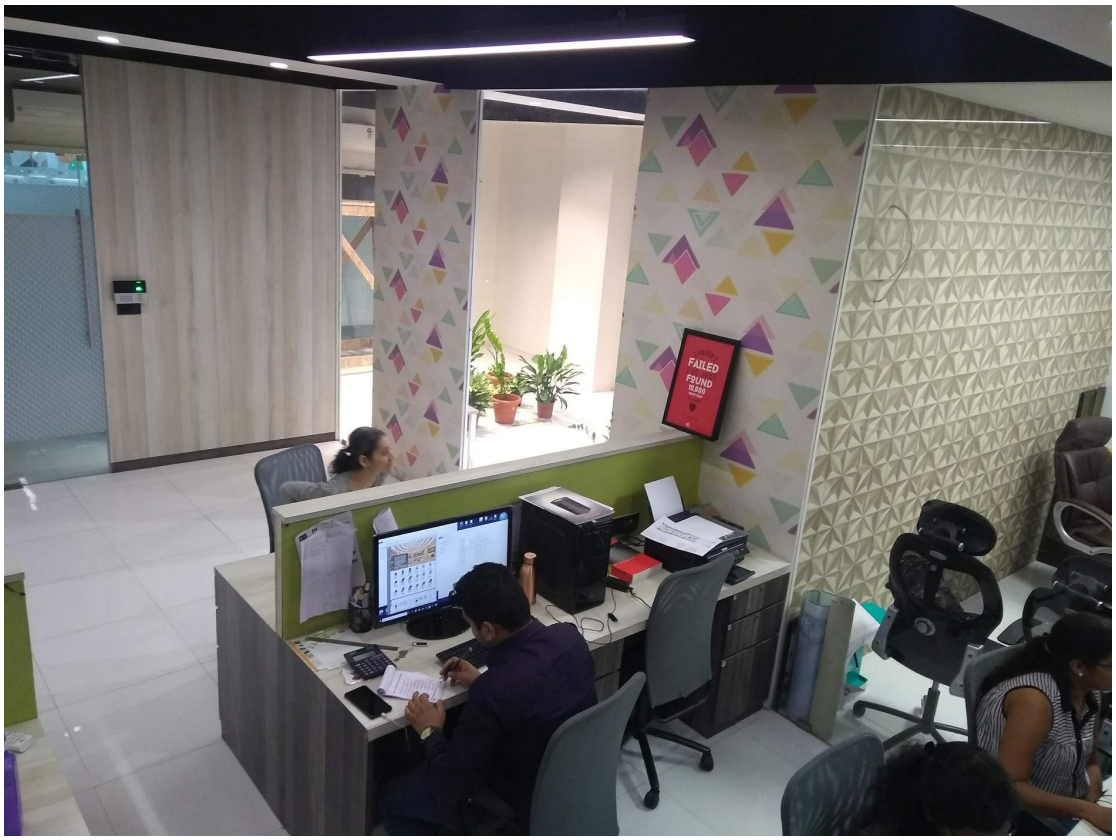
The following is the list of plants used in the office experiment

Area @ 3000k

Dracena	Scindapsus	Syngonium
Zamioculcus	Aglaonema	Calathea
Spathiphyllum	Sansevieria	Bird Nest

Area @ 4000k

Dracena	Scindapsus	Syngonium
Zamioculcus	Aglaonema	Calathea
Spathiphyllum	Sansevieria	Bird Nest



View of the multipurpose room with plants installation from the office working space

Two sets of the same potted plants illuminated in 3000K and 4000K

4.2.2. Experiment-1 – Plants Lighting Design

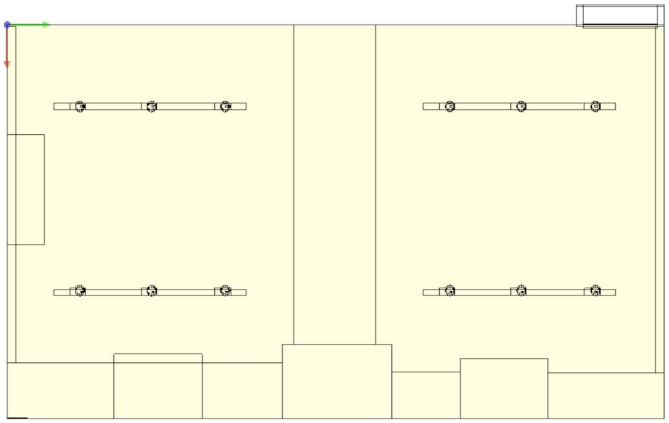
As the idea was cohesively blend the lighting for this room with the overall office environment, it was important to maintain the right colour temperature and intensity. A linear parallel track mounting arrangement was made above both the set of plants in order to install track lights focusing on these plants and providing them with the required nutrition. Hazel Lighting provided the luminaires for this experiment.

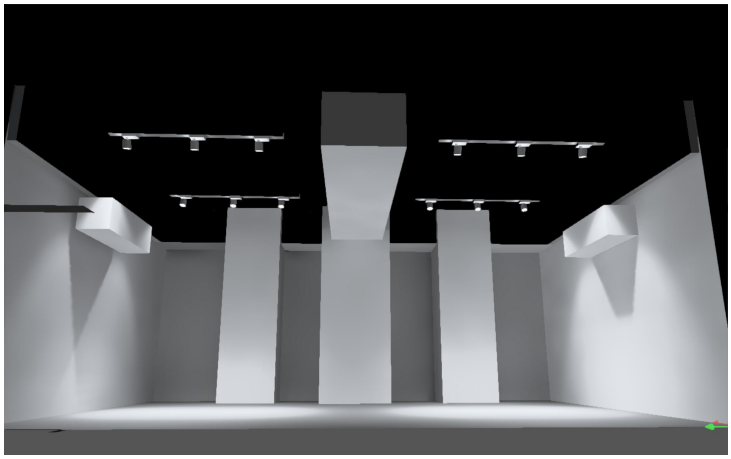
Track lights placed with three luminaires on each side; and a total of six luminaires for each set of plants in 3000K and 4000K respectively

The same set of plants being set up in two different colour temperatures 3000K and 4000K

Track mounted LED fixture
Set of six fixtures placed in parallel manner
Fixture wattage 30w
Lumens 3150 lm
Beam Angle 24 degree
CCT 3000k

Intensity @ 3000K
The average lux achieved on the leaves / plants is 1140 lux
The average lux achieved on the other areas of the floor is 530 lux
The average lux achieved on the surrounding wall is 280 lux





Track mounted LED fixture
Set of six fixtures placed in parallel manner
Fixture wattage 30w
Lumens 3300 lm
Beam Angle 24 degree
CCT 4000K

Intensity @ 4000K
The average lux achieved on the leaves / plants is 1260 lux
The average lux achieved on the other areas of the floor is 700 lux
The average lux achieved on the surrounding wall is 440 lux

Duration – The duration for lighting these plants as recommended by the horticulturist was about 10-12 hours. In order to achieve that on a regular basis it was decided to follow and test the normal working hours of the office: open at 9:00AM in the morning and close at 7:00PN thus providing the plants with 10 hours of light on a daily basis except weekends when the office was closed. No additional hours of light were provided to the plants apart from the usual working hours of the office. The intent was to study how the plants react to this duration along with the two days off period during the weekends.

4.2.3. Experiment-1 – Survey Questionnaire

Survey Before Installation – A survey questionnaire was prepared and a paper-based survey was conducted with people from the office. As the same basement floor consisted of four other offices, people from the neighbouring office were also invited to be a part of the survey in order to obtain a larger sample size. Additionally people who regularly visited that office such as vendors, housekeeping staff, along with the building facility management staff were invited to be a part of the survey. A total of 25 subjects – 13 from the office staff, 5 from the neighbouring offices and 7 visitors – were interviewed before installing the plants. The survey questionnaire was designed to get a broad understanding of people's reaction to having plants in indoor spaces. The questions included whether they feel the need for plants in their office, would feel any different (good or bad) when they have plants in their office, do they feel that plants would increase their productivity or health, or de-stress them, where do they prefer to have these plants, are there any particular colours of plants they want, are they willing to volunteer to take care of these plants, are they willing to sacrifice some space from their office for these plants and finally would they be comfortable if some changes in lighting was done to accommodate these plants. A wide range of answers was received.

Survey After Installation – After installing these plants, the entire office was allowed to use the room, although not in the same manner as before. The office staff volunteered to maintain these plants on a regular basis e.g. watering and feeding. Interviewed subjects of the neighbouring offices including the visitors were invited to visit the room. Post installation a new survey was conducted on 20th August after nearly 45 days of installation. This survey was conducted amongst the same set of people with whom we had spoken before the installation took place including the office people, the vendors and the neighbours. This time the set of questions were focused on their experience towards having plants in the space. The questions asked were whether they wanted the plant to continue or wanted it to be removed, whether they would like to add more plants in other spaces, were they willing to sacrifice some of their space to accommodate these plants, were they willing to take care of these plants, did they feel better health wise and stress wise after installation of plants and finally was the lighting installed for these plants comfortable.

4.2.4. Experiment-1 – Challenges and Remedies

A weekly review was conducted to observe the changes in behaviour of the plants especially in terms of their health and growth. During the second week, it was observed that some plants were wilting. The usual assumptions were due to the lack of natural light or air; or due to the lighting intensity, duration or colour temperature. It was observed that the plants under 3000K were more affected than the plants under 4000K.

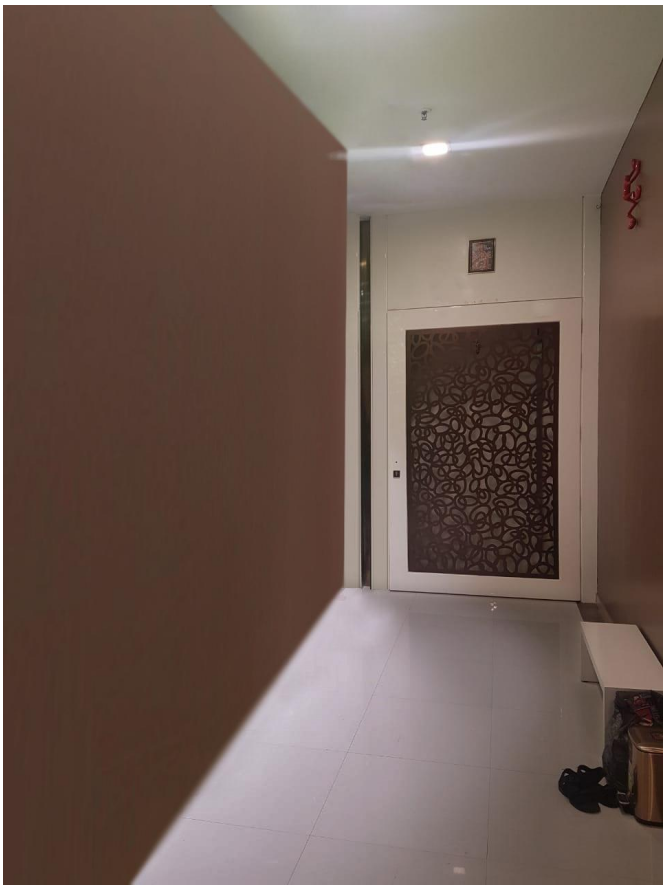
According to Dr. Hansoti this phenomenon was not due to the lack of natural light or air as these were indoor plants and they should survive. However, one of the volunteers who had experience growing and maintaining plants at her home suggested that this might be due to the fact that the plants were watered once in 10 days. We realised that the air in the indoor environment was has lower moisture component, which also affected soil composition thereby affecting the plants. As a remedial measure, the plants were watered immediately which resulted in the plants bloom back to normal within few hours of watering. Thus we were able to understand that the watering cycle in such a situation has to be more regular and we decided to water the plants every 2 days. After changing the watering schedule there was no such issue observed over the rest of the experiment.

The plants began wilting in the 2nd week due to lack of water

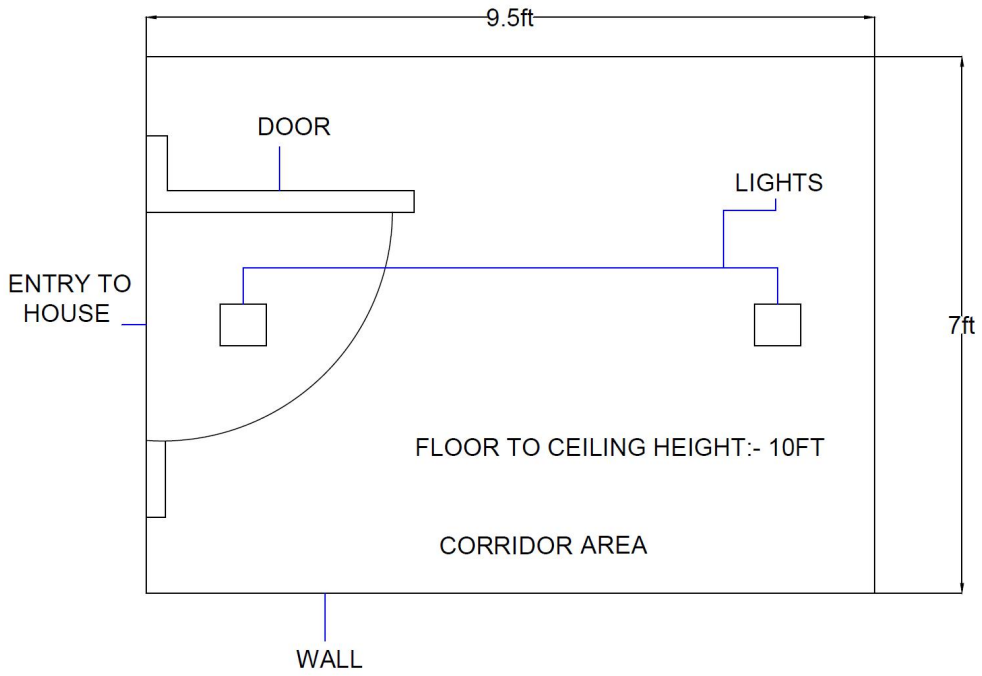
4.3. Experiment-2

The site selected for the second experiment was a corridor located within a residential tower that also did not have any access to natural light. This selection of this location was based on the difference in architectural typology compared to the first experiment. This narrow corridor was used as a lobby for an apartment owned by Mr. Hetal Joshi. Mr. Joshi volunteered to let his residence corridor be used as an installation for this experiment. Both sides of the corridors had blank walls. One side of the corridor wall was used to create a vertical green wall installation. This further ensured that the typology of plant installation was different from the first experiment of potted plants. However, in this case the users did not have to move or change anything since the as the installation it was just an addition to the blank wall. Also there was no sacrifice of space made by the residents since it was installed on an unused wall outside the apartment unlike the office space. Very little horizontal space was used which is a big advantage for such installations.

Site Details :
Building Name : Aquaria Grande
Location : Mumbai
Site location : 9th Floor
Area : 6ft x 12ft
Height : 10ft ground to ceiling



Residential Corridor showing the two walls and front entry door.



Corridor plan: Length 9.5ft x Width 7ft x Height 10ft

4.3.1. Experiment-2 – Plants Installation Design

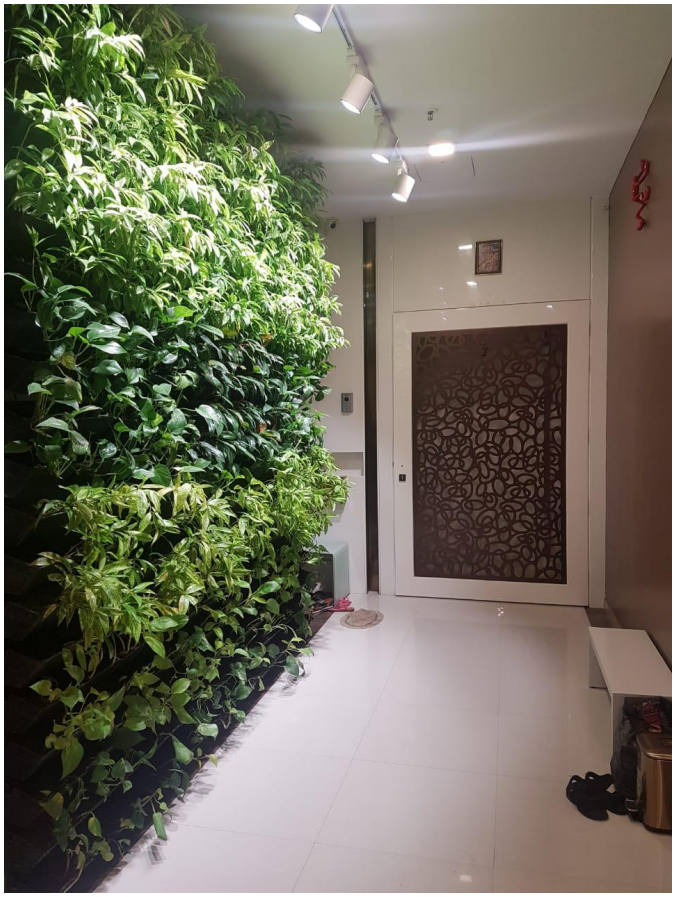
A vertical green wall installation was decided for this experiment as it provides an opportunity to experiment with a different type of installation. As this involved creating a structure on the wall for mounting the plants, Vert Vista a professional agency with an expertise in creating vertical green wall was contracted. Mr. Joshi sponsored this installation involving installation of the structure and the required plants for the vertical green wall. Although this corridor did not have any direct natural light, there provision for natural ventilation through open able windows on both ends. Thus it was a different installation both in terms of typology and ventilation pattern when compared to the office installation. Vert Vista suggested a colour temperature of 4000K. Here again there was no special agency involved in the day-to-day maintenance of pants and the watering was left to the volunteers from the residence. The watering interval was suggested to be once a week by the agency. This installation was completed on 20th May 2018.

Plant Details – The plant species were recommended by the agency since they had experience on such vertical wall installation. So all the plants were provided by the agency based on what they generally do for such installations.

The following is the list of plants used in the residence experiment

Vertical Wall @ 4000k

Scindapsus	Syngonium
Aglaonema	Calathea



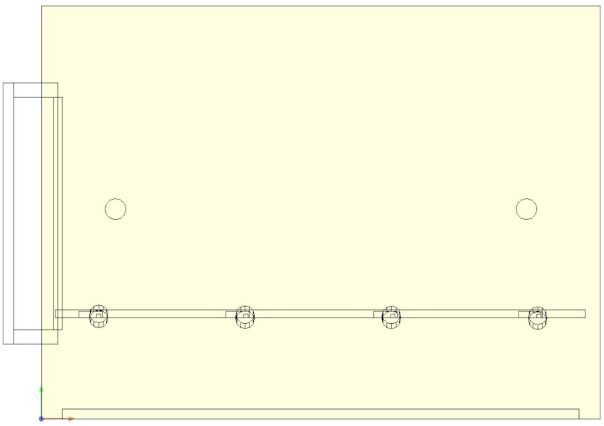
4.3.2. Experiment-2 – Plants Lighting Design

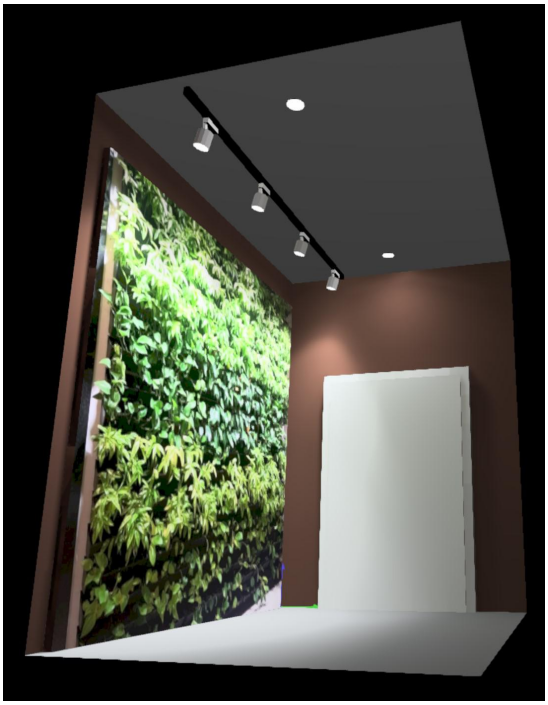
In this experiment as well, the idea was to cohesively blend the lighting with the overall environment while maintaining the right colour temperature and intensity. A linear parallel track mounting arrangement was made above both the set of plants in order to install track lights focusing on these plants and providing them with the required nutrition. Hazel Lighting provided the luminaires for this experiment.

However, there were two existing ceiling recessed downlights installed in the corridor, which could not be removed, as they were a part of the facility team. Additionally, as the lights for the vertical wall could not be switched on all the time it was decided to retain the two existing downlights.

Track mounted LED fixture
Set of 6 fixtures placed in parallel manner
Fixture wattage 30w
Lumens 3300 lm
Beam Angle 45 degree
CCT 4000k

Intensity @ 4000k
The average lux achieved on the leaves / plants is 1320
The average lux achieved on the other areas of the floor is 760





Duration - The duration for lighting the green wall as recommended by the agency was 8 hours. The residents were therefore instructed to switch on the lights at night from 10:00pm until 6:00am in the morning thereby providing 8 hours of artificial lighting for the plants. This also ensured that there was no glare or unusual lighting for the users of the corridor during the day.

4.3.3. Experiment-2 – Survey Questionnaire

Survey Before Installation – A survey questionnaire was prepared and a paper-based survey was conducted with people from the residential tower. The residents of the apartment in the floor involved a family of six members. Apart from the people in the apartment, regular visitors including vendors and facility staff invited to be a part of the survey. People from the neighbouring apartment on the same floor were also invited. All the vendors and neighbours were informed about the installation since they were a part of the conducted survey. A total of 6 apartment residents, 5 vendors and 4 neighbours house were interviewed before installing the vertical green wall. The questions included whether they feel the need for plants in their surrounding interior spaces, would feel any different (good or bad) when they have plants there, do they feel that plants would increase their activity or health, or de-stress them, where so they prefer to have these plants, are there any particular colours of plants they want, are they willing to volunteer to take care of these plants, and finally would they be comfortable if some changes in lighting was done to accommodate these plants.

Survey After Installation – Post installation a new survey was conducted on 24th August after three months of installation. This survey was conducted amongst the same set of people with whom we had spoken before the installation took place including the residents, the vendors and the neighbours. This time the set of questions were focused on their experience towards having plants in the space. The questions asked were whether they wanted the plant to continue or wanted it to be removed, whether they would like to add more plants in other spaces, were they willing to sacrifice some of their space to accommodate these plants, were they willing to take care of these plants, did they feel better health wise and stress wise after installation of plants and finally was the lighting installed for these plants comfortable.

4.3.4. Experiment-2 – Challenges & Remedies

After nearly one month of the installation it was observed that the plants on the lower 2ft section of the wall were beginning to wilt. Some plants had completely dried. It was observed that the illumination level in the lower section of the green wall was much lower than the upper areas thereby causing a light deficiency for those plants. Therefore it was decided to change the luminaire optics to wall-washer optic in order to ensure a better coverage of light and more evenly illuminated wall. This change was incorporated in mid June and ever since there have been not been any report of drying plants. The wattage and the colour temperature were maintained as before.

4.4. Results and Analysis

4.4.1 Result of Plant Growth

In both the experiments it was clearly observed that if proper care was taken it is easily possible to maintain plants using artificial lighting. None of the plants where sufficient lighting was provided dried during the course of the experiment. In both cases in spite of being different typologies the end result was similar including the intensity and duration of illumination. The experiment was conducted using smaller plants since it was logistically not feasible to install larger plants or trees. But it can be safely concluded that even larger plants or trees can be grown using artificial lights of similar intensity and duration. In both the experiments some remedial measures were required in order to ensure plant growth. However, these were minor adjustments to be made considering the prevailing site and typological conditions.

4.4.2. Lighting for Humans and Plants

The fact that in both experiments we were able to maintain plant growth using regularly used colour temperatures i.e. 3000k-4000k shows that plants can be installed and maintained in any possible indoor environment without specially designed luminaires with different colour spectrum. The optical characteristics of luminaires used for humans and plants were similar. Therefore it is possible for us to collaborate and cohesively design for humans and plants, thereby integrating with the architecture of any space.

4.4.3. Analysis of User Feedback Survey

There was an overwhelming response from both surveys. During the first survey before installation all of subjects reported a preference for plants in their space. However, few of them were willing to sacrifice their space for plants and a lot of them denied to take responsibility to maintain these plants. This was completely reversed when we conducted the surveys after installation. Most of the users were willing to sacrifice their space to accommodate plants and also willing to personally take care of these plants. All the users confirmed that they felt better and healthier with less stress with having plants in their surroundings. Even the vendors, visitors and neighbours confirmed that they felt better to visit this space with plants installed. All the people surveyed felt the lighting was comfortable for them and did not feel the need to change. Most of the users wanted us to install more plants in other spaces as well if possible. Thus all in all it was observed that all users were keen to have been surrounded with plants in their environment.

Chapter – 5: Conclusions

5.1. Lack of Awareness

The most important conclusion that can be drawn from this research is that although a wide variety of indoor plants can thrive and grow under electric lighting, there is very little awareness from the design community including architects, interior designer and lighting designers. Even horticulturists and nursery owners were not willing to believe that this was a possibility and on the contrary they were discouraging us from conducting this experiment under this misconception that plants cannot grow or survive without natural light. The benefits of plants are very well described in the previous chapter and the results of this research show that people feel the need form plants in their interior environments regardless of age, gender, etc. This is primarily because most urban spaces, in this case the city of Mumbai, are deprived of natural greens. This also reinforces the need to design lighting for plants in a manner that blends with overall architecture of the space. There is a greater need to create awareness about this fact that plants can indeed be grown in interior environments and the available design possibilities.

5.2. Responsibility of the Design Community

It is the responsibility of the entire design community including architects, interior designers and lighting designers to attain basic knowledge about plants and plant related horticulture. Learning about horticulture should be considered a mandatory requirement of the designers' professional scope thereby enabling clients to incorporate plants in interior spaces. This additional amount of effort by the design community will have long-term benefits globally by making a positive difference to the built environment and serve the larger goal of creating balanced ecosystems in a world is deprived of natural green spaces.

5.3. Plant-related Lighting Maintenance

Interior installations with plants need regular maintenance, observation and care just like any other landscaped areas. It cannot be assumed that just with appropriate installation and lighting, the plants can take care of themselves. The users of the space can either themselves or appoint agencies to undertake this responsibility of maintenance depending on the scale of the installation. Therefore plant-related lighting maintenance should also be considered during the process of design.

5.4. Competition from Artificial Plants

While this research has focused on the use of natural plants, it important to acknowledge the competition from artificial plants. A variety of artificial plants that match the look and feel of natural plants are available in the market, thereby increasing their use. Apart being more cost effective than natural plants, artificial plants are require very little maintenance. But users and the design community have to realise that artificial plants do not provide any health or other larger benefits offered by natural plants. Artificial plants can only be used of decorative purposes thereby warranting some consideration while designing lighting for interior spaces.

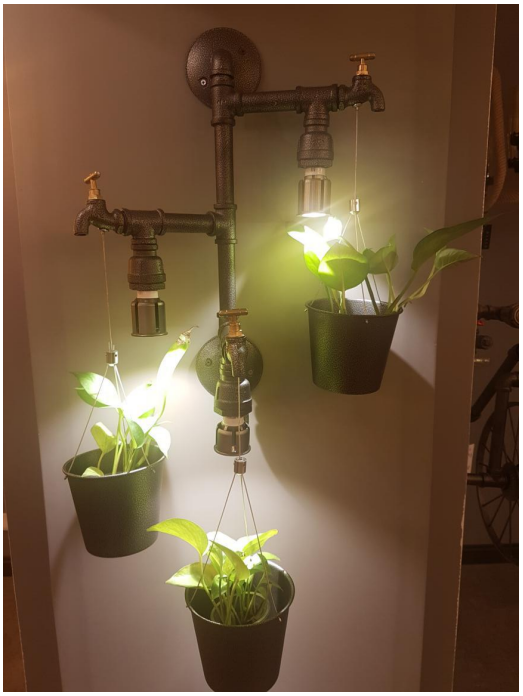
5.5. Consideration for Temperature

While the scope of this research is restricted to the design-related aspects for the growth and maintenance of plants with electric lighting in interior environments inaccessible to daylight, temperature also plays a key role. Temperature often is a neglected factor in interior environments as it is maintained at ambient level regardless of the external climate conditions.

5.6. Future Work

As an extension to this research and future work is to create a modular and scalable system, which can be used as a simple reference guide by architects, landscape designers, interior designers and lighting designers. The guide can include simple lighting strategies including luminaire typologies, intensity, spectral content and duration to suit different plant installation typologies e.g. wall-washing for vertical green walls. This requires further research and experimentation to understand plants behaviour under different lighting situations such as study of large-scale plants installations corporate lobbies with a larger number of users. This in turn will open avenues to set new standards for the design of lighting for humans and plants in interior environments inaccessible to daylight.

An example of how creatively plants can be installed in indoor space using such design techniques.



Appendix 1

Survey Before Installation (Specimen)

Experiment-1 – Survey Questionnaire

Survey No :
Date :
Name :
Location :

Questions

1. Do you prefer to have plants in your workspace? If yes, which type of plants?

2. In your personal opinion is it necessary to have green spaces within offices? Would having plants be conducive to an office environment?

3. Do you think keeping plants would cause a change in the performance and health of the employees?

4. Where would you place the plants? Would be willing to sacrifice a bit of your work space for the plants?

5. Would you volunteer to care and nurture the plant?

6. Would you be comfortable to alter the lighting condition of your personal workspace as would be conducive for the plant growth?

Appendix 2

Survey After Installation (Specimen)

Experiment-1 – Survey Questionnaire

Survey No :
Date :
Name :
Location :

Questions

1. How do you feel with the plants in your workspace?

2. Is there any particular color or type of plant you would like in your office?

3. Have you taken time to nurture and care for the plants?

4. Do you feel healthier and active with plants in your office?

5. Is there a change in your and your colleagues performance? Is there any change in the stress level?

6. Do you need the plants removed? Or would you like to have some more plants? Are you willing to sacrifice your work space for plants?

7. Are you comfortable with the lighting modifications made to ensure a conducive environment for the plant growth?

8. Should there be more plants and green spaces in office complexes, airports, restaurants and many other public places and how do you suggest to implement them?

Appendix 3

Survey Before Installation (Specimen)

Experiment-2 – Survey Questionnaire

Survey No :
Date :
Name :
Location :

Questions

1. Do you prefer to have plants within your homes?

2. Is there any particular color or type of plant you would like in your home?

3. In your personal opinion is it necessary to have green spaces within houses?

4. Do you think keeping plants would cause a change in the health of the family?

5. Where would you place the plants? Would be willing to sacrifice a bit of your personal space for the plants?

6. Would you volunteer to care and nurture the plant?

7. Would you be comfortable to alter the lighting condition of your home as would be conducive for the plant growth?

Appendix 4

Survey After Installation (Specimen)
Experiment-2 – Survey Questionnaire

Survey No :
Date :
Name :
Location :

Questions

1. How do you feel with the plants in your home?

2. Have you taken time to nurture and care for the plants?

3. Do you feel healthier and active with plants in your home?

4. Is there a change in your and your family's health, physically and mentally?

5. Do you need the plants removed? Or would you like to have some more plants? Are you willing to sacrifice more of your personal space for plants?

6. Are you comfortable with the lighting modifications made to ensure a conducive environment for the plant growth?

References

1. Colony and Summer Pavilion, Singapore - www.nipek.jp
2. Bosco Verticale, Italy - Stefano Boeri. www.stefanoboeriarchitetti.net
3. Park Royal Hotel, Singapore - WOHA Architects. www.woha.net
4. Russian botanist Andrei Famintsyn research study (1868)
5. Phillips Interior Plants & Displays for Images
6. Heroman Services Plant Company for Images
7. Kathy Fediw - The manual of interior plantscaping for data and images chapter 1
8. Mimosa Interior Landscape for Images
9. Stress and Productivity Study - (Shibata and Suzuki 2002)
10. Study on “attention system” (R. Kaplan and S. Kaplan 1990, S. Kaplan 1995)
11. Exam stress study for college students (Ulrich 1979)
12. Office and Plants relative study (Lohr et al. 1996)
13. www.ambius.com for Images
14. Study on VOCs (Wood et al. 2006)
15. Study on levels of carbon monoxide (Tarran et al. 2007)
16. Office fatigue and illness (Fjeld et al. 1998)
17. Office absenteeism (Fjeld 2002)
18. Blood pressure levels study (Lohr et al. 1996)
19. Humidity and temperature study (Costa and James 1999)
20. Comfort level in office spaces (Lohr and Pearson-Mims 2000)
21. Study on consumer spend behaviour (Wolf 2002)
22. www.nytimes.com for Images
23. LEED certification www.new.usgbc.org
24. Human issues in horticulture research by NASA www.ambius.com
25. Green wall installation www.inhabitat.com
26. Lobby at Chamber of Commerce, Ljubljana, Solvenia by Sadar+Vuga
27. Light spectrum chart www.gardeners.com
28. Red and Blue LEDs being used together for plant growth. www.uponics.com
29. Multiple spectrums used in plant growth. www.ge.com
30. LED horticulture COB chip. www.luminus.com
31. Human design requirements - Lighting Research & Design
32. www.inscapeindoor.com for Images
33. Pasona Tokyo Headquarters Case Study. www.konodesigns.com
34. Changi Airport - Singapore Case Study. www.changiairport.com
35. Mumbai International Airport Terminal 2 Case Study. www.csia.in
36. Plant details and knowledge. Dr. Ashish Hansoti Tropica Nursery
37. Plant details and knowledge. Dr. Vaishali Pawaskar