Enhancing the Indoor Lighting Quality of U.A.E Museums
A Case Study of Louvre Abu Dhabi

تحســـين جودة الإضاءة الداخلية في متاحف الإمــارات

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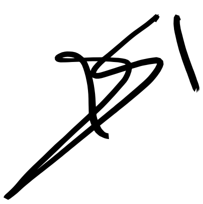

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ABSTRACT

The role of museums is to conserve and protect history. Over the years, the public perception of museums has greatly improved due to a popular spread of awareness and appreciation of history and culture.

This study will focus on museums from a sustainable design perspective. The primary relationship between sustainability and museums is related to the ideas of preservation and protection. This is based on the meaning of sustainability, which is the concept of preserving the environment from any harmful or unwanted impact. This is closely linked to the main aim of museums to preserve history from being damaged or wrecked. Furthermore, museums play a significant role in spreading the concept and awareness of sustainability, both through design and through exhibited items.

The research will mainly focus on the indoor quality of the museum, by focusing on lighting. Museum lighting is the main element of the story-telling process of the museum. Lighting in museums plays an essential role in giving the visitors the true experience of their surroundings. Additionally, in a museum, visitors are expected to interact with, see, and experience the space and objects, and without optimal lighting, this experience would be impossible.

This paper will use a case study to analyze these topics related to lighting and sustainability. The selected case study is located in the United Arab Emirates, specifically in Abu Dhabi. The Louvre Abu Dhabi is considered to be one of the most important museums in the U.A.E. This case was chosen for consideration due to this particular museum's high potential for impact on the public an also for the sophistication of its design. The author was intrigued to study all of the aspects related to the design of the Louvre Abu Dhabi and to analyze whether there could be any enhancements that could help develop the museum.

This research focused on analyzing different data using multiple methods and techniques. The use of survey data was an important method to determine users' perspectives and perceptions. Another important method was the use of simulation programs to come up with accurate results that would benefit the objective of the paper.

Keyword: Lighting, Museums, U.A.E, Sustainable Design, Sustainable Lighting, Museum Lighting, Indoor Environment, Indoor Quality, Energy Consumption

يركز دور المتاحف بشكل أساسي على مفهوم الحفاظ على التاريخ وحمايته ، ولكن على مر السنين ، تحسن تصور المتاحف .بشكل كبير بين الناس. ويرجع ذلك إلى انتشار وعي الناس وفهمهم للتاريخ والثقافة.

ستركز هذه الدراسة على دراسة جميع الجوانب المتعلقة بالمتاحف من منظور التصميم المستدام. بشكل أساسي ، ترتبط العلاقة بين الاستدامة والمتاحف بفكرة الحفاظ والحماية. والسبب في ذلك يترجم إلى معنى الاستدامة ، وهو مفهوم الحفاظ على البيئة من أي أثر ضار أو غير مرغوب فيه. هذا ، من ناحية أخرى ، والهدف الرئيسي للمتاحف للحفاظ على التاريخ من التلف أو التحطيم. علاوة على ذلك ، يلعب المتحف دورًا مهمًا في نشر مفهوم الاستدامة والوعي بها ، سواء من خلال التصميم أو من خلال العناصر المعروضة.

سيتم إجراء البحث بشكل أساسي على الجودة الداخلية للمتحف ، ولكن من خلال التركيز فقط على الإضاءة. إن إضاءة المتحف هي العنصر الرئيسي وجزء من عملية سرد القصص في المتحف. تلعب الإضاءة في المتاحف دورًا أساسيًا في منح الزوار التجربة الحقيقية لمحيطهم. بالإضافة إلى ذلك ، في المتحف ، من المتوقع أن يتفاعل الزوار ويرون ويختبرون المساحة والأشياء ، وبدون الإضاءة ، ستفشل هذه التجربة بشكل كبير.

ستركز هذه الورقة بشكل أساسي على تحليل جميع الجوانب المذكورة فيما يتعلق بدراسة حالة معينة. تقع دراسة الحالة المختارة في الإمارات العربية المتحدة ، وتحديداً أبو ظبي. يعد متحف اللوفر أبوظبي من أهم المتاحف في الإمارات العربية المتحدة. ترجع معايير اختيار دراسة الحالة هذه إلى التأثير الضخم لمثل هذا المتحف على الناس وأيضًا بسبب تطور التصميم. كان المؤلف مفتونًا بدراسة جميع الجوانب المتعلقة بتصميم اللوفر أبو ظبي وتحليل ما إذا كان هناك أي تحسينات يمكن تنفيذها من شأنها أن تساعد في تطوير المتحف.

ركز هذا البحث على تحليل البيانات المختلفة باستخدام طرق وتقنيات متعددة. كان استخدام أسئلة الاستطلاع المختلفة طريقة مهمة لتحديد وجهة نظر المستخدمين وإدراكهم. طريقة أخرى مهمة هي استخدام برامج المحاكاة للتوصل إلى نتائج دقيقة من شأنها أن تفيد الهدف من البحث.

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Taher, Dina, Omnia, Dalal and Ayat. Who without them this wouldn’t be possible.

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List of Abbreviations

WHO: World Health Organization

MOI: Museum of Impact.

DCTB: Dubai Commerce and Tourism Promotion Board

LED: Light Emitting Diode

OLED: Organic Light Emitting Diode

UNESCO: United Nations Educational, Scientific and Cultural Organization

ICOM: International Council of Museums Members

STI: Speech Transmission Index

IAQ: Indoor Air Quality

LEED: Leadership in Energy and Environmental Design

BREEAM: Building Research Establishment's Environmental Assessment Method

IEQ: Indoor Environmental Quality

RH: Relative Humidity

BSI: British Standards Institutions

UV: Ultraviolet

CCI: Canadian Conservation Institute

CIE: International Commission of illumination

CIBSE: Chartered Institution of Building Services

CRI: Color Rending Index

ANSI: American National Standards Institute

IESNA: Illuminating Engineering Society of North America

DF: Daylight Factor

DOE: Department of Energy

SSL: Solid State Lighting

IES: Integrated Environmental Solutions

GEM: Grand Egyptian Museum

CFL: Compact Fluorescent Light

PEX: Polyethylene tubes

VOC: Volatile Organic Compounds

PV: Photovoltaic

VGS: Vertical Greenery System

MDF: Medium-Density Fiberboard

CHAPTER 1

Introduction

1

C H A P T E R   I

1. Introduction

1.1 Environment Impacts

"We never have 100 percent certainty. We never have it. If you wait until you have 100 percent certainty, something bad is going to happen on the battlefield" – this is Former U.S. Army Chief of Staff Gordon Sullivan's reflection on the environmental crises ahead, and especially the extent to which people perceive the problem but don't understand the magnitude of it (Gerson et al., 2007). Furthermore, future environment crises and problems are not only related to climate and weather change but actually have multiple possible outlines and outcomes. For instance, the increasing Neglected Water Crises is one of the main problems attracting attention recently; one study has shown that most of the Middle East and Northern Africa Countries have water problems and that by 2025, South Africa, Pakistan, and huge parts of India and China will have the same (Amarasinghe & Smakhtin 2014). Another area of huge impact that must be considered is health and the health effects of environmental crises; for instance, the World Health Organization (WHO) has expressed concern that with the increase of environmental problems over time, there can be an ensuing increase in health issues and spread of disease (McMichael 1995). Many other problems may also result from environmental and weather change, stemming from increased CO_2 emissions. The increase in CO_2 emissions has severe outcomes such as an increase in the overall global temperature, which stimulates global warming and affects the growing seasons of plants and crops (*Consequences of Carbon Emissions for Humans* n.d.). All of these problems are increasing due to human consumption. Therefore, this paper will focus on analyzing the problem by focusing on the effect of building on the environment and its part in these environmental crises, as well as how to resolve them. The Global Alliance for Buildings has shown that approximately 40% of global annual CO_2 emissions are from buildings, therefore the move towards building more green and sustainable buildings would help in the process of limiting and decreasing harmful environment impacts (Cole, Lindsay & Akturk 2020). Furthermore, to understand and help deal with these issues it is important to understand what

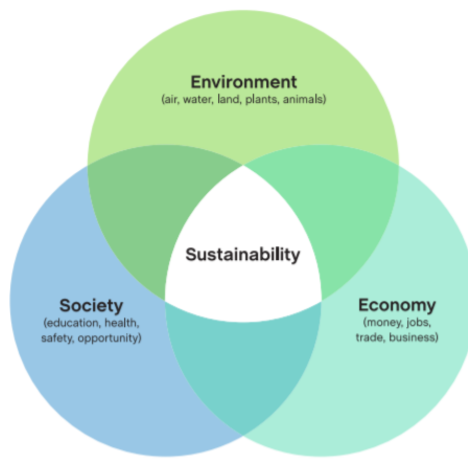


Fig. 1.1 3 Elements/Outcomes related to Sustainability *(Mack et al. 2006)*

sustainability is. Stated simply, it is the process of preserving and protecting the environment from various negative outcomes that can be caused by humans (Davidson Reynolds 2021). Therefore, sustainability is the solution to all of these impacts. One study has shown that sustainability has a huge impact on people due to three main outcomes/factors: economic (jobs, businesses), society (education, health, safety), and the environment (air, water, land) (Pop et al. 2019). This was also illustrated in Figure 1.1 (Mack et al. 2006). All of these factors are affected and influenced by human actions; being part of this Earth, therefore, it is our obligation and duty to ensure the limitation of acts that lead to hazardous impacts. And as Wendell Berry said, "Earth is what we have in Common."

1.2 Museum Impact

This paper will seek to explain these environmental issues as well as how to increase public awareness of them, by focusing on and analyzing museum design from a greener perspective. When museums provide a sense of belonging for visitors, they inspire and increase the visitors' sense of security and comfort by providing a healthy environment and space for all. Traditionally, when the impact of museums is studied, those studies focus on the impact museums have on visitors. One study indicated that museums impact visitors in multiple aspects: enjoyment, spending quality time with family and friends, educational visits to learn new things, and multiple other reasons. The nature of the visit is defined based on the type of visitors (Anderson, Storksdieck & Spock 2006). Additionally, the Museum of Impact, or MOI, is a European project funded by the Creative Europe Programme. This program is devoted to understanding the impact of museums in order to help museums evaluate their projects and increase their impact on the environment and users (*MOI - Museums of Impact - Finnish Heritage Agency* n.d.). The museum's impact on users can be defined into 3 main aspects**:** First, Educational Impact: A study has shown that 55 million visits each year are from students. Second, Economic Impact: Oxford Economics illustrated that US museums generate approximately USD 17 billion per year, which is a huge income when compared to other organizations (*New National Data*

Fig 1.2. Museums Social Impact *(Measuring the Social Impact of Museums – American Alliance of Museums n.d.)*

Reveals the Economic Impact of Museums Is More than Double Previous Estimates – American Alliance of Museums n.d.). Third, Figure 1.2 illustrates Social Impact via the results of a survey study conducted with visitors to 8 museums, who reported an increase in the for social aspects as shown (*Measuring the Social Impact of Museums – American Alliance of Museums* n.d.).

In contrast, this paper will focus on museums' impacts on the environment from a sustainability point of view rather than the impact of museums on visitors. This focus is relevant and pressing. As the preservers and protectors of history, museums must provide a safe and healthy environment for the artifacts and people of different cultures different eras, which is the main concept of sustainability. As mentioned earlier, sustainability helps to preserve the environment and protect it, while museums help preserve and protect history, which on the other hand, improves and protects the environment (Davidson Reynolds 2021). Furthermore, the main concept of this paper is to understand the process of designing a museum with a fully sustainable and renewable background to achieve a space that helps and promotes the idea and concept of sustainability. The reason for this orientation is the high relation between museum design and cultural impact, meaning that when a museum is designed in a more sustainable and environmentally-friendly manner, this can increase the awareness and understanding of sustainability due to the magnitude and impact of museums on people. The quality of the museum environment is influenced by multiple aspects: indoor air quality, visitor enjoyment, visitor comfort, display type, and the preservation of the artifacts. Therefore, as mentioned before, a well-designed museum will have a huge impact on the users (Baer, Norbert S. 2000). In addition to that, a museum is a huge space that requires specific elements and a specific method of study. When a designer works on museums, they deal with the museum space as a form, which creates a challenge due to the size and extreme height of many museums. Therefore, the focus on museums is essential due to their outsized impact on the environment.

1.3 Aims and Objectives

The concepts of museum and museum improvement concerning the environment have multiple aspects ranging from lighting and acoustics to indoor air quality or psychological impacts. Therefore, focusing on each aspect separately will enable a greater level of detail and depth of analysis as each element is examined along with its particular issues and possible solutions. Additionally, this paper will focus on the analysis of the different interior environmental aspects that would impact and influence the quality of the museum. There are many museum features or elements that influence user experience. For instance, in the year 1908, the Boston Museum of Fine Arts was the first museum in the US to change the relative humidity from 55% to 60%. This was done after multiple trials and tests conducted over a period of 2 years and was shown to have a huge impact on the museum's indoor air quality (*Precaution, Proof and Pragmatism: Evolving Perspectives on the Museum Environment (article)* n.d.). In addition to humidity level, many other factors might also have a huge impact on a museum's artifacts, especially delicate artifacts that require specific and detailed types of treatments and solutions. This paper will analyze a specific case study in Abu Dhabi, with an analytic emphasis on the museum's lighting as a key element of museum improvement. Specifically, this paper will undertake the following analyses:

- Studying different lighting elements by analyzing different types of lights along with their pros and cons.
- Examining and comparing the effects of different lighting on museum artifacts
- Analyzing daylight and its impact on museum design.

Therefore, on the basis of these key areas of focus, the research questions are as follows:

1. To what degree does daylight impact the museum and its artifacts from a design perspective?
2. To what degree does lighting impact energy consumption in museums?
3. What limitations might occur while analyzing the museum from a designer's perspective?
4. How can improvement in lighting as an element of museum design impact the environment?

1.4 Paper Structure

This paper will consist of different parts that will help to better understand the deep relationship between museums and sustainability, and how green museum design is beneficial to the environment and can spread the concept of sustainability. The paper's parts are illustrated below.

- Part 1 – Introduction

This part of the research will focus on explaining an overview of all aspects related to the environment and how museums impact the environment. As museums have a huge impact on the environment, as mentioned before, this chapter will translate this importance and the source of it. Also, this chapter will focus on explaining all the procedures of the research and its structure.

- ➢ <u>Part 2 – Literature Review</u>

In this part/portion of the research, the main aim is to help understand and analyze different outcomes of different studies related to the theme and title of the paper. Moreover, the key purpose of the literature review is to help study most of the available information related to the project or research. The study of missing information or findings to answer a specific topic would make up a huge area of this part.(Evans et al. 2008). So mainly Literature Review is the process of obtaining data from different studies and researches (Bruce, 1994, p. 218).

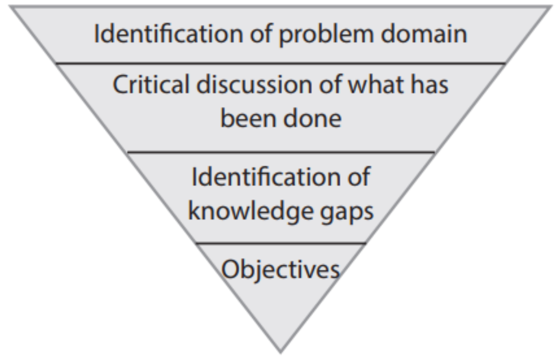


Fig. 1.3 Literature Review Process *(Maier 2013).*

Additionally, reading different papers and extracting different information is the main aim of this Part. Figure 1.3 reflects the purpose and aim of the Literature Review from the point of view of Maier (Maier 2013).

The Literature Review mainly consists of different Types which was studied and analyzed by different studies using different perspectives but based on the study done by Evans et al mainly reflect the 4 main types which are as follows:

- **Narrative:** This type of Literature Review mainly consists of analyzing the information to come up with new research paths or identities.
- **Systematic:** This type mainly is used to study and answer specific research questions.
- **Meta-Analysis:** This type mainly helps in detecting similar grounds between the results using statistical analysis and measures.
- **Meta-Synthesis:** This is mainly the use of non-Statistical analysis to help analyze the results.

- ➢ <u>Part 3 - Methodology</u>

"Methodology is the systematic, theoretical analysis of the methods applied to a field of The study" (Igwenagu 2016). As a result, the majority of this chapter of the paper will be devoted to the examination of the methodology that will be used throughout the research process. The main aim of a research paper or research report is to answer a specific problem, to find a solution for a specific topic, or to help society with a specific issue. The way this is done is by investigating the problem by using different techniques or approaches to help answer the problem. Moreover, the selection of these techniques is sometimes done by studying different papers and research that have close or similar studies and topics to help select the most effective method or technique to ensure achieving the research objectives. The main objectives or goals of the research methodology are to ensure the quality of the research, to ensure that the research goals are accurate, provide a detailed tool to help analyze the interpretations and create them, guarantee smart and precise evaluation of the research, and enhance the research ability and understanding of a specific topic. (Igwenagu 2016).

- <u>Part 4 – Case Study Analysis</u>

In this part of the research, the study will focus on the analysis of different case studies designed from multiple aspects concerning designing an entirely green museum. When designing a museum that is completely green, it's important to answer an important question: what makes it green? This part of the paper will help answer this question by defining multiple aspects that would help design a museum based on some selected case studies. The 3 selected case studies are as follows: The first case study is located in Egypt, specifically Giza. This will be the largest museum dedicated to one civilization. The second case study is located in the United States of America, specifically San Francisco, and this is counted as the greenest museum to be built. The third and last case study is located in the Netherlands, specifically in Hague. This is a conceptual project that will help in the analysis of different lighting aspects.

Furthermore, a study has illustrated that a building is green once the building is efficient, and it's efficient when it's designed in a process that provides a green and sustainable outcome from the design phase (Wilson 2018). Also, to achieve a fully sustainable building, it's important to study the sustainable rating system that the country follows. This will allow the designer to follow specific standards to help achieve the target of the building or spaces. It's important to study the site and location of the building in the beginning phases to ensure the complete achievement of green design. As seen below in Table 1, the number of multiple protocols or standards that some countries follow as a sustainable rating system (Wang & Adeli 2014). These ratings would help buildings achieve more efficiency by following the country's required standards. Furthermore, these protocols are spreading and are becoming more famous over time. For instance, LEED has registered approximately 80,000 projects in 2019, while BREEAM has around 560,000 certified projects. Each rating system has its own rating categories and groups. For instance, BREEAM's rating categories are: management, health, transport, water, materials, land use, and pollution. Therefore, it's not easy to earn 1 of these rating system certificates as it is necessary to achieve all 9 points when talking about BREEAM.(*Top 12 Green Building Rating Systems Sustainable Investment Group* n.d.). Therefore, to achieve a fully green and sustainable museum, it's important to follow a specific rating system to help ensure the coverage of all the aspects. Moving along, the design or achievement of green design is the main goal and discussion of this chapter as it will discuss how to achieve green design from a museum point of view as each building has its own perception and vision. So mainly, the target of this chapter is to analyze these perceptions to ensure complete awareness of the design phases and processes to help achieve the ultimate green design from the perspective of the designer.

- Part 5 – Selected Case Study Analysis

This portion of the Paper will mainly focus on studying the selected Case Study which will be discussed in detail later on. The selected Case Study is located in the United Arab Emirates specifically Abu Dhabi. Museums have multiple beneficial impacts on countries one of the most important impacts is the improvement of Tourism, as it has a huge impact in increasing the tourist demands. The importance of tourism is reflected through the program that was created in Dubai in 1989 which is the Dubai Commerce and Tourism Promotion Board (DCTPB), in order to enhance and help promote tourism in the UAE. Additionally, as illustrated in Figure 1.4, tourism spending in Dubai is the highest in the world, and this, on the other hand, has a huge and positive impact on

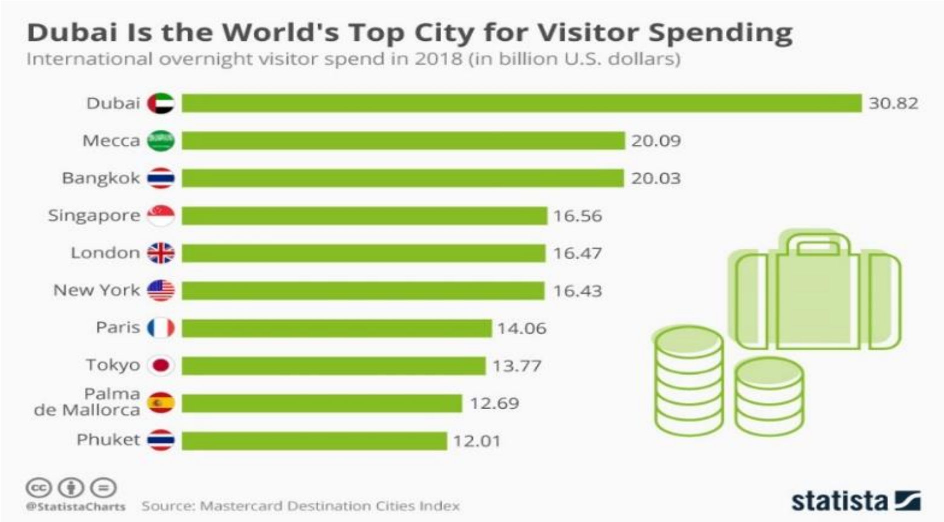


Fig 1.4. Tourism Economical Spending in Dubai *(• Chart: Dubai Is the World's Top City for Visitor Spending | Statista n.d.).*

the economy of the country (• *Chart: Dubai Is The World's Top City For Visitor Spending | Statista* n.d.). But of course, tourism has decreased due to the COVID-19 pandemic, which resulted in a slowdown in multiple fields in the UAE, and one of them is tourism. But in the first 2 months of 2020, the economy in the UAE was stable, but due to a slowdown in some of the activities, the economy started to decline again (Central Bank United Arab Emirates 2020). Moreover, the shift in oil prices has enhanced the concept of improving other sectors such as tourism. Therefore, the improvement of museums was the main goal and target as it would help with tourism, which will, on the other hand, impact the economy of the country. Furthermore, for those reasons, the improvement of the museum sector has become one of the main targets in the Gulf region. This being said and due to all of these factors, the plan to build the largest art museum in the Arabian region, the Louvre Museum located in Saadiyat Island, Abdu Dhabi, was held with an agreement with France. The arrangement was signed in 2007 and illustrated that the UAE can use the Louvre France franchise for thirty years (Effiom Ephraim 2019). France described this project as "France's Largest Cultural Project Abroad". The museum is approximately 24,000 square meters, which makes it, as said before, the largest art museum in the Arabian Region (*Louvre Abu Dhabi - Wikipedia* n.d.). The selection of this case study was based on multiple factors: 1-The huge value and recognition that the UAE gives to museums; 2-The size and impact of the Louver Museum on the region; and 3-The huge challenges that might face the designer while designing in the Gulf region.

- <u>Part 6 - Data Analysis and Discussion</u>

This part of the Chapter aims to achieve the main goal of this Research or Paper to be more accurate an article in the Journal of the Association of Physicians of India has shown that this part of the Research is the main and most important part as it showcases the writer or authors point of view in a more direct way that would allow the reader to understand the main purpose of the Research (Bavdekar 2015). So mainly it will include all the analysis that was concluded to help come up with a more obvious and understandable outcome and also as it mostly illustrates the study outcomes and demonstrates the importance of the Research.

- <u>Part 7 - Conclusion</u>

The Conclusion of the Research gives a briefer overview of the goal of the paper and all the findings that were discussed in the data analysis and discussion portion. The main aim of a research conclusion is to connect all parts of the research, to answer or provide a brief answer to the research questions, and to give direction or zones of future research related to the field of the paper. The Conclusion of the Research gives a briefer overview of the goal of the paper and all the findings that were discussed in the data analysis and discussion portion. The main aim of a research conclusion is to connect all parts of the research, to answer or provide a brief answer to the research questions, and to give direction or zones of future research related to the field of the paper.

1.5 Research Limitations

When research is initiated, a researcher will face some limitations. These limitations are the restrictions that the researcher faces during the research process. The first limitation is the timeframe of the project. Usually when research is done that analyzes different weather aspects, such as daylight, it requires the analysis of different months and seasons of the year to get an accurate outcome that would reflect the whole building's consumption, but due to the submission date and requirements, this was not possible. The second limitation is the survey analysis; the questionnaire was submitted through various sources, one of which is the museum's staff and workers. This was a restriction due to the availability of the staff, and conducting such a survey would require approval from the Louvre Museum Research Board, which consumed some time.

CHAPTER 2

Literature Review

2

C H A P T E R   I I

2. Literature Review

2.1 Introduction

The literature review is divided into several parts that will mainly help in the process of analyzing and understanding the museum's impacts on the environment. Part One which will analyze different case studies of museums that were designed based on sustainable Background and Analysis, to help in understanding museum design from different perspectives. Part Two will mainly focus on the analysis of different sustainable materials, especially in the selected case study location. Part Three of the literature view focuses on the role of lighting in shaping art viewers' experiences, as this offers a snapshot into the state of research on art and lighting in exhibitions. Art is one of the main avenues of preserving the history of a people, and sustainability is a key aspect to make art even more efficient. Sustainable participation in art can come from different aspects such as the reflection of the natural landscape, the expansion of cities, the effects of industrialization, the emergence of female artists, and the utilization of resources, and the reuse of waste (Fathy et al., 2020). Moreover, this paper will also analyze and study the different lighting factors that influence a space from different perspectives, focusing on natural and artificial lighting sources and how to improve the lighting to ensure the best experience for users and best environment for artwork, specifically that which is delicate. Lighting is hugely important to the display of art and can magnify these elements through the use of different technologies, such as the use of LED sources marked by a spectral emission of light by adhering to surface color and related transmission picture content details (Fathy et al., 2020). Additionally, the literature review will have one part that delves into people's views of art, whereby the common themes of subjectivity and effect are covered. By analyzing how art was used in the past and its different types, this paper will show how the development of art over time impacted museum design. Through careful design that recognizes and complements the development of the art itself, it is possible to attract visitors to enjoy a distinct itinerary that assists them in comprehending this context for the art they view. Moreover, sustainability is strongly connected to the development of perception and visual welfare, light communication, and lower consumption of energy. The irreplaceable nature of some of the art pieces demands a balance between display and security.

Every display in a museum or gallery has to ensure the aesthetics and security work in tandem, thus these two elements must be designed into the galleries and museums.

2.2 Museum

In the words of Islamoglu (2018), “The safeguarding of cultural heritage allows for cultural continuity and creates a sense of history in the minds of people who then can better understand the present.” This clearly illustrates the importance of museums and their impacts on humans. The whole concept of the museum was inspired by the human need to understand the world through the process of collecting (Pearce, 1994). Museums were first inspired by the Greek word *Mouseion*, which means *the place where the Muses live* and originated in the Temple of the Muses in Alexandria in 305-283 BCE. The Muses are the sisters of Greek Goddesses who were responsible for inspiring science and art, and the concept of the museum was mainly inspired by the 9 Muses including Clio the Muse of history (Günay 2012a). Museums have traditionally been defined as a space to store old materials and items. But in the present day, due to people's awareness and the UNESCO procedure of creating the International Council of Museums Members (ICOM), the concept of museums has evolved and developed (Kamaruddin, 2019). According to ICOM, a museum is defined as an everlasting organization that is publicly available that acquires, conserves, investigates, and exposes the direct and indirect course of human history and its surroundings for the sake of education, study, and enjoyment (Günay, 2012b). Furthermore, over 800 million visitors visit museums yearly, making them popular and highly valued destinations (Group 2011). A 2010 Australian study indicated that 25.9% of the Australian population over age 15 has visited art galleries and 25.5% have visited museums while another 36.8% visited zoos (*4172.0 - Arts and Culture in Australia: A Statistical Overview, 2011* n.d.). Over the years, museums have had the important role of protecting history and providing users a specific place where they can understand the culture and history of a specific region; museums always have reflected the concepts of perceiving and protecting but they also need to be entertaining and provide an exciting experience for the user. It has been shown that when users interact with different art or artifacts from different periods this opens up a new perception and understanding of the world, which gives a new perspective on the environment (McNichol 2010). Therefore, it is important to study all of these different elements to create a space that achieves these cultural, educational, and entertainment goals.

2.2.1 Museum Design

When designing a museum, the main aim and target of the designer is to increase communication between the visitor and the art/artifacts. This communication happens through various and multiple methods from presentation to murals type and more (Bayer 2010). Moreover, over the years, the usage and role of museums have developed and grown. In the past museums were mainly designed as educational facilities. In the early 19^{th} century, museums were only designed and focused only on experts but by the end of the 19^{th}-century, they were open to all and began to focus on both education and entertainment. Their focus also shifted from objects and services to information delivery (Kamaruddin 2019). According to Bitgood and Patterson, museums' main functions are to collect, research, translate, and document collections to visitors (in West 1990), while another study showed that the main function of museums is their ability to tell a story through object display (Neal 1987). This point was also reflected by Hooper-Greenhill in 1994, who reinforced that an exhibition must communicate with a visitor through storytelling (Green-Hill 1994).

In order to help understand the concept of museum design, it's important to understand the different types of museums. The Classification of Museums was illustrated in different studies using different methodologies and terminologies. Museums can be divided into 7 main categories (*Different Types of Museums The defining characteristic of any museum is its collection | Course Hero* n.d.):

1- Art Museums: exhibit artwork, sculptures, and any decorative element.
2- Children's Museums: exhibit elements that communicate with children and increase their awareness and knowledge.
3- College/University Museums: educational museums that focus on educating students.
4- History Museums: showcase historical elements from one or more civilizations.
5- Nature Museums: showcase different natural elements and nature-related outcomes.
6- Science Museums: showcase all science-related studies such as archeology, geology, paleontology, and medicine.
7- Specialized Museums: exhibits focus on different specific areas or elements such as architecture, guns, etc.

Another study has classified museums as follows (*Types of Museums - Museum Types and Categories* n.d.):

1- Archeology Museums: mainly focus on displaying all archeological artifacts.

2- Art Museums: showcase any type of artwork or any art objects.
3- Encyclopedic Museums: mainly illustrates different information from different themes and different regions.
4- Historic House Museums: a house or a space that is transferred into a museum, often due to the person that was living in this house.
5- History Museums: showcase historical items through storytelling.
6- Maritime Museums: focus on marine-related history, for instance by displaying shipwrecks.
7- War Museums: focus on explaining and displaying war-related stories and also exhibit object from past wars.
8- Mobile Museums: showcase items and objects in a temporary and movable demonstration such as cars or vehicles.
9- Natural history museums: showcase natural creatures such as stuffed animals, also the evolution of some creatures, etc.
10- Pop-up Museums: museums that don't last long and which are irregular and non-traditional.

A more detailed classification of museums based on multiple factors is presented by Hobsbawm (2007):

The first factor is the type of exhibited objects, this type is focused on the nature of the collection.

- Historical Museums focus on exhibiting collections from the past, showcasing artifacts from archeology, art, ethnography, personalia, etc.
- Site Museums focus on showcasing artifacts from one area or site that sometimes focuses on one group of people.
- Natural history museums exhibit multiple nature-related artifacts and objects.

The second factor classifies objects based on the owner or the person who runs them and they are as follows:

- Governmental Museums are run by governments such as central government museums, state museums, municipality museums, and some university museums.
- Military Museums are controlled by the military and serve to exhibit and showcase their achievements.
- Private Museums focus on showcasing private items or private individual collections.

The third factor is based on the museum's location and they are as follows:

- State or District Museum: usually located in national capitals, these museums are typically located in each state and are financed by the government.
- Rural Museums are located in rural areas and showcase the heritage of the area.
- Water Front Museums are located in front of a water features such as seas, rivers, or oceans.

Based on all of these classification systems, museums can be divided into five main types: general museums, natural history and science museums, technology museums, history museums, zoos, and art museums. The results of a 2006 survey comparing visitor rates by museum are illustrated in Figure 2.1 below (Group 2011).

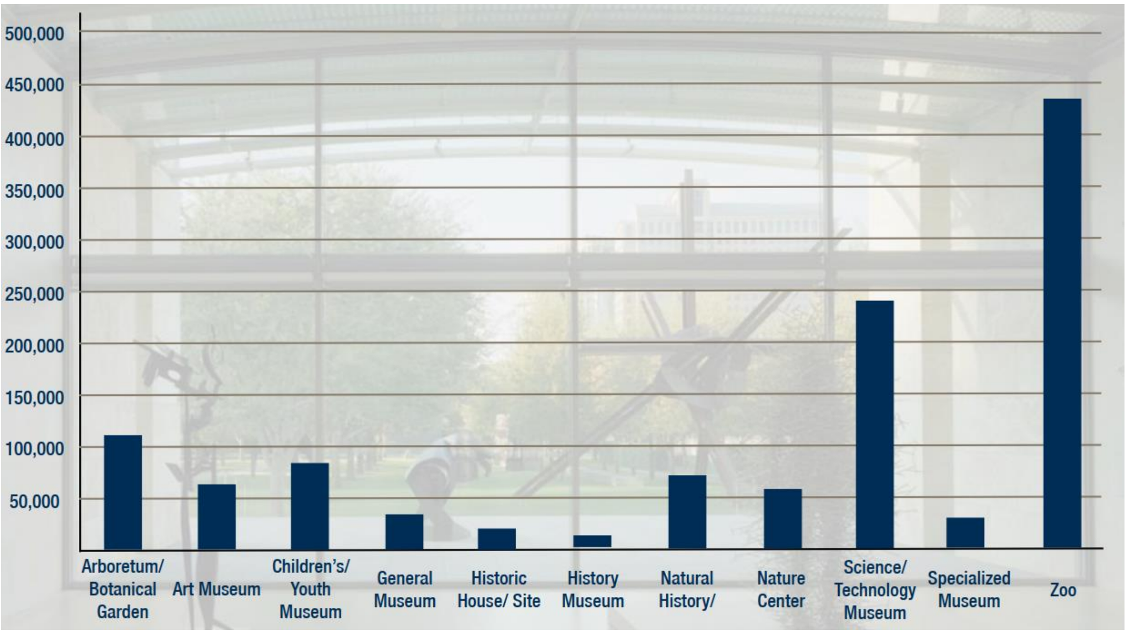


Fig2.1. Comparing Museum Types based on Number of Visitors *(Group 2011).*

Museum design is mainly focusing on the visitor experience: the visitor enters the space for an individual experience with the exhibited objects and the key for enhancing this experience is the ability to circulate effortlessly in the museum (Museums and Galleries 1928). Many factors contribute to museum impacts; as illustrated by Sahar Safavi, several of these are most important (Architecture 2013). The first is *Economical Impact*: museums provide a huge economic benefit which is mainly reflected in tourism. Carey, Davidson & Sahli (2013) demonstrated that a primary role of the museums is to contribute to the country's economy through tourism as some people rely on museums to learn about the visited country or area. They showed that museums contribute around 21 billion dollars to the US economy each year (*Museums and Economic Impact. If you read my commentary last week on… | by Bob Beatty | Medium* n.d.). Likewise, Stylianou-Lambert (2009) illustrated that most tourists orient themselves to the visited destination or country through museums. Based on the Tourism Research Guide of Australia, around 7 million tourists visited Australian museums in the year 2010 (*Home | Tourism Research Australia* n.d.). The second factor in calculating museums' impact is *Social Impact*, which is mainly reflected in education. John Falk & Lynn illustrated that the educational role of museums is due to the wide range of exhibits that gives viewers a meaningful educational experience where they can learn from multiple and different aspects. A small study was done comparing both schools and museums in relation to education; results are illustrated in Table 2.1, showing that museums have a huge impact and influence in specific courses such as history, geography, and art (Singh 2004). In addition to that, as illustrated by David Lowenthal in his book *The Past is a Foreign Country*, museums strongly influence communities to understand their past and present (Web & Lowenthal 1985).

Table 2.1. Comparison between Museums and School in relation to Education *(Singh 2004).*

Subject	School	Museum
1. Free choice	No	Yes
2. Instruction based on	Text	Object
3. Senses most used	Oral	Visual
4. Syllabus-Oriented	Yes	No
5. Formal assessment	Yes	No
6. Time Schedule	Yes	No
7. Learning	Linear Non-Spontaneous	Multi-Faceted Spontaneous

The last important factor contributing to museums is *Political Impact*, acknowledging museums' function as a safe environment for artifacts and works of art that would require special care. This also promotes visitors' sense of belonging due to historical and heritage aspects that are included in museums. Additionally, to help clearly understand the museum design it is important to analyze the museum from a visitor's point of view. As explained by Bataille (1930), all of the museum and its artifacts are just vessels, the real content of the museum is the visitors. Screven (2010) explains that understanding the visitor's reason for the visit is divided into two main elements: Intrinsic Incentives and Extrinsic Incentives. Intrinsic Incentive is the challenge a museum might give the visitor, or the personal relationship between the visitor and the museum. Extrinsic Incentive refers to any type of reward or gift that might be provided to the visitor. Rapaport (1982) showed that for the visitor to have a fulfilling experience in a museum, its design must focus on three main factors:

- *The setting of the scene*, meaning that the visitor should be able to be well oriented in the space to view all of the artwork and artifacts. Missing this point would result in an unwanted outcome for visitors in the museum.
- *Mapping of the space* indicates there must be clear passage and easy movement within the space as to enhance the user experience, and lacking this type of mapping would result in a chaotic experience for the visitor.
- *Crowding* indicates the amount of crowd gathering in one area at a given time, as this will result in an unwanted experience for the users.

Another study done by Hood (1981) divided museum visitors based on the amount and number of times they visit museums; Hood identified three main types: frequent visitors, occasional visitors, and non-museum visitors (who have never visited a museum). This takes us to the next and the most important part of museum design, which is understanding the elements of design of the space and the specific elements that will be followed in the process of design. Furthermore, the first element of design that is selected and followed by the designer is the *form* of design: every shape is created from a form, and the designer's objective deals with these forms when designing a space (*Elements of design | InVision* n.d.).

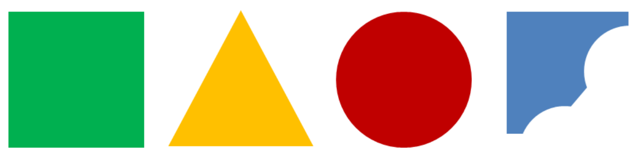


Figure 2.2. Different Form Shapes *(Elements of Design – Shape and Form « Lens, light & Composition n.d.)*

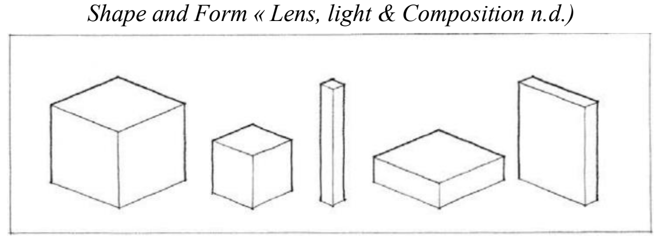


Figure 2.3. Different Form Sizes *(Ching 2007)*

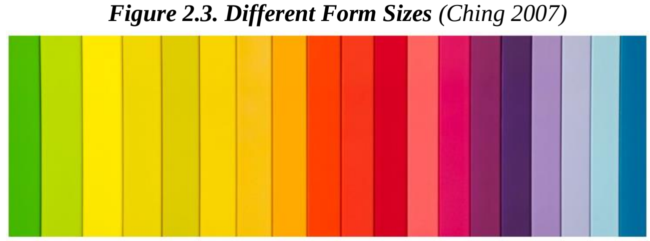


Figure 2.4. Different Form Color (Meola 2001)

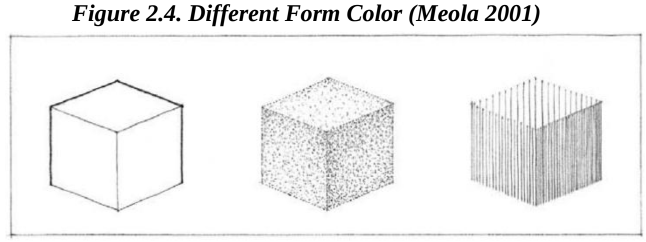


Figure 2.5. Different Form Texture *(Ching 2007)*

The form is affected by various aspects as illustrated by Francis Ching. First is the shape of the form, as the shape differs from one form to another as seen in Figure 2.2 (*Elements of Design – Shape and Form « Lens, light & Composition* n.d.). The second aspect that affects form is size: the size of the form will have a huge impact on the designer as it might affect the proportion and the circulation within the space as illustrated in Figure 2.3 (Ching 2007). The third aspect is the color of the form: this aspect has a huge impact on the interior design of the space as color pychology is related to every element and aspect of design. A study illustrated that 90% of a space is judged based on its colors (Hilliard 2013). However, the perception of colors is based on three main conditions: the color's huge, which is the complete color; the color's value, which refers to the brightness of the color; and chroma, which refers to the saturation of the color as seen in Figure 2.4 (Meola 2001). The fourth aspect is the texture of the form, which is a visual and perceptible effect given to the form to enhance the quality of an object as seen in Figure 2.5 (Ching 2007). The fifth and last aspect is the line of the form: the line is the connection between two shapes or forms and also it is created when two shapes are encountered (Stewart, Archibald & Junior 2016). Lines are the constant movement of a point, and the line can have multiple thicknesses and lengths (*Elements of Design* n.d.).

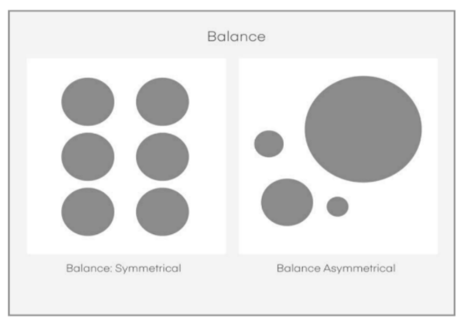


Figure 2.6. Balance 2 Different Types
(Principles of design 2012)

The next important aspect when starting any design is the principles of design. These are the concepts and principles that are used to organize and implement the elements of design described as the most functional and systematic matter to improve the design (Principles of design 2012). In general, the principles of design are divided into seven main types. The first principle is balance, which Haylett (1991) described as the distribution of visual mass in the space. Another study described balance as the placement of items in respect to one another in the space (Pandey 2012). Balance can be divided into three main types, which are symmetrical (both sides are the same or a design is mirrored in the other direction exactly), asymmetrical (the opposite of symmetrical; both sides are not mirrored but visually they are the same weight of design), and radial (the design is evolving from the center point or the middle of the space) as illustrated in Figure 2.6 (Principles of design 2012). This principle is visible in museums as illustrated in Figure

2.7, which shows symmetry left of the red line from fight red line zones (*Free Images : person, architecture, wood, building, symmetrical, museum, hall, sitting, indoor, church, chapel, concrete, place of worship, interior design, symmetry, tourist attraction, estate 3233x4041 - - 160031 - Free stock photos - PxHere* n.d.). The second principle is emphasis, which is used when the designer aims to attract the viewer or the visitor to a specific element or object and it is usually called a focal point (*The Principles of Design and Their Importance | Toptal* n.d.). Usually, emphasis is achieved by changing the size, color, weight, or position of a specific element to garner the spectator's interest. This is illustrated in Figure 2.8, which also illustrates multiple other principles such as symmetry (*Zaha Hadid to create maths gallery at London's Science Museum* n.d.). The third principle is contrast, which refers to the amount of difference between two or more objects in the design. As illustrated in Figure 2.9, the amount of contrast is differentiated by different impacts such as color, scale, and shape (*Principles of design | InVision* n.d.). As illustrated by Reid, contrast is reflected when a viewer defines the design as "It pops" meaning that the design has high contrast (*The 7 principles of design - 99designs* n.d.). The fourth principle of design is repetition. As the name suggests, this indicates repeating a specific object or element throughout the design as illustrated in Figure 2.10 (*The Principles of Design* n.d.). Some studies illustrate that repetition, pattern, and rhythm are equal because if repetition exists then pattern and rhythm are necessarily created. This was also illustrated in Figure 2.11, which demonstrates the Singapore ArtScience Museum designed by Jouin Manku (*6 Simply Amazing Museum Interiors - Interior Design* n.d.) The fifth principle of design is unity or harmony and it is created when a

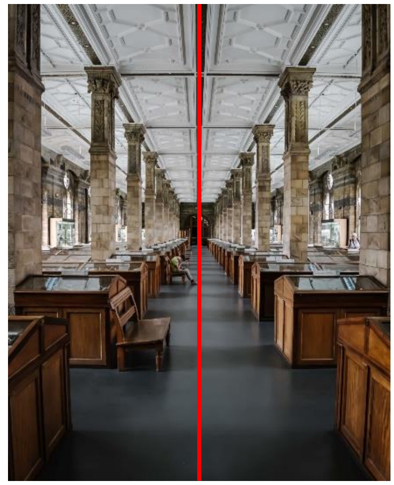


Figure 2.7. Symmetry in Museum Design

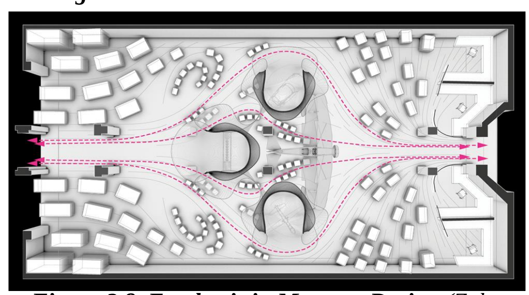


Figure 2.8. Emphasis in Museum Design *(Zaha Hadid to create maths gallery at London's Science Museum n.d.)*

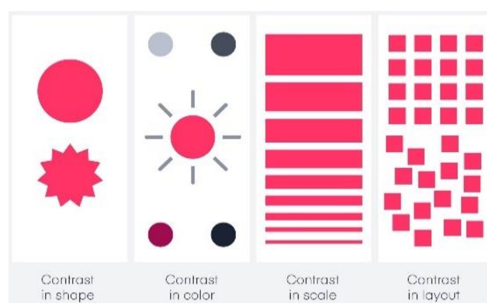


Figure 2.9. Elements that Impact Contrast *(Principles of design | InVision n.d.)*

similar relation is created between different elements, for instance by adding the same color for different elements. How well the elements work together defines how much harmony exists (*Principles of Design Importance. The principles of design are made up of… | by Suleiman Bashiru | UX Collective* n.d.). The sixth principle is movement, which refers to the flow of objects within the space. This is translated in museums with the flow created by the artifacts and objects, which allows visitors to smoothly move along. The seventh principle of design is hierarchy, which is basically the arrangement of items or objects in the design based on importance. These are most important principles that are used when designing a new space in order to ensure it is efficient and well-designed. Some studies add or remove other principles based on the authors' perception and understanding. Ching (2007) divided the principles as follows: Axis, Symmetry, Hierarchy, Rhythm, Datum and Transformation.

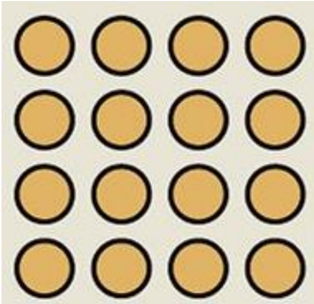


Figure 2.10. Repetition of Design (*The Principles of Design n.d.)*

Figure 2.11. Repetition of Design In Museums *(6 Simply Amazing Museum Interiors - Interior Design n.d.)*

The next phase or aspect of designing is the employment of all of these principles and elements based on the requirements through the careful organization of the space to enhance the user experience. This phase is usually done at the starting point for any interior design process. This phase is divided into two main categories based on the relation of the spaces. The first is the **Spatial Relationship**, or the relation between different spaces or zones. When multiple spaces are involved with each other, in order to enhance the interior space these spaces must have an association with each other; this association is called the spatial relationship (*Spatial Relationships for Interior Designers - InteriorPH* n.d.). Ching (2007) describes four main types of spatial relationships. *Space within a space* defines the relationship wherein one space is integrated into another space, seen in Figure 2.12 (Ching 2007). *Interlocking space* is a result of overlapping or interlocking

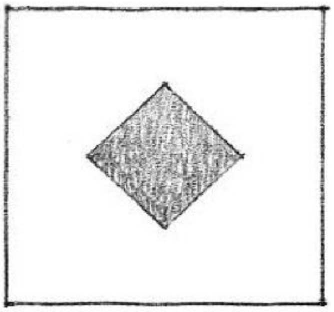


Figure 2.12. A Space within a Space Illustration *(Ching 2007)*

volumes or space (*Spatial Organization in Architecture - Your Own Architect* n.d.). Usually, an interlocking creates some sort of shared space that might be used for a specific function as illustrated in the Figure 2.13. In the Grand Egyptian Museum, the interlocking space has created a shading and lighting element to the space (*Grand Egyptian Museum - BESIX* n.d. a).

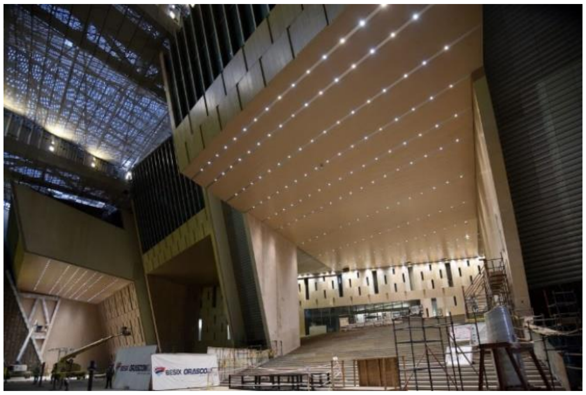


Figure 2.13. Interlocking spaces in Grand Egyptian Museum *(Grand Egyptian Museum - BESIX n.d. a)*

Adjacent space is the concept of having two separate spaces that can each have their own function and requirements while having a shared space between them, as illustrated in the Figure 2.14. Having a partition between two spaces is an example of adjacent spaces. Furthermore, as illustrated in Figure 2.14, both spaces could be completely different in shape but still having a joined space or area between them (*Spatial Organization in Architecture - BlARROW* n.d.). Having a column or even a step that changes level between the spaces could imply or suggest some type of adjacency between them.

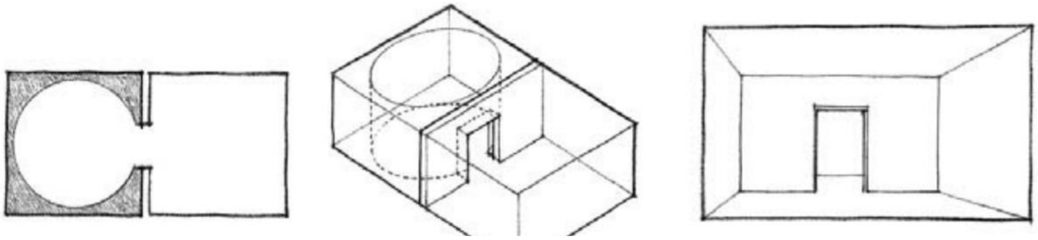


Figure 2.14. Adjacent Spaces Relation between 2 Different Spaces *(Ching 2007)*

Space linked by a common space is the concept of having two different spaces connected by one common space such as a bridge for instance. Figure 2.15 shows both spaces A and B connected with a common space C (*Think simple: Chapter 4* n.d.). These are the four common spatial relationships that are built between two or more different spaces.

Figure 2.15. Space Linked by a Common Space *(Think simple: Chapter 4 n.d.)*

The second category is *Spatial Organization*, which is the concept of adding order and arrangement to the functions and objects in the space using specific rules and guidelines (*Organization In Architecture. – Shivali akki* n.d.).

Linear organization is the first type of spatial organization and refers to creation in a linear concept focusing on arranging the spaces and objects on a straight or single-axis rather than randomly arranging the space or objects (*Organization of forms* n.d.). *Centralized organization* refers to arranging the objects from the center of the space based on the concept of the design. In Figure 2.16, centralized organization is visible as all of the design originates from or is focused on the center of Al Wasl Dome (*Al Wasl dome for Dubai Expo 2020 is an architectural marvel* n.d.). *Radial organization* is a concept combining both linear and centralized organization wherein objects are initiated from the center in a linear manner, which is also visible in Al Wasl Dome in Expo 2020 Dubai. The clustered organization focuses on arranging the objects or spaces based on function but they are arranged using a specific technique or system such as arranging the objects on a specific axis, or arranging objects sharing the same shape, or arranging the objects along a path (*5 Basic Design Organizing Principles for Facilities | Schmidt Associates* n.d.), as illustrated in Habitat 67 Figure 2.17 (*More than half century after construction, Montreal's Habitat 67 still captivates* n.d.). *Grid organization* is the last type of spatial organization and it focuses on arranging the objects or spaces using a Grid. Some grids can be developed based on the designer concept, or a simple grid could be used in order to arrange the space in a more organized manner. The use of a grid to create a design that would help define the space is visible in Figure 2.18 (*Toyo Ito – IAAC Blog* n.d.).

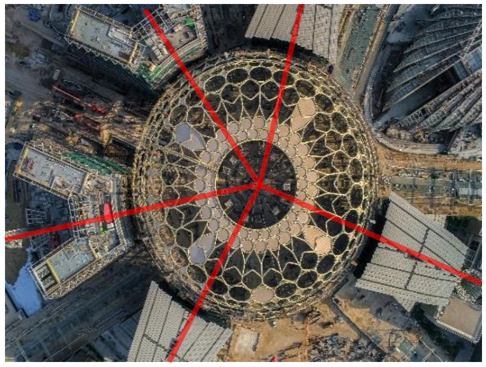


Figure 2.16. Centralized Organization in Expo 2020 Dubai *(Al Wasl dome for Dubai Expo 2020 is an architectural marvel n.d.)*

Figure 2.17. Cluster Resedential Building organization in Canada *(More than half century after construction, Montreal's Habitat 67 still captivates n.d.).*

After finishing the initial phase of design, there are other aspects to consider. When designing a museum, it's important to focus on three main elements. First is the acoustics of the space. The study of acoustical behavior is diverse especially in the spaces that are acoustically-related such as theatres and concert halls (Pelorson, Vian & Polack 1992). Additionally, Carvalho et al demonstrated that some specific parameters define a successful acoustic museum design or space; those parameters are reverberation time, which is the period required for sound to decay (Olshausen 2019); Speech Transmission Index or STI, a method used to predict speech fluency (Rindel 2014b); and background noise from visitors and the HVAC system. Furthermore, the authors used two different case studies from both traditional and modern designs. These case studies illustrated that the ideal average reverberation time for museums is between 0.8 s and 1.4 s, while the STI level ranges between 0.45 s and 0.65 s to enhance and improve speech conditions. Additionally, for the HVAC background noise, the study illustrated that the value should be less than or equal to 45 dB (Carvalho, Gonçalves & Garcia 2013). Another study done in Oslo illustrated after following the Norwegian Standards for Acoustics that the average reverberation time is based on the type and the amount of sound (Rindel 2014a). Additionally, as shown in Figure 2.19 where the reverberation time was calculated using different aspects for the interior space, the standard reverberation time based on the Norwegian Standards is between 0.8 s and 1.2 s in different frequencies (Olshausen 2019).

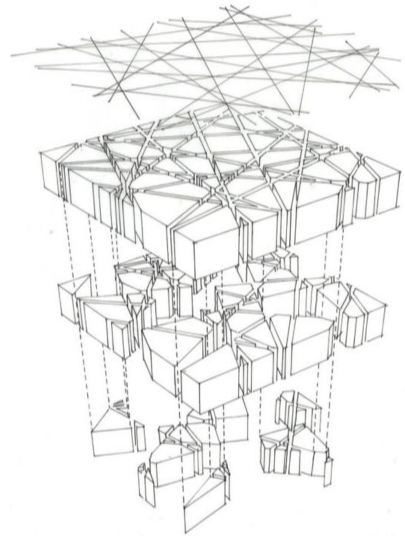


Figure 2.18. Using Grid to Create organization concept for objects and spaces *(Toyo Ito – IAAC Blog n.d.)*

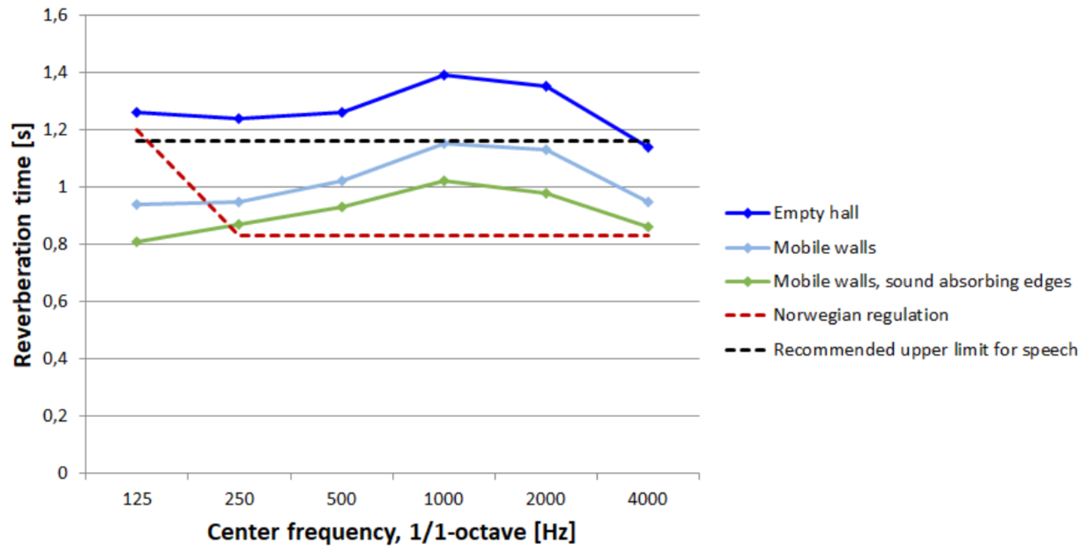


Figure 2.19. Reverberation Time Average based on Norwegian Standards and the result in the studied Case Study *(Olshausen 2019)*

The next important aspect that is counted as the most important phase when designing a museum is lighting. Rosenfeld demonstrated that lighting in museums acts as a reference for all other interior spaces, which means if the lighting is good for museum application, it's good for other functions as well (*The Art of Museum lighting* n.d.). Lighting is the main key and aspect in the success of museums; the main aim of this paper is to focus on analyzing different aspects of lighting, therefore, there is a section of the literature review that will discuss lighting thoroughly. A study done by Kevan Shaw demonstrated that lighting could be a damaging tool or force, especially in museums, as it might interfere with the concept of history preservation and might damage the artifact (*museum lecture - Kevan Shaw Lighting Design* n.d.). Ajmat et al. (2011) illustrated that the damaging effects of lighting on artifacts can fall under multiple factors. One of these is the amount of light: uncontrolled amounts of lighting can significantly damage artifacts. The materials that the artifact and/or art are made of might increase the possibility of their being damaged by lighting, but this factor is uncontrollable by the designer. The role of the designer is to showcase these works of art as they are, taking their materials into account. The last aspect is the amount of time the artifacts are exposed to the light, which will certainly have a huge impact on the artifacts (Ajmat et al. 2011). Therefore, well-studied lighting is crucial for the success of the museum space. Lighting also impacts the enjoyment and journey of the museum's visitors. Rosenfeld illustrated that lighting gives more context to the existing art (*The Art of Museum lighting* n.d.).

Another important aspect and phase of design is to study the Indoor Air Quality (IAQ) and all the HVAC systems of the space. All these aspects contribute to a healthy indoor space especially when it comes to museums. Carmuffo et al. (2004) demonstrated after multiple trials and examinations that HVAC and IAQ can have a huge negative impact on the preservation of the work or objects in a space. They also illustrated that having a Microclimate, which is an environment inside an environment, might help in the preservation of the art if the indoor climate isn't controllable (Camuffo et al. 2004). Angela Chang also demonstrated that having such Microclimates in old and traditional buildings acts as financial aid to these spaces to help preserve the objects without being required to completely add or change their HVAC systems. This aspect was also demonstrated by Karen Gausch, who said that microclimate helps to protect historical objects and ensure people can enjoy them for many years to come (*Microclimates in the Museums | Index Magazine | Harvard Art Museums* n.d.).

2.2.2 Green Museum Design

A green design focuses on minimizing damage that might occur from construction, which might affect human health as well as the environment. Designing an environmentally-friendly building is sometimes a challenge to the designers as it required following different codes and regulations to help ensure an environmentally-friendly space or building (*Introduction to Green Architecture and Design* n.d.). Additionally, designing a museum with a fully sustainable environment and design has multiple aspects to focus on, starting with the protocols and standards followed by the country in which the museum is located. These protocols or standards typically govern all the emissions and energy consumption associated with the building during its phases of construction and the lifespan of the building. The first standards and protocols were launched in 1990 – the Building Research Establishments Environmental Assessment Method (BREEAM) (Reeder 2011). In 2000, the Green Building Council in the United States Developed Leadership in Energy and Environmental Design (LEED), a rating system developed to help improve the environmental performance of buildings. However, a 2006 study demonstrated that few UK-based museums are thinking seriously about sustainability when it comes to museum design (Museums Association 2008). The United States built their first museum that earned LEED in 2004, meaning that this museum achieved the sustainability standards and protocols that are required by the country (Günay 2012b). The green museum design process is similar to any design procedure, but designing a green building always seeks to maximize the site's capability, reduce the use of nonrenewable energy, make use of eco-friendly products and goods, and necessarily improve the quality of the interior environment (*Sustainable Design | GSA* n.d.). Jong Jin demonstrated that the design of an environmentally-friendly building occurs under three main principles. The first of these is the *Economy of Resources*, essentially the 3 R's – Reduce, Reuse, and Recycle – and also through the conservation of resources such as materials, water, and energy. The next principle, ***Life*** *Cycle Design*, emphasizes understanding the life cycle of building materials through the pre-building phase, building phase and the post-building phase (these will be discussed thoroughly later in this paper). The final principle is *Human Design*. Humans spend around 70% of their life indoors therefore it is essential to design spaces that can sustain users' psychological and physical health and this is achieved with well-designed and sustainable spaces (Trimingham 2016).

2.2.3 Environmental Conditions

Another important aspect of museum design is the status of environmental conditions or Indoor Environmental Quality (IEQ). These affect the health and well-being of museum users or occupants. IEQ is influenced by air quality, lighting, thermal conditions, and humidity (*Green Building 101: What is indoor environmental quality? | U.S. Green Building Council* n.d.). These are illustrated by Muhammad Abul Mujeebu in Figure 2.20 (Ivanova et al. 2016) (Mujeeba 2018).

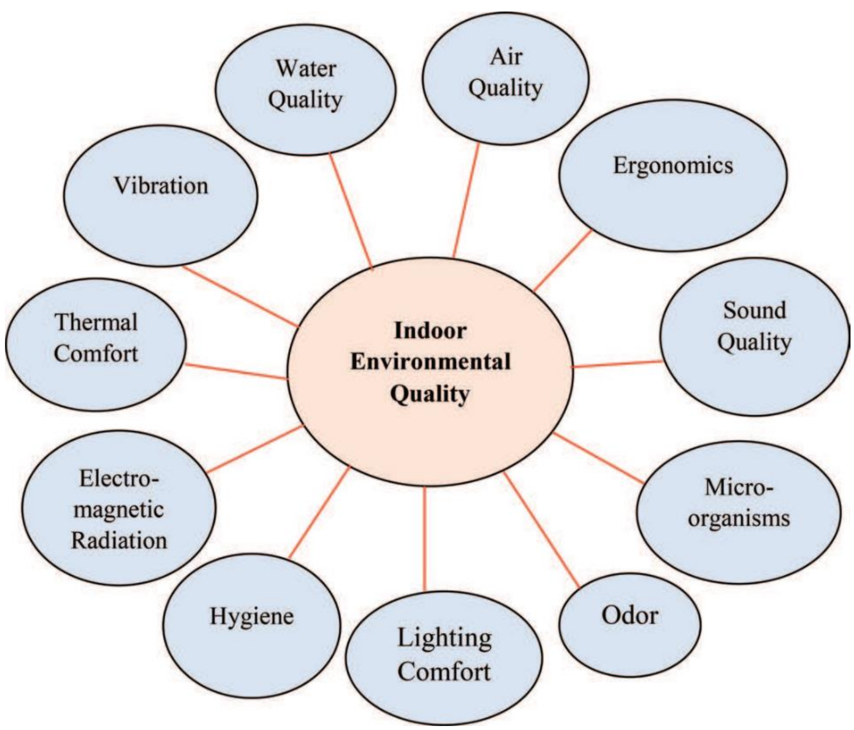


Figure 2.20. Indoor Environmental Quality Aspects *(Mujeeba 2018).*

Museum considerations usually focus on IEQ from a different perspective based on two main factors: the artifacts and the visitors.

A) <u>Artifact</u>

When a museum is designed, it is important to understand the type of artifact that will be exhibited. Objects or artifacts are divided based on the materials they're composed of, which could be organic, inorganic, or mixed materials. (Pavlogeorgatos 2003). Additionally, the main parameters that will have a huge impact on the artifacts are humidity, temperature, lighting, and pollution.

Relative Humidity (RH) has a huge effect on the objects and the artifacts as it has a huge influence on the chemical, biological, and physical status of the objects. Based on the British Standards, the RH might be high, low or unstable and each of these will have a specific impact on the artifact (BSI British Standards Institutions 2011). High RH might lead formation of mold, which occurs when RH exceeds 65%. Materials in low RH might dry out, leading to cracks and breakage; therefore an RH between 40 and 60% is ideal to avoid that damage (*Managing relative humidity and temperature in museums and galleries - Preservation Equipment Ltd* n.d.). It is also shown that the RH should not go lower than 25% and every 5% drop increases the potential for more physical damage to the objects (Mecklenburg 2004). Overall, the ideal or recommended RH for museums in UAE is between 50% and 55% (*Recommended Humidity levels for residential and commercial applications* n.d.). The annual RH in Abu Dhabi is illustrated in Table 2.2 (Statistics 2019).

Table 2.2. Relative Humidity in UAE *(Statistics 2019)*

(%)

Month	Abu Dhabi	Al Ain	Al Dhafra	The Islands
January	67.3	60.4	66.5	68.7
February	62.3	55.0	63.2	70.0
March	62.3	43.9	56.5	72.0
April	52.0	28.9	41.6	59.0
May	50.8	27.4	36.5	55.3
June	57.0	30.4	39.8	57.0
July	45.5	26.3	39.8	58.7
August	46.8	28.6	44.8	59.0
September	54.8	28.6	47.5	61.0
October	64.5	38.1	52.0	62.0
November	54.0	47.0	55.2	55.7
December	67.0	56.3	60.5	68.0

Therefore, it is greatly advised to make sure to monitor museum humidity levels daily using multiple methods such as humidity cards, hygrometers, and data loggers (*Managing relative humidity and temperature in museums and galleries - Preservation Equipment Ltd* n.d.). Table 2.3 illustrates RH values for different museum artifacts and objects based on sensitivity.

Table 2.3. Relative Humidity Guidelines *(BSI British Standards Institutions 2011) (Author)*

	Relative Humidity%										
	0	10	20	30	40	50	60	70	80	90	100
High Sensitive Object											
Moderate Sensitive Object											
Low Sensitive Object											
Mould Risk											

B) <u>Lighting</u>

Lighting is the main foundation for a successful museum experience for visitors. If lighting isn't well designed it will cause huge collateral damage on the artifacts and objects in the museum. The reason for this damage is caused by the wavelength from the light: when wavelength radiation decreases, photochemical damage increases (Durmus 2021). The effect of lighting is based on two factors, namely UV radiation and light intensity. It is shown that natural light has the highest UV radiation therefore it is important to apply UV filters on the windows and openings in order to reduce the impact of the UV radiation from natural light (Pavlogeorgatos 2003). The maximum UV radiation to which museum artifact should be subjected to is 75 µW/lm, based on the Canadian Conservation Institute (CCI) and the British Standards Institute (BSI) (*Environmental Guidelines for Paintings – Canadian Conservation Institute (CCI) Notes 10/4 - Canada.ca* n.d.) (BSI British Standards Institutions 2011). Maximum intensity is measured in Lux and varies based on the type of artifact, which can be defined as very sensitive, moderately sensitive, and not sensitive. BSI has divided the intensity as follows: very sensitive objects can endurance maximum intensity of 50 Lux, while moderately sensitive objects can endurance a maximum of 200 Lux, and objects that are not sensitive can endurance maximum of 300 Lux (BSI British Standards Institutions 2011). Different studies have concluded the same results, such as Negar Hassanizadeh (2020), which demonstrated a variation from 50 to 70 Lux for very sensitive objects, 200 to 250 Lux for moderately sensitive objects, and more than 300 Lux for objects that are not sensitive (Hassanizadeh, Noorzai & Mohseni 2020). Additionally, various authorities have established guidelines for designers to follow in order to protect art and artifacts such as the Illuminating Engineering of South America. These guidelines concluded similar results as in the BSI which are all illustrated in Table 2.4. The International Commission of illumination (CIE) has the most limiting outlines or standards to follow in museum illumination. They identify a maximum of 15 Lux for materials with high sensitivity, around 150 Lux for the moderately sensitive materials, and the materials with low sensitivity around 600 Lux. This difference is due to the different categories of materials utilized by the CIE. The CIE divided the materials into four categories based on how the material responds to visible light. These restrictions in the CIE outlines become equal to the other standards such as BSI after examining the materials in each category (CIE 157 2004).

Table 2.4. Lighting Guidelines based on Various Organizations (*BSI British Standards Institutions 2011) (Illuminating and Engineering Society of North America 1996) (CIE 157 2004) (Author)*

Organization	High Sensitivity	Medium Sensitivity	Low Sensitivity
British Standards Institute or BSI	50 Lux	200 Lux	300 Lux
Illuminating Engineering Society of North America or IESNA	50 Lux	480 Lux	300 Lux
International Commission of illumination or CIE	15 Lux	150 Lux	600 Lux
Canadian Conservation Institute or CCI	100 Lux	1000 Lux	-

Additionally, the differences between values in the guidelines are mainly due to differences in how long the object is exposed to light, as each standard follows a different scale. For instance, IESNA standards are based on 8 hours of light per day and 125 days of exposure per year, while the CCI is based on an 8 hrs/day and 250 days/ year exposure. The Chartered Institution of Building Services (CIBSE) in 2006 gave a specific value for lighting using general tasks as examples. For interiors that require casual seeing without details, a Lux value of 100 would be efficient. In a space where visual tasks are moderately easy, a Lux value of around 1000 Lux would be required. Spaces that require very difficult tasks with detailing would require a value of 1000 Lux. This could be a rule of thumb based on typical tasks, which is useful for designers (Andersen 2014).

2.3 Sustainable Materials

Rapid increases in pollution and environment hazards are caused by many different factors, one of which is the urgent requirement for waste disposal due to the increase in demand for numerous products. One study illustrated that around 7 to 8% of total greenhouse gas is produced from only Portland Cement Production (Rousseau n.d.). Portland cement is the most common cement used for buildings and other construction needs and it is the main ingredient for the production of concrete (*How Cement Is Made* n.d.). To help better understand materials, it's important to know their origins and development over time. Materials are divided based on the ages in which they were developed and first used. This began with the Stone Age and the use of stones, clay, wood, etc., During this era, the use of natural materials was the only option. After that, the Copper Age started around 9000 BC (Ruqin, Sun & Liang 1995) and the Bronze Age in 3000 BC (Kränzler 2010). After that, the Iron Age began, which is the latest period of the materials division which started around 1200 BC. When thinking specifically of sustainable materials, one can find different definitions. Some studies would illustrate that people define a product or outcome as sustainable or green if the used Materials was green. Others focus on the journey of the material or product and those which involve the least CO2 and gas emissions and throughout their transport. Some have argued that as long as a material has at least one good impact on the environment, it can be counted as sustainable (Cody & Sheets 2009). The idea of using sustainable materials has been increasing greatly in popularity in different industries, and mainly in the construction and building field. A green building is a configuration that is environmentally friendly throughout the building life cycle, from the designing phase to the construction or building phase (CEPT University, Ahmedabad 2011). Furthermore, building construction is considered to be the highest consumer of energy; the International Energy Agency reports that buildings are responsible for approximately 40% of the World's total energy consumption and 24% of the world CO2 emissions (CEPT University, Ahmedabad 2011). Another study showed that around 41.1 % of U.S energy consumption is from buildings (Environmental Leader LLC 2012). Buildings produce around 30% of the world's greenhouse gas emissions (Venkatarama

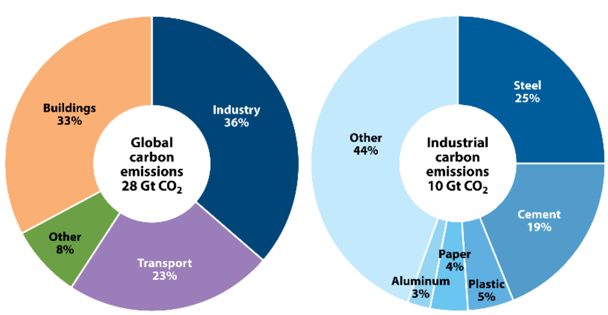


Fig 2.21. Distribution CO2 Emission between different Sectors *(Worrell, Allwood & Gutowski 2016)*

Reddy & Jagadish 2003). The industries and buildings producing the most greenhouse gases are illustrated in Figure 2.21 (Worrell, Allwood & Gutowski 2016).

These outcomes are mainly due to the use of materials that are not green and not environmentally-friendly. So, it's important to focus on studying green materials to help reduce these huge negative outcomes not only in buildings but in different industries, fields, or domains. Additionally, one study has illustrated the use of green materials in different applications from kitchen utilities such as spoons, forks, and knives produced from water bottles as seen in Figure 2.22. This study has also illustrated the use of green materials in hospitals in imaging systems as seen in Figure 2.23 (Turan 2015).

Fig 2.22. Kitchen Utilities *(Turan 2015).*

Fig 2.23 Hospitals Imaginary System *(Turan 2015).*

Another study illustrates shades that are completely made of renewable fibers that can be made in different shapes based on the requirements and needs as illustrated in Figure 2.24. Also, the use of durable environmentally-friendly wood flooring is made of bamboo and palm is shown in Figure 2.25 (McGee & Spiro 1988).

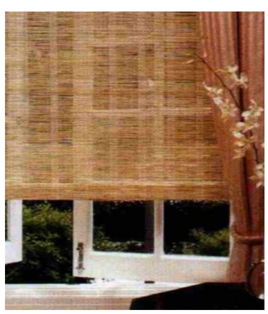


Fig 2.24. Renewable Fibers *(McGee & Spiro 1988)*

Fig 2.25. Bamboo Hardwood Flooring *(McGee & Spiro 1988)*

Another company called Etsy Reclaimed Furniture has made progress in creating furniture such as tables, benches, and shelves from sustainable materials, mainly wood, and also by using recycled used furniture to create new pieces as illustrated in Figure 2.26 (*11 Eco-Friendly Furniture Brands To Shop Online For Your Home* n.d.). Another company has created a couch that is environmentally friendly but the whole concept is not only in the couch but also encompasses the recycled cardboard boxes in which the product is shipped. This has a huge environmental impact, as shipping boxes and containers can have a huge effect on the environment: one study has illustrated that the use of plastic consumes around 12% of the worldwide oil supply so replacing plastic boxes with cardboard boxes can have a significant environmental benefit, on the condition that the trees of which the cardboard are made are no longer part of deforestation (McGee & Spiro 1988). Unfortunately, most of the materials used for packaging come from non-biodegradable and non-eco-friendly materials.

Fig 2.26. Coffee Table from Green Materials *(11 Eco-Friendly Furniture Brands to Shop Online for Your Home n.d.)*

Another initiative that encourages the use of sustainable and green ideas is the use of Greencrete, which applies concrete flooring or paved ways in a more environment-friendly manner. This method leaves gaps of spaces between tiles this would ensure that the grass underneath can grow, which also reduces the number of tiles of flooring used for a walkway as illustrated in Figure 2.27. There is a material similar to concrete called Hempcrete made from wooden fiber which is bound with lime, also illustrated in Figure 2.28 (*11 green building materials that are way better than concrete* n.d.). These are just some examples of the use of green materials and their huge impact on the environment. Furthermore, it has been illustrated that the use of green materials can help to

Fig 2.27 GreenCrete Walkways *(11 green building materials that are way better than concrete n.d.)*

Fig 2.28 Wooden Fiber filled materials similar to concrete *(11 green building materials that are way better than concrete n.d.)*

decrease greenhouse gas emissions and help in spreading the awareness and multiple different positive outcomes.

Moreover, when defining a green and sustainable material it is evaluated under multiple conditions, as one study illustrated that its mainly defined into three main categories: environmental, economic and sociological as seen in Figure 2.29 (Turan 2015).

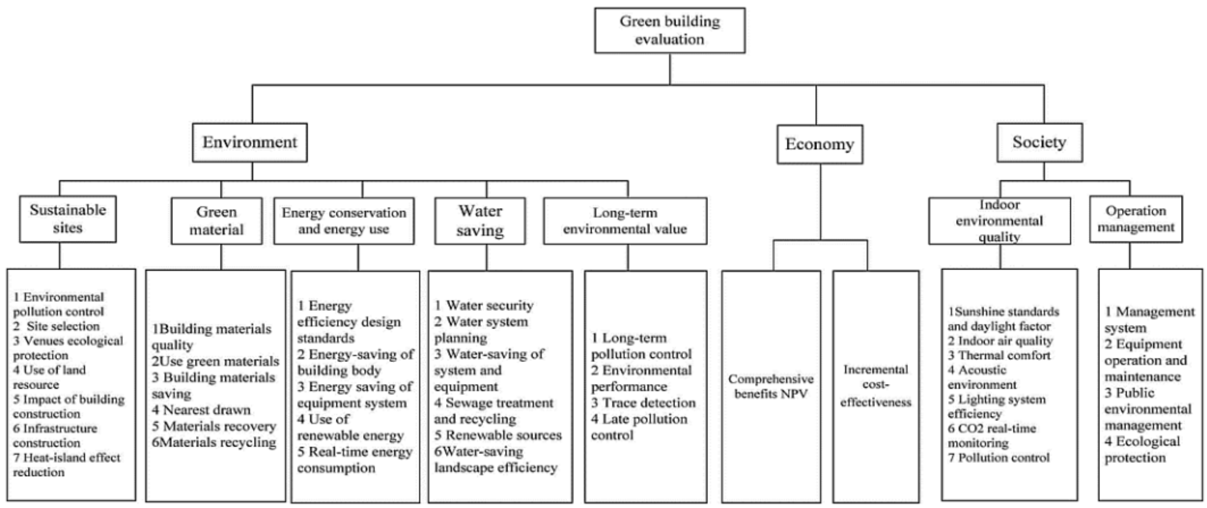


Fig 2.29 Green Materials Classifications Categories *(Turan 2015).*

Materials efficiency is a concept whose main idea is to mainly reduce the negative environmental impact of materials. Materials efficiency is the process of the exploitation of a material in a more natural manner without reducing the quality and visibility of this material (Ho et al. 2019). Material efficiency is also defined as “the ratio of the output of products to the input of raw materials” (Abdul Rashid et al. 2008). Material efficiency is related to the concept of energy efficiency. Energy efficiency is the reduction in the required or needed energy to achieve a specific task or service (Keay n.d.). Material efficiency will help in achieving three main goals: enhancing the quality of the material from a more economic perspective, decreasing energy requirements for the materials during the process of manufacturing or even before, lastly the decrease in greenhouse gas emissions (Cooper et al. 2016). The idea behind the implementation of this concept is to analyze the material from the starting point. A study done by a Swedish organization has shown that focusing on material efficiency from the start would help reduce the energy consumption of this material production (Allwood et al. 2011). This illustrates the huge relation between energy efficiency and material efficiency, as illustrated in Figure 2.30. This Figure illustrates how material efficiency would be more effective than the energy efficiency, the reason being that the timing of each concept, for instance energy efficiency, can be implemented from the user's starting point while materials efficiency can be achieved in the design phase of the material or project (Allwood et al. 2011).

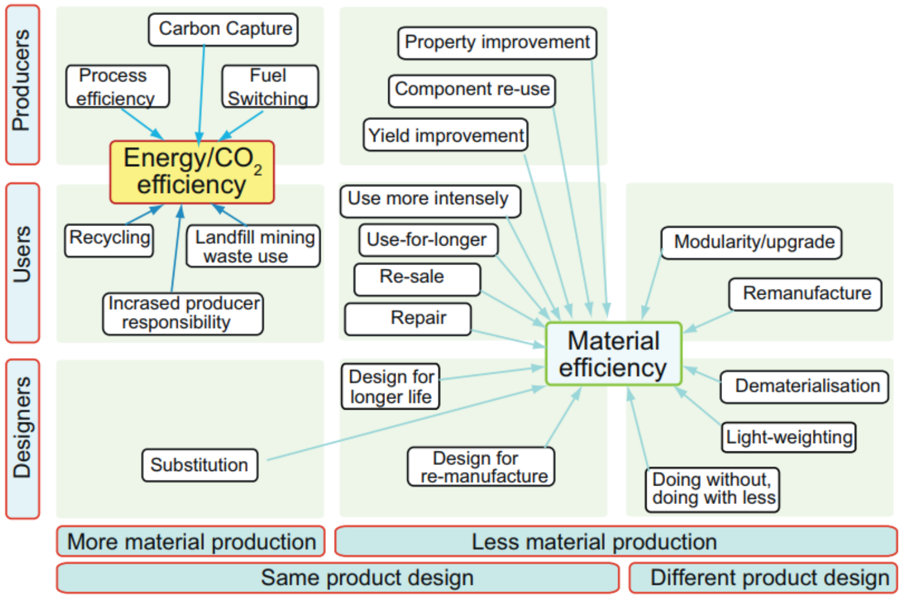


Fig 2.30. Material Efficiency in Relation to Energy Efficiency *(Allwood et al. 2011)*

The cycle of the building materials determines whether this material is green or not, which is defined from the moment the materials are extracted from the ground all the way to the termination of the material, a so-called cradle-to-grave definition. This cycle can be mainly divided into the pre-building stage, building stage, and post-building stage; together, these stages are defined as the life cycle of the material or life cycle stages. The pre-building stage is when the material is extracted from its source and then transported to the site or project location; this stage includes the process of searching for a material prior to extraction. Additionally, the number of materials that are being transported during the process of construction is massive and this is a critical aspect to the success of the project (*A Guide to Material Transport During Construction Projects - BOSS Magazine* n.d.). The building stage begins after the delivery of the material to the site. So, any energy consumed in the process of building and constructing the material on-site based on the project requirement is part of this stage. The post-building stage includes the phase when the material has been fully consumed in the building. All the phases and parts of the phases are indicated in Figure 2.31 (Kim & Rigdon 1998).

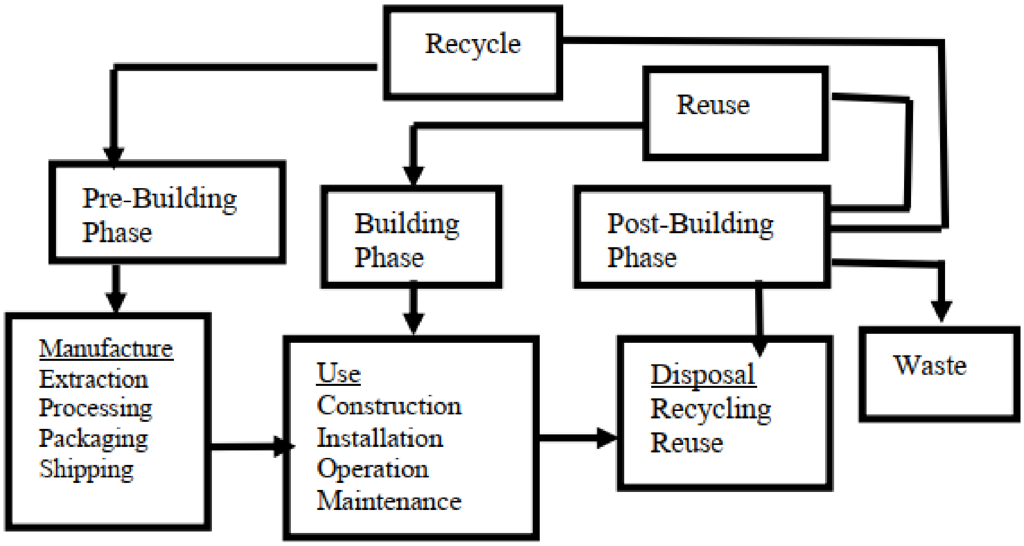


Fig 2.31 Building materials Life Cycle Stages *(Kim & Rigdon 1998).*

When designing a green museum, it is important to focus on different aspects that might enhance and support the green design and improve the environment. Some of these aspects are lighting, acoustics, HVAC, and materials. Additionally, material selection is one of the most important aspects as it has a huge impact on the environment throughout its process or as mentioned before the life cycle of the material.

When designing a building its important to study all the elements that are involved in the project from the start. Some of these elements are problem analysis, brainstorming, research, sketches, solutions, design, and implementation (*What are the 7 Steps of the Engineering Design Process? | Indeed.com* n.d.). Part of these phases is material selection, which goes under the process of designing. When designing it's important to carefully select materials based on the design and project requirements. This is done based on the material type which is defined based on the project needs. The selection of green materials when designing a green building presents a challenge due to the limited n umber and amount of green materials that are available. The solution is always to find local materials that fit the project needs; those materials are produced in the country of the project which will help greatly financially when initiating the project. Structural engineer Bruce King demonstrated that focusing on locally produced materials is an essential strategy to achieve a more energy-efficient and environment-friendly building (*Building with Local and Alternative materials | Architect Magazine* n.d.).

2.4 Lighting

This part of the paper will mainly focus on the analysis of the lighting system from different perspectives, mainly focusing on analyzing the effects of lighting on museum design. Based on one study, lighting has been a major part of workers' quality of performance in multiple countries since the 1920s (Çakir 2009). But lighting is also one of the main energy consumers in most countries; in the U.S lighting consumes around 10% of the total electricity usage in commercial buildings (*CBECS 2012: Energy Usage Summary* n.d.).

To help understand different aspects of lighting consumption and usage it's important to understand the basic lighting elements, starting with defining light. Light is the eye's perception of electromagnetic waves and this wavelength varies between 380 nm to 780 nm as seen in Figure 2.32.

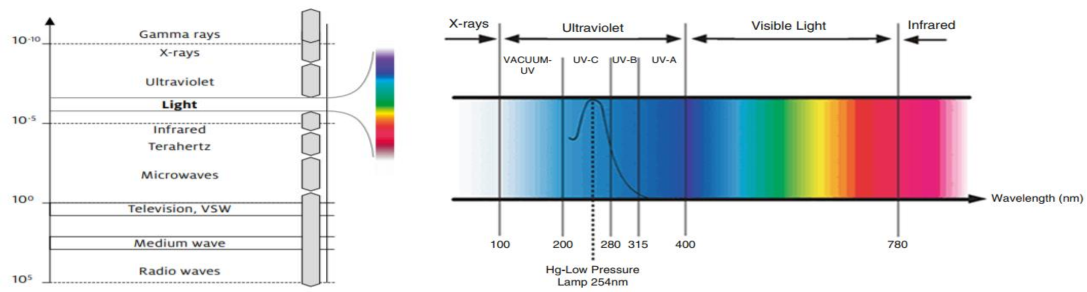


Fig 2.32. Electromagnetic Spectrum *(DiLaura et al. 2017)*

Lighting usually circulates through space at a speed of 300,000 Km/s (Cortem Group n.d.). Another illustration of the wavelength and its applications in the daily environment is illustrated in Figure 2.33. A Wave is regular disruptive from a rest state which is available in the space as seen in Figure 2.34 (CESAR 2017).

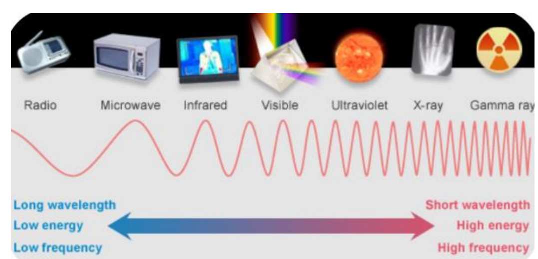


Fig 2.33 Electromagnetic Wave and its functions *(DiLaura et al. 2017)*

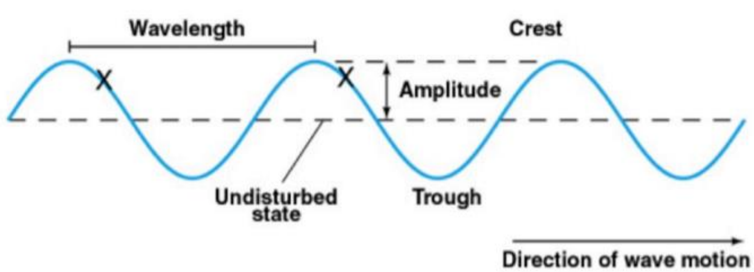


Fig 2.34. Wave Properties (*CESAR 2017).*

In order to understand how the eye perceives light, one must understand the component parts and functions of the eye. The human eye consists of multiple parts or slices. Starting with the cornea which is the part of the eye that works as a lens: it is a clear layer on the front of the eye that is shaped like a dome to help curve the light to increase focus (*How the Eyes Work | National Eye Institute* n.d.). After that the light passes through the pupil, a space or opening in the middle of the iris, the area where the light cross into the eye. The function of the iris is to increase or decrease the size of the object that is visible based on the amount of light that enters through the pupil, this is done through thin muscles that support the pupil where it opens and closes the opening based on the amount of light (*How the Human Eye Works | Cornea Layers/Role | light Rays* n.d.) as seen in Figure 2.35. This Figure indicates another process which is the process in which the lens contracts and changes size to increase the focus based on the location of the object is called accommodation.

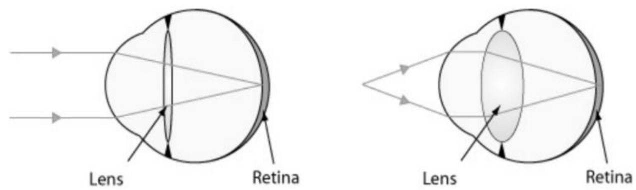


Fig 2.35. Lens function in the focus of light on the Retina *(How the Human Eye Works | Cornea Layers/Role | light Rays n.d.)*

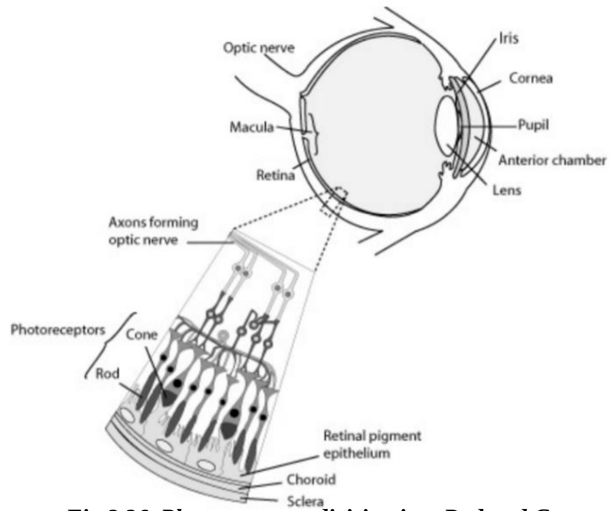


Fig 2.36. Photoreceptors division into Rod and Cone ***(****Ramamurthy & Lakshminarayanan 2014)*

Another important part of the eye is the retina, which is located at the back of the eye. This is a screen that the light is projected on. The retina consists of multiple layers, but the most important layer is the photoreceptors, consisting of rods and cones. Rods are responsible for night vision while the cones are responsible for the daytime vision, illustrated in Figure 2.36 (Ramamurthy & Lakshminarayanan 2014). This anatomy of the eye receives light and translates it into shapes and colors. After understanding

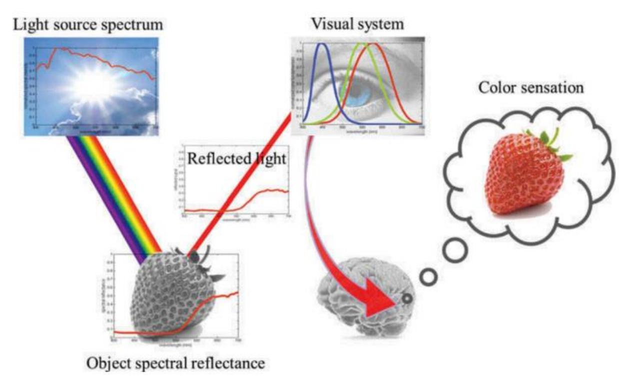


Fig 2.37. Brain Perception of Object Color through Light *(Houser et al. 2016)*

the process of analyzing light, the steps of analyzing the colors of an object is as follows: light falls on an object whatever the source of light is, the object reflects the light, the eye absorbs the reflected light, and then the eye sends the signal to the brain which analyses the object and translates it. All of these steps are illustrated in Figure 2.37 (Houser et al. 2016). With this basic understanding of light and the eye, we can focus on the relationship between light and interior space.

Light Color Temperature.

The first analysis of color was done by Newton in 1704 where he studied that the color white has a different wavelength which was illustrated in his Color Circle as seen in Figure 2.38 (Schwartz 2016).

The color of the light is affected by the light temperature, which is measured in Kelvin (Elvin olor emperature n.d.). The higher the Kelvin rating the whiter the light is as seen in Figure 2.39 (*Kelvin Color Temperature | lighting Color Scale at Lumens.com* n.d.).

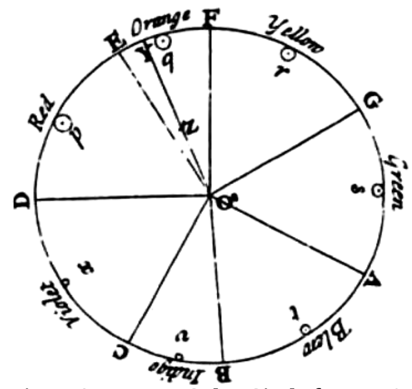


Fig 2.38. Newton Color Circle from 1704 *(Schwartz 2016)*

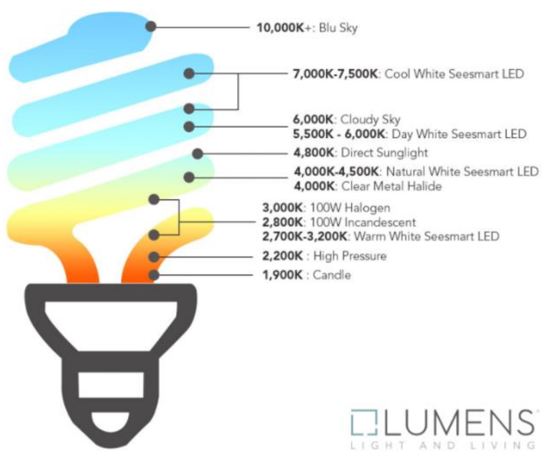


Fig 2.39. Light Temperature Color in Kelvin *(Kelvin Color Temperature | Lighting Color Scale at Lumens.com n.d.)*

Additionally, less than 2000 gives more of a dim light close to the one seen from a candle. Moving to higher Kelvin rates, the light starts to get more cold and close to the color blue as seen in Figure 2.40 (*lighting 101: Color Temperature – What is the Kelvin Scale? - Larson Electronics* n.d.). These variations have impacts on perceived human comfort. Huebner et al. (2016) has shown evidence that the Thermal Comfort Rating with a light that has a Kelvin Value of 2700 K is higher when compared to a light with a value of 6500.

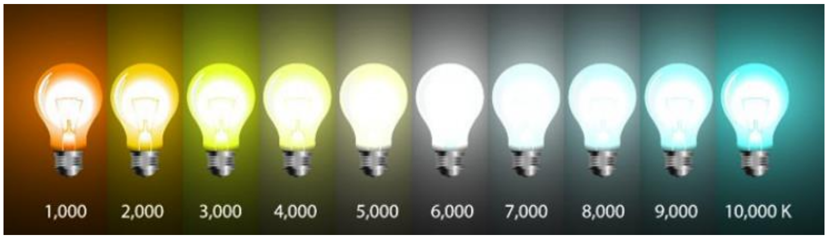


Fig 2.40. Light Temperature Color in Kelvin *(Lighting 101: Color Temperature – What is the Kelvin Scale? - Larson Electronics n.d.)*

Color Rending Index or CRI

This concept mainly focuses on how finely the light purifies the colors of any object; it is the capability of a light to view an object's colors when compared to sunlight. Mainly because sunlight shows the object in its true colors. This Index is usually measured on a scale from 1 to 100 as illustrated in Figure 2.41. The closer it gets to 100 the more the colors of an object will be clear (*Color Rendering Index - What Is CRI? | lighting CRI Explained at Lumens.com* n.d.). Figure 2.42 shows how CRI truly affects the colors of an object as it increases the true colors of the object it more accurately viewed (*CRI - Color Rendering Index* n.d.)

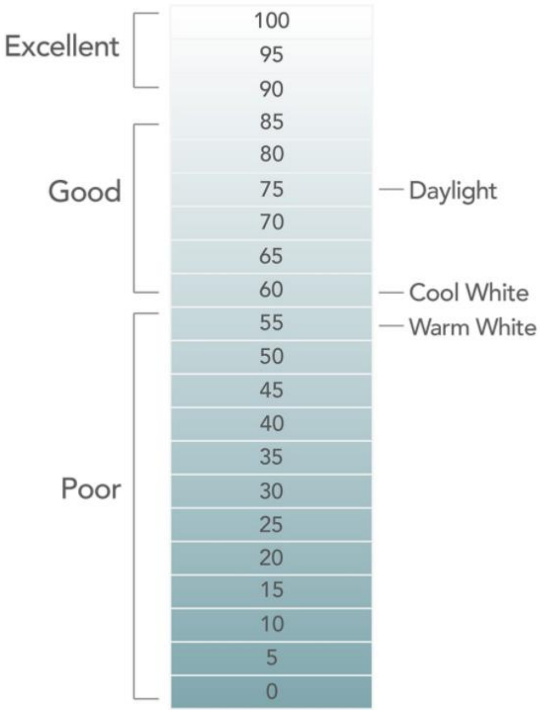


Fig 2.41. CRI Scale

Fig 2.42. Different CRI Rendering of 1 Object *(Color Rendering Index - What Is CRI? | lighting CRI Explained at Lumens.com n.d.).*

Moreover, lighting has multiple important definitions that must be understood to fully go deeper in understanding the effect of light on indoor spaces.

- ***Reflection***

This concept mainly focuses on the idea of the light being reflected from different objects: this is the idea of the electromagnetic waves being returned in a specific direction and this is based on multiple factors (*Reflection, Transmission, and Absorption* n.d. a). First the texture of the object the light falls on, for instance if it is a rough surface some of the light will be diffused and will be reflected in different directions, while a smooth surface would reflect the light in one known direction. Second, the angle at which the light hits the surface has a huge impact on the direction of the reflected light. Additionally, an important concept when understanding a smooth surface such as a mirror is the Law of Reflection which indicates that the angle of incident is equal to the angle of reflection as illustrated in Figure 2.43 (Academy 2008).

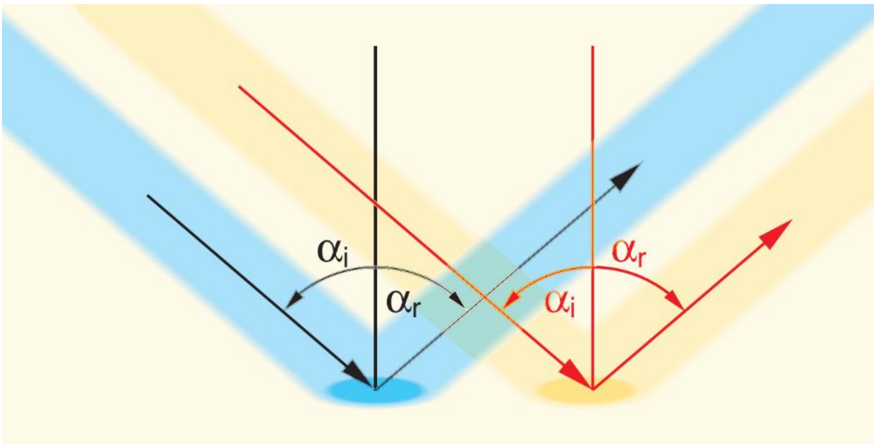
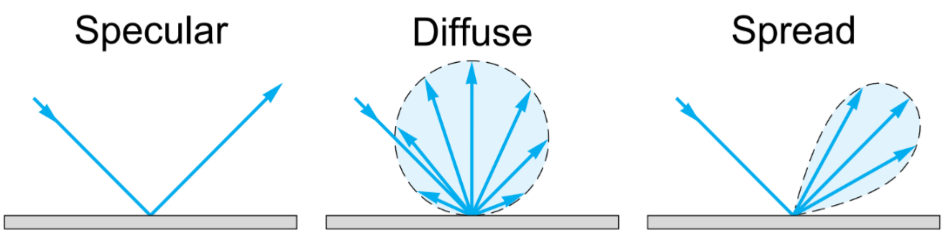


Fig 2.43. Law of Reflection angle of incident = angle of reflection (*Academy 2008)*

Usually when the light is reflected it goes through one of the below phases. The light is either specular, which is reflected at the same angle as mentioned before, or diffused, where the light goes in different directions. The last possibility is spread, where the light spreads in the same angle of the incident but in different directions. In these three cases, only specular obeys the Law of Reflection where the Angle of Incident is equal to the Angle of Reflection (See Figure 2.44) (Ryer 1998).



A. *Smooth Polished Surface* ***B.*** *Matte Surface* ***C.****Rough Surface*

Fig 2.44. 3 Cases of Reflection based on different surfaces *(Ryer 1998)*

A smooth surface can completely reflect the light that can be visible as the reflected light is completely reflected into our eyes whereas a rough surface doesn't reflect all of the light – some of the light is dispersed as seen in Figure 2.45 (*Reflection, Absorption & Transmission - Maggie's Science Connection* n.d.).

Fig 2.45. Comparison between Reflection from Smooth and Rough object *(Reflection, Absorption & Transmission - Maggie's Science Connection n.d.)*

- ***Transmission***

This is the process when a light is transferred through an object and the amount of light that is transmitted is related to the type of material the light passes through. For example, glass is a high transmitting material, meaning that most if not all of the light passes through the materials with minimal to no light absorption (*Absorption, reflection and transmission of visible light - What happens when light and sound meet different materials? - OCR 21C - GCSE Physics (Single Science) Revision - OCR 21st Century - BBC Bitesize* n.d. a). Another important aspect of Transmission is the Regular τ_r and Diffuse τ_d Transmission where the Total Transmittance τ is as shown below (*Reflection, Transmission, and Absorption* n.d. b):

$$\tau = \tau_r + \tau_d$$

Using color filters with a specific color will help change the color of the light during the process of transmission as seen in Figure 2.46 (*Absorption, reflection and transmission of visible light - What happens when light and sound meet different materials? - OCR 21C - GCSE Physics (Single Science) Revision - OCR 21st Century - BBC Bitesize* n.d. b).

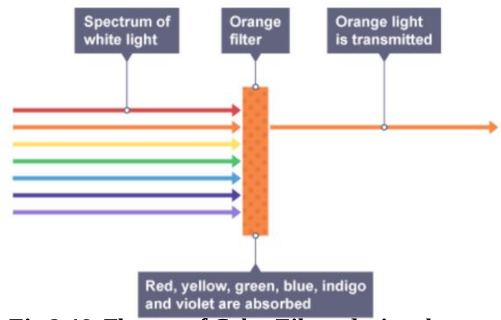


Fig 2.46. The use of Color Filters during the process of Transmission (Absorption, reflection and transmission of visible light - What happens when light and sound meet different materials? - OCR 21C - GCSE Physics *(Single Science) Revision - OCR 21st Century - BBC Bitesize n.d. b)*

Absorption

This is the concept that refers to the amount of light that is lost when transferring between objects. An object can absorb light and transfer it to a different type of energy (*What happens when light is absorbed- Oxford Instruments* n.d.). As seen in Figure 2.47 the materials absorb the light to transfer it to another source of energy where it does not pass the object as a source of light (*Reflection, Absorption & Transmission - Maggie's Science Connection* n.d.). Lambert's law of absorption states that the amount of light absorbed is linked to the thickness of the surface or materials, for instance if light passes through a material with a specific thickness the surface will absorb half of the light; if it passes through another material with the same thickness, it will absorb another half of the light as seen in Figure 2.48 below (Watkins, 2000).

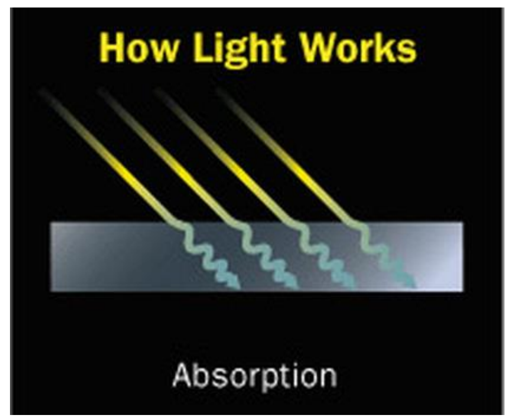


Fig 2.47 Absorption *(Reflection, Absorption & Transmission - Maggie's Science Connection n.d.)*

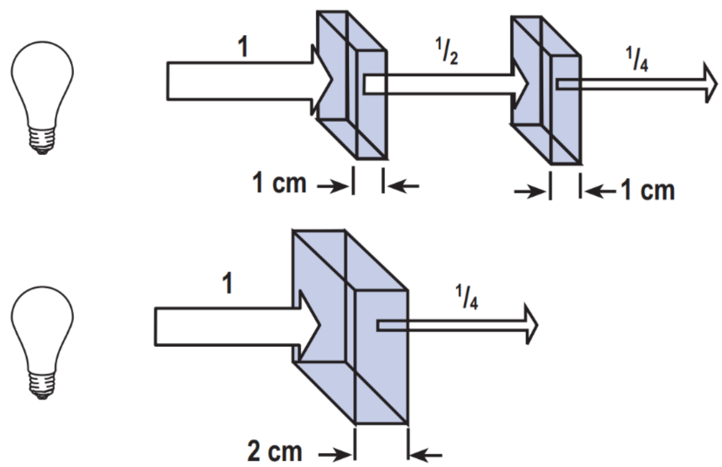


Fig 2.48. Lambert's Law of Absorption

The next important aspect of light to understand is the measurement of light which is mainly focusing on three main aspects.

- *Luminous Flux* indicates the amount of light produced from the source which is measured in Lumin or lm (Schielke 2008). Lighting is power as mentioned before and power is typically measured in Watts but in lighting it is measured in Lumens (Cortem Group n.d.).
- *Luminous intensity* is luminous flux in relation to the angle: the amount of light is affected by the angle of light. For example, if there is a light source with luminous flux of 1000 lm and spreads at an angle of 12.5, then the luminous intensity will be 1000/12.5 which is 80 cd, and the unit of luminous intensity is Candela or cd. To understand luminous intensity it's important to understand the Steradians, which is the three-dimensional angle, for instance taking a circular surface on sphere then from the center of this surface moving to the center of the spherical shape the angle that is created is the solid angle which is measured with Steradian. A 1 Steradian is equal to the total area of the surface over the square radius of the sphere (Tippens 2007).

The Steradian = A / R2

- *Illuminance* is the amount of light that falls on and spreads on a surface and is measured in Lux, though in some countries such as the U.S it is measured in foot-candle which refers to a surface that is the source is 1 foot away and the 1-foot candle is equal to 1 lumen per square foot as seen in Figure 2.49 (*Luminance vs. Illuminance* n.d.). Where 10 Lux is equal to 1 footcandle (*How to Measure light Intensity: Understanding & Using a Lux Meter* n.d.).

Fig 2.49. Luminance and Illuminance difference

2.4.1 Sustainable lighting

After discussing and understanding the main concepts of lighting and light works, we can focus on different lighting implementation and techniques. The main function of lighting is to enhance and improve the quality of life whether in the exterior – such as building lighting, street lighting, billboards, landscape or gardens, retail outdoor or shop windows – or interior use such as offices, shops, houses or residential spaces, hospitals, universities, schools, and airports. To help achieve this goal of improving the quality of the space in a more sustainable and energy efficient manner, it's important to follow some of the standards that were achieved by some of the institutes such as the American National Standards Institute (ANSI) and the Illuminating Engineering Society of North America (IESNA). Some lighting-related standards were accomplished such as the IES Lighting Handbook. All of these standards were achieved to help produce a more energy efficient space in relation to lighting (Wagiman & Abdullah 2018). Mainly lighting is divided into two main categories.

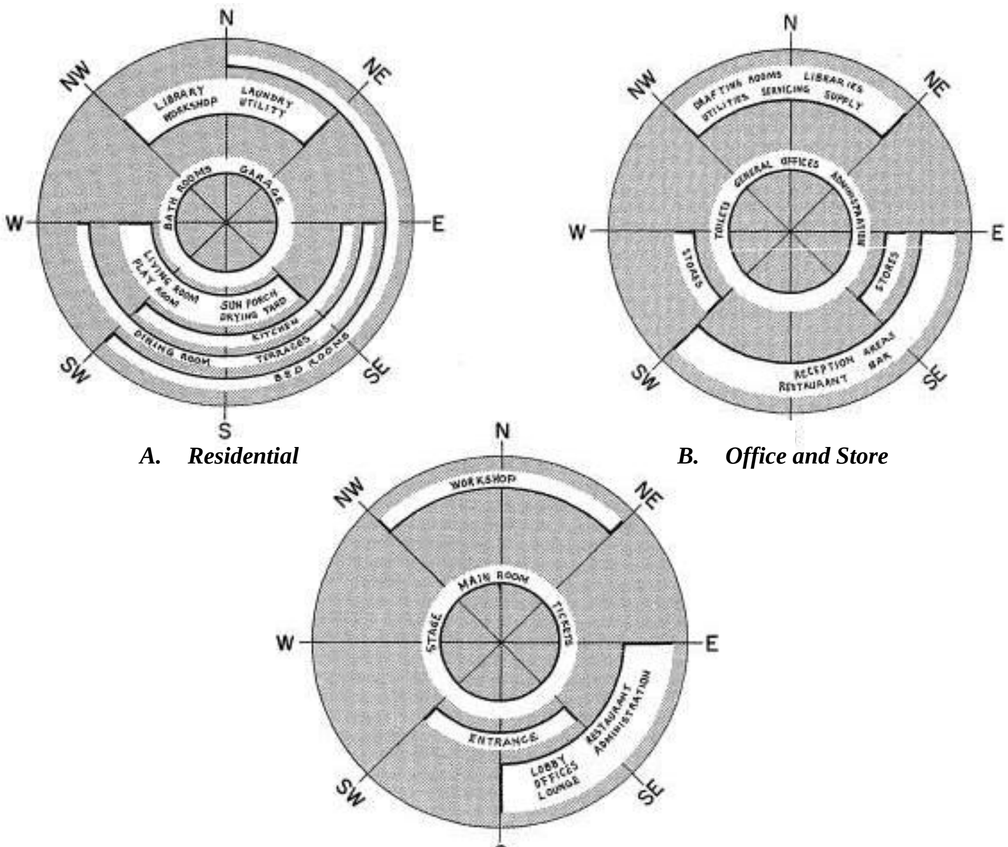
- *Interior Lighting*

When an interior space is designed, multiple factors influence its Indoor Quality such as HVAC system, furniture selection, material selection, acoustics, and lighting. Lighting sources can be either natural or artificial.

A) Natural Lighting

Natural lighting is the oldest type of lighting known to the human race, as daylight was the only method of lighting the indoor space of Early Man (Phillips & Gardner 2012). Daylight has multiple positive impacts on people, including psychological health and physical health benefits. One study showed that daylight can increase users' productivity, reduce depression and agitation, and improve sleep (Beauchemin & Hays 1996). When relying on daylight, multiple aspects must be considered when designing. Pooja Singh (2018) demonstrated that in order to utilize daylight it is important to consider both the quantity and quality of the light produced from the sun (Singh 2018).

The quantity of light that enters the space is based on multiple factors including the size of the opening; Randy Frans illustrated that the size of an opening will completely influence the amount of lighting that enters the space and also that the type of materials used as a finish for the opening will have a huge impact on the quantity of natural light that the space receives (Fela et al. 2019). The orientation of the building is another important factor that affects the quantity of light that enters the space. A designer must study the site and location of the project in order to determine the best orientation to enhance the quantity of light that the building is receiving based on the project requirements (Kaminska 2020). Another study also illustrated optimized building orientation based on the function of the space which is demonstrated in Figure 2.50 (Singh 2018).



A. Residential

B. Office and Store

C. Public Spaces

Figure 2.50. Different Building Orientation based on the Function of the Space
(Singh 2018)

Additionally, Daylight Factor (DF) is an important term that most designers focus on while studying the amount of daylight the space receives. It is the relationship between the outside illuminance over the inside illuminance and it is reflected according to the below equation (*Daylight factor* n.d.):

DF = Ein / Eext * 100

Ein = Inside Illuminance

Eext = Outside Illuminance

More Daylight Factor means more natural light in the space. A sample study was done using Velux Simulator where a small room with 6 m length X 7 m width X 4 m height with three window openings and one glass door was studied in order to understand the impact of DF on a space. This is illustrated the Figure 2.51.

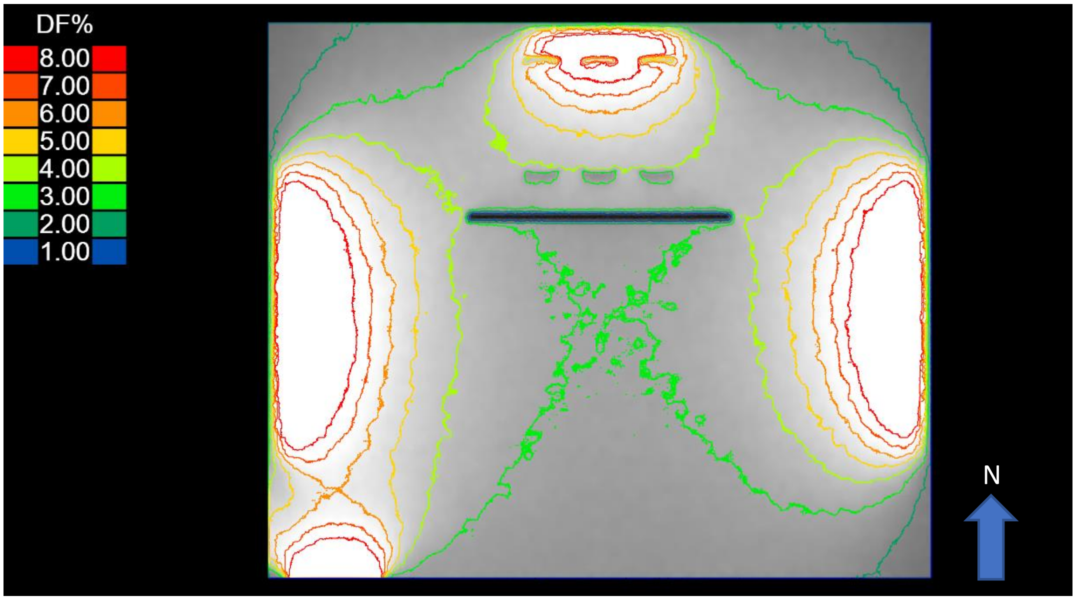


Figure 2.51. Openings and North Orientation Impact on the Daylight Factor *(Author)*

Moreover, the amount of DF that the space received especially near the openings is high due to the amount and size of openings and also due to the orientation of the building. This is an example of a space that received enough amount of daylight, which would enhance the quality of life and increase productivity in the space. Using the same space another sample was done but with only one opening and one glass door with a different orientation as well. Figure 2.52 demonstrates that the amount of daylight the space received was highly affected by the number of openings and the space orientation.

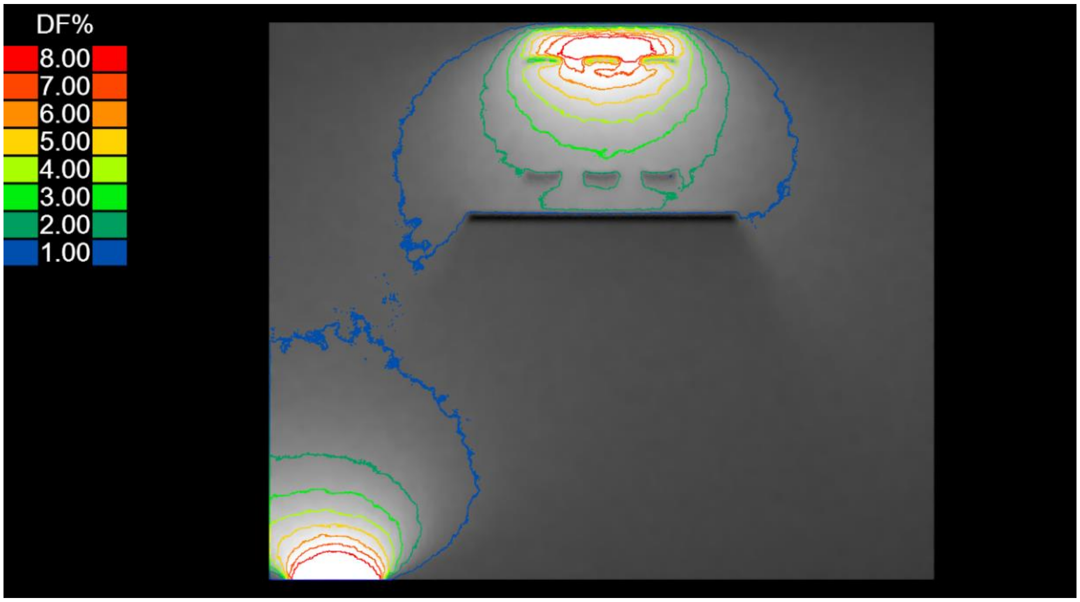


Figure 2.52. Openings and South Orientation Impact on the Daylight Factor *(Author)*

Other important aspects that are usually calculated in order to fully understand the amount of light that the space receives are luminance and illuminance, illustrated in Figure 2.53.

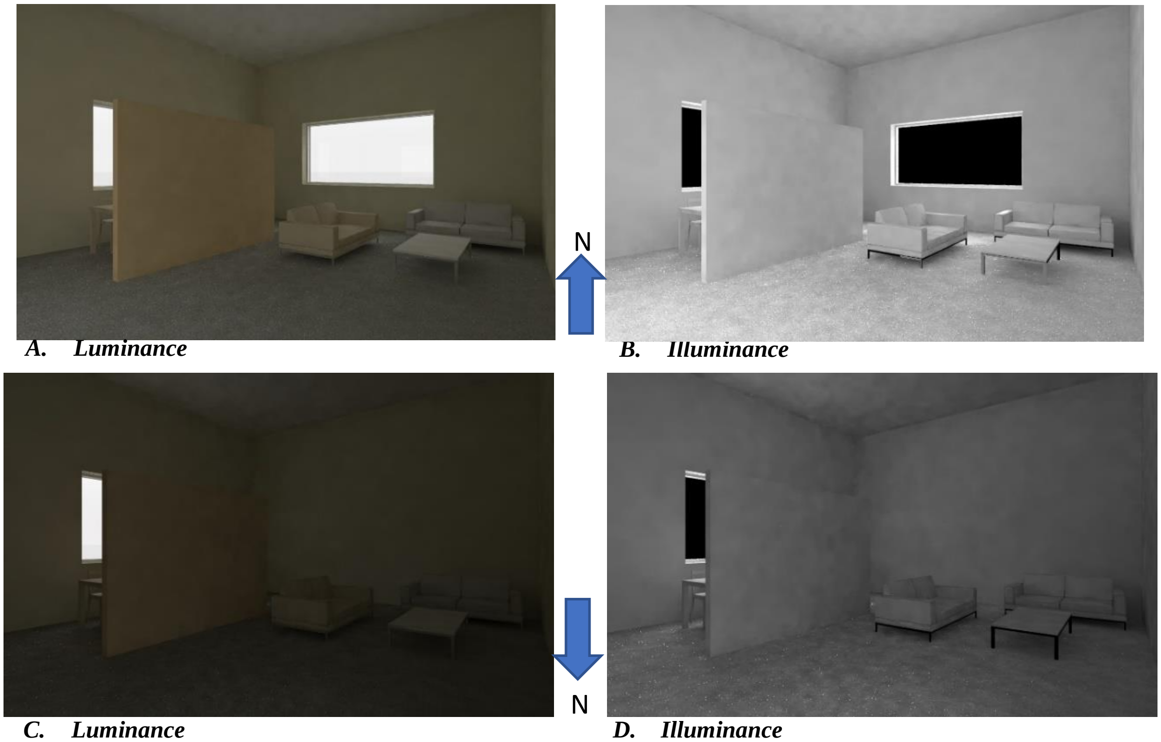


Figure 2.53. Openings and Orientation Impact on Luminance and Illuminance *(Author)*

The daylight illuminance and luminance are changeable according to the space orientation and opening’s size. This is also illustrated using the same sample space with the same number of openings in both samples of comparison. In Figures 2.53 A & B, the luminance and illuminance of the space with three openings and one glass door with a northern orientation is high when compared to the other sample with one opening and one glass door with a southern orientation which is shown in Figures 2.53 C & D. A case study done in London’s Victoria & Albert Museum illustrates the impact of daylighting in the space at different periods of the day, which is illustrated in Figure 2.54 (Astuti, Arso & Wigati 2015).

Figure 2.54. Different Days’ Impact on Daylight within the Space *(Astuti, Arso & Wigati 2015)*

Additionally, the use of daylight in spaces is not as popular as using artificial lighting: it was illustrated that only 10% of US commercial buildings have daylighting plans while 50% of buildings focus on using artificial lighting (Moncef Krarti, 2011). The use of daylight would have a huge impact from a lighting perspective. One report showed that the use of daylight would reduce electricity use by 1% but might increase the demand for more heating or cooling. Another report also showed that heating demand would increase by 9% depending on daylight (*Does Daylight Saving Time Really Save Energy?* n.d.).

B) *Artificial Lighting*

The impact of artificial lighting on energy consumption is reflected in the study done by Claude Weisbuch which showed that around 15 to 20% of electricity in developed countries is consumed by artificial lighting (Weisbuch 2018). As illustrated in Figure 2.55, manmade light has taken numerous forms over time, from the initial torch as the first manmade light source to the first fuel-powered lamps in 4500 BC using gases like methane, ethylene, and kerosene. In the 1800s, the first electric lamp was invented, followed by the bulb in the 1830s. In 1879 Thomas Edison

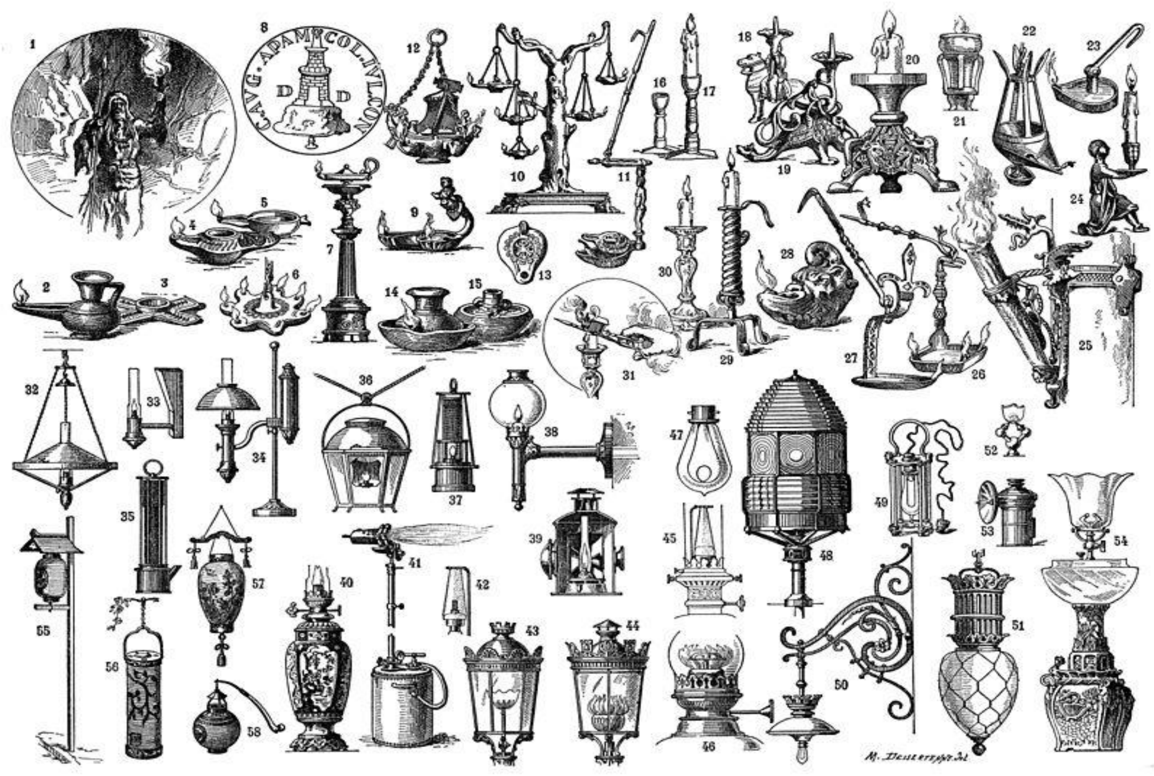


Figure 2.55. Development of lighting along the years (1)Pre-Historic, (2-3) Egyptian era/civilization, (4-5) Assyrian era, (6-13) Roman era, (14-15) Carthaginian era, (16-17) Merovingian era, (19-20) 11th century, (21) 12th century, (22) 13th century, (23-24) 14th century, (25-27) 15th century, (28) 16th century, (29) 17th century, (30-31) 18th century, (32-54) 19th and 20th century *(History of lighting - Development of lighting Technology n.d.) (File:Eclairage.jpg - Wikimedia Commons n.d.).*

invented the Carbon Filament Incandescent Bulb, which was used for years (Brown 2020). As illustrated in the Figure, the development of lighting started from the Pre-Historic Period which is (1) until the 20th century lighting systems which are (32-54) (*History of lighting - Development of lighting Technology* n.d.).

The lighting in an interior space will completely revolutionize the space. Lighting is an important factor in the visibility of the space. This is defined by the Illuminating Engineering Society (IES) as “the ability to extract information from the field of view” (Rea, 2000). When focusing on lighting in the space, usually try to overcome some challenges that might occur such as acclimation, delineation, and glare. Derlofske demonstrated that glare is the extreme amount of light that the eye receives, causing the eye to barely identify details and contrast of the image (Derlofske, Bullough 2004). Moreover, Guyer divided glare into three main types: direct glare, reflect glare, and overhead glare (Guyer, Asce & Aei 2010). Another study divided glare into four types based on two conditions: the nature of the source and the impact on vision (see Figure 2.56) (Putnam, 2017) (*Glare and Factors Controlling It - Archinomy* n.d.).

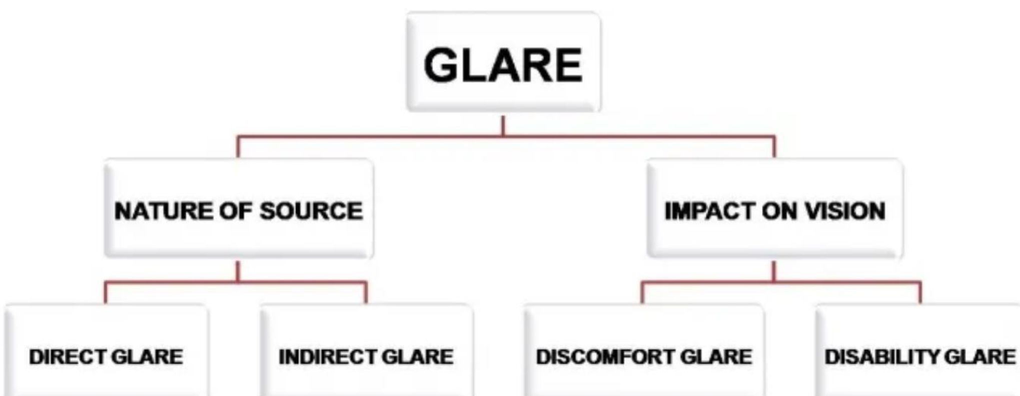


Figure 2.56. Glare Types based on 2 Different Conditions *(Glare and Factors Controlling It - Archinomy n.d.)*

Artificial lighting is divided based on the lighting source. In interior design there are three main types of light sources. Incandescent light is lighting producing light by heating materials such as metal filaments (Astuti, Arso & Wigati 2015). There are multiple types such as incandescent lamps, Tungsten Halogen, and Tungsten Xenon lamps (*Incandescent light - examples, body, used, process, life, type, form, energy, gas* n.d.). The second type of light source is discharge light – light which is emitted by generating an electrical charge through a gas. This source includes different types such as fluorescent lamps, metal halide lamps, and more (Miebach n.d.). The third and last type of lighting source is electroluminescent light, which uses electric current directly through phosphor to create light. Some types of this source include Light Emitting Diode or LED, Organic LED or OLED (*Electroluminescent Lamps - How They Work & History* n.d.). Lighting in the interior space is divided into direct and indirect lighting. Direct lighting focuses light from fixtures on a specific element or object (*Direct vs Indirect lighting | Suggestions for Indirect & Direct Lights | Warehouse-lighting.com* n.d.). Direct lighting is divided into three main types:

1- Ambient lighting: this type of illumination focuses on increasing the illumination and brightness of the whole space, such as ceiling fixtures or wall-mounted fixtures (*Ambient, task and accent lighting 101 | Vibia* n.d.).
2- Task: this focuses on focusing the illumination on a specific task. This is used if the user requires to focus on a specific task such as reading or working (*A Quick Guide To Ambient, Accent, & Task lighting | Fablite Blog* n.d.).
3- Accent: this type of illumination is used if there is a specific object or item in the room that needs to be focused on, such as paintings or sculptures (*Ambient lighting & Other Types| Choosing The Right lighting* n.d.).

All of these different illumination methods are illustrated in Figure 2.57

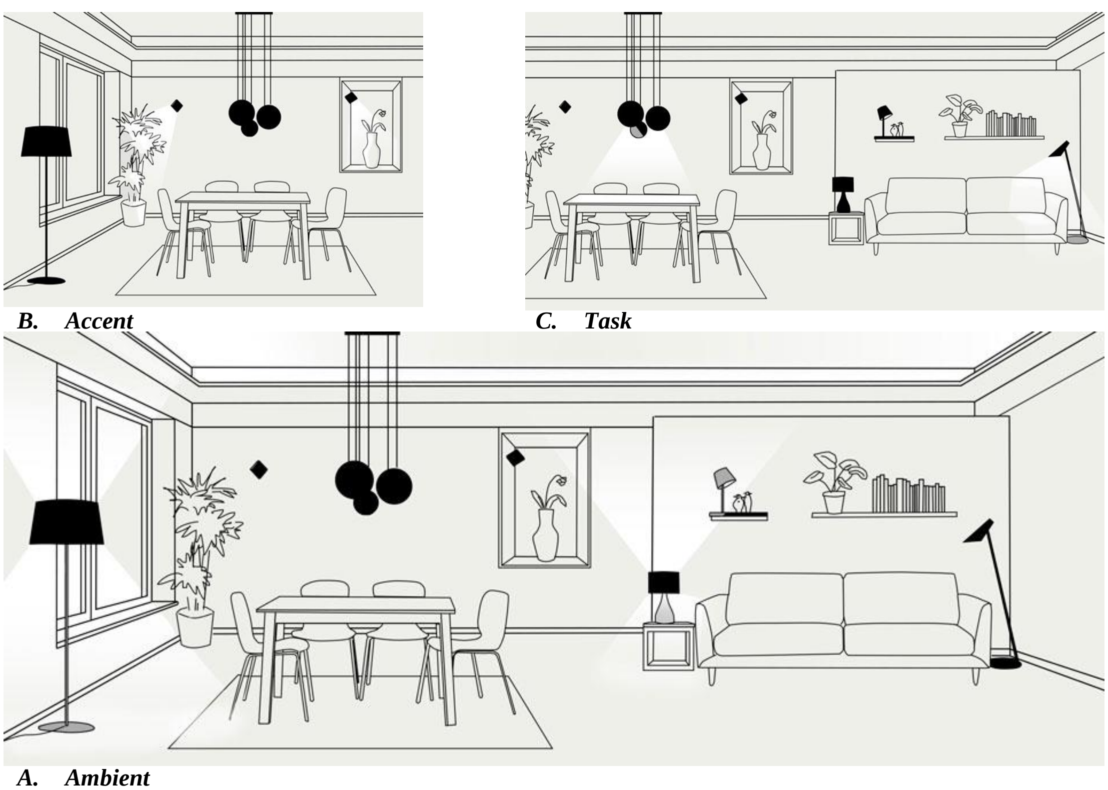


Figure 2.57. Accent, Task and Ambient type of Illumination *(Ambient, task and accent lighting 101 | Vibia n.d.).*

Indirect lighting uses light fixtures as a source of light that spreads the light in different directions or light can be reflected from another surface (*Direct lighting VS Indirect lighting - When & Where To Use* n.d.). Furthermore, the selection of lighting or type of lightings is mainly based on the function and the size of the space. Optimal lighting is between 0 to 20 % in areas that require task performance, while in stadiums the optimal light is around 70 to 90 %; this shows that lighting assessment is based on the function and the space (Çakir 1975). Ceiling height and space depth directly associate to the amount of light. Natural light or daylight is changeable across the day based on multiple natural factors.

Regarding the energy-saving aspect for both natural and artificial lighting, Paul Littlefair illustrated that there is a huge interest for designers to integrate daylighting in their designs in order to decrease the energy consumption of buildings (Littlefair 1998). Almost all buildings function in the daytime which gives the opportunity for designers to incorporate daylight in their designs (Krarti, Erickson & Hillman 2005). Nevertheless, as Danny has shown in his study using surveying, daylighting is usually not considered in commercial buildings (Li & Lam 2003). Additionally, some strategies need to be followed in order to help consume less energy in indoor spaces. First is following the concept that more light doesn't mean better Indoor Quality (EERE 2002), Second, the selection of lighting type is the key to reducing consumption. The UN Environment Program illustrated that the use of LED lighting is spreading due to the huge difference in price and due to the high efficacy of those types of lighting. Table 2.5 demonstrates a small comparison between different type of lighting systems (United Nations Environment Programme 2017).

Table 2.5. lighting Types Comparison *(United Nations Environment Programme 2017) (Author).*

	CFL	**High-Intensity Discharge (Mercury Vapour)**	**LED**
Efficacy Range	50 – 70 lm/W	45 – 55 lm/W	60 – 130 lm/W
Lifetime	6000 – 12000 Hr	20000 Hr	15000 – 30000 Hr
Color Rendering Index	70 - 85	15 – 50	70 – 95
Correlated Color Temperature	2500 – 6500 K	3900 – 5700 K	2700 – 6500 K

Third, the use of daylight in moderation would help the energy consumption in buildings as mentioned before. The fourth aspect is the use of lighting controls such as occupancy sensors, timers, photosensors, and dimmer controls (*The Benefits of Using lighting Controls and lighting Control Systems | Warehouse-lighting.com* n.d.). These systems would help in the reduction of energy consumption from lighting. Figure 2.58 illustrates an example of dimming options and how they change the quality and appearance of the space (*Introduction to lighting Controls* n.d.).

Figure 2.58. Dimming Impact in the Interior Space *(Introduction to lighting Controls n.d.).*

<u>*2.4.2 Museum Lighting*</u>

This paper has provided a brief understanding of lighting and some of its basics, which will form the foundation for the main focus of this paper: museum lighting. "Museum are places where lighting design is critical to the overall experience" (Lowe,43, 2009). There are two main parameters to achieve a successful museum design. The first is the Indoor Air Quality or IAQ, and the second is the Indoor Environmental Quality or IEQ. To achieve a successful IAQ and IEQ it's important to ensure achieving a space that ensures good humidity, good temperature control, control of pollution sources like noise or scent, and having a space with good lighting sources (Pavlogeorgatos 2003). It is extremely important to have a well-managed lighting system for museums, particularly to ensure that all of the artifacts and pieces are not damaged or affected by the type of lighting from a visual perspective and also from a conservation perspective. The Illumination Engineering Society of North America has created

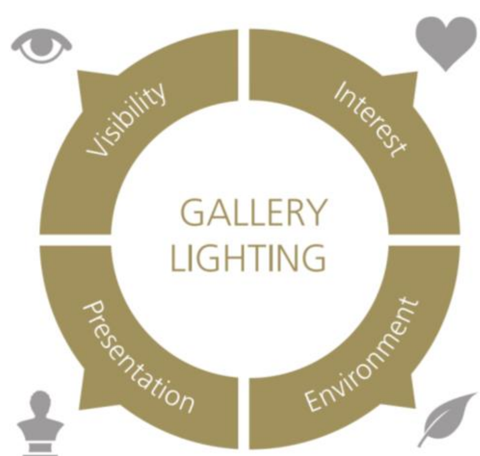


Figure 2.59. Museum lighting Challenges *(Sylvaniia Feilo 2015).*

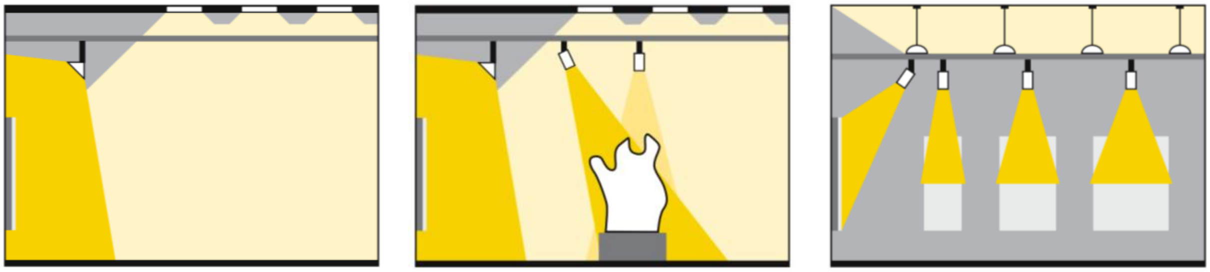


Figure 2.60. Diffuse and Directional lighting in exhibitions *(Fördergemeinschaft Gutes Licht 2000)*

standards to ensure the achievement of that and they are humidity, atmospheric pollution, noise and vibration, temperature, and illumination. All of these factors needs to be managed to achieve a successful interior space (Pavlogeorgatos 2003). Additionally, there are four main challenges that the designer faces in designing lighting for museums (See Figure 2.59): 1- The visibility of the work and space, 2- Interest of visitors that could be enhanced with lighting, 3- The presentation and preservation of the art and artifacts which are highly affected by lighting, and 4- The impact of lighting on the environment (Sylvaniia Feilo 2015). Moreover, museum lighting is divided into two types, diffuse (ambient) lighting and directional (accent) lighting. Diffuse lighting focuses on radiating light from a different direction in order to light up the space without focusing the light on a specific object, while directional lighting's main aim is to focus lighting on a specific object or art as illustrated in Figure 2.60 (Fördergemeinschaft Gutes Licht 2000). Jelena also illustrated that lighting systems in museums can be divided into five main types. 1- Indirect luminaires, 2- Cove lighting, 3- Wall washers, 4- Luminous ceiling usually with opal glass, and 5- Spot light (Armas 2011). Failure to select the type of lighting based on the objects' and artworks' requirements would have a huge negative impact on the artifacts. As seen in Figure 2.61, most LED lighting does not produce IR or UV rays which will in the long term have visible harm and damage the art (Sylvaniia Feilo 2015)

Figure 2.61. Different type of lighting impact on Artwork

Some of these impacts are high when daylight is used as daylight has a high UV wave that will damage the art and artifacts, as ultraviolet waves are known to damage works of art. IESNA demonstrates that a Lux value between 54 to 323 Lux for daylight is more than enough to preserve and protect artifacts, while for artificial lighting it's around 215 to 540 Lux according to the Illuminating Engineering Society of North America or IESNA.

CHAPTER 3

Methodology

3

C H A P T E R   I I I

3 Methodology

This part of the research will emphasize the use of different methods in order to achieve the required aim and also to answer the research question stated before. The process of selecting the right Methodologies that is suitable for the research goals and objective is the main key for the success of the research. Moreover, the Research Methodologies are mainly divided into 3 main categories. Quantitative Research mainly this type of research focuses on analyzing the collected data by expressing them using Graphs, Numbers, Theories, or Assumptions. Some examples of this type of Method are Surveying, Experiments, Simulations, Observations, etc. The second type of Methodology is Qualitative Research this type of Research usually focuses on analyzing the data based on thoughts and understanding in order to find the solution for the project aim. Some examples of Qualitative Methods are Interviews, Case Study Analysis, Literature Review, etc. The third type or method is using Mixed Mode analysis which focuses on combining both Methodologies Quantitative and Qualitative in order to achieve the goal of the Research and answer the Research Question.

3.1 Research Approach

This paper will focus on analyzing the Louvre Museum in Abu Dhabi from an indoor quality perspective by focusing on lighting and how lighting will impact the users and the energy consumption of the space. Therefore, the use of the mixed method for the research will help achieve the research goal and answer the research question.

3.1.1 Case Study Analysis

This method refers to the analysis of existing projects that focuses on analyzing specific topics related to the research study. Yin defines "case studies" as an investigation of specific phenomena within an actual context to relate between real-life and the existing situation (Yin 1984). Several studies, such as those done by Gulsecen & Kubat (2006) and Graham & Schirmer (2006), reflect the importance of case studies in issues related to education, sociology, and community problems. Case studies are divided into several categories based on different studies. For instance, in the study done by McDonough and McDonough, they divided case study analysis into 2 main categories: interpretive and evaluative (McDonough & McDonough 1997). While Yin (1984) divided the case study analysis into 3 main categories: exploratory, descriptive, and explanatory (Yin 1984). According to Yin, using multiple case studies allows the researcher to analyze different aspects of the study based on multiple factors and compare them across case studies (Yin 2003). Baxter & Jack (2008) illustrate that in multiple case studies analyses, the research has the opportunity to compare between them and find the resemblances and differences. That being said, Yin also demonstrates that the use of a single case study allows the researcher to analyze different and multiple angles of a case study in more detail. Additionally, the use of a single case study requires less time when compared to multiple case study analyses (Yin 2003). This paper will analyze various case studies from various regions before implementing the findings on a selected case study.

3.1.2 Surveying

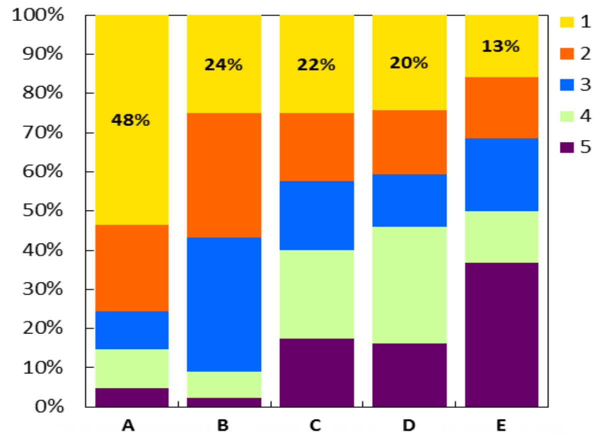
The first method that will be utilized in this paper is surveying, which focuses on gathering information by asking a specific number of questions to particular individuals in order to gather information related to the study. Kraemer demonstrated that surveying usually focuses on quantitative data that is collected via questions (Kizilaslan 2006). Additionally, based on the study done by Levy and Lemeshow, surveying is divided into 2 main steps. The first step includes defining the selected population that the survey will target. This is based on a selection plan (Loughin et al. 2009). In this paper, the selected population was as follows:

1- **Public Users** are operators that are not related in any way to museums or have any experience in the museum field, but they are people from different and random fields. This would help to gather general information that would benefit the research.
2- **Museum Visitors**, people who visited the Louvre Museum in Abu Dhabi. Asking them about their experience in the museum would help in providing an understanding of the space. Also, the visitors of the museum have a clear view of the space from a visitor and user perspective.

The surveying in this paper will be conducted using the questionnaire engine.

A) Questionnaire

B) This surveying method or tool focuses on analyzing the problem by asking the target population-specific questions related to the research. These questions can be answered with a yes or no answer. Multiple-choice questions that focus on a specific part of the research. Written questions where users can express their answers in their own words and perceptions. Usually, the questionnaire is conducted physically or via online engines. This paper will focus on using a mixed-mode by combining the physical and online together. By visiting the Louvre Museum in Abu Dhabi and asking the selected population using the online engine Questionpro, which will provide accurate results. Moreover, in order to evaluate the use of this type of Methodologies different studies have been analyzed in order to understand the effectiveness of Surveying Questionnaire in Museum-related research. Usually, some studies start their Survey by conducting a pilot study which focuses on asking a small number of individuals the survey questions before conducting the Questionnaire on a bigger scale. Alexandra Bounia et al conducted a study for 4 months from May 2011 until September 2011. This survey was distributed to around 5356 individuals in different European Museums. This survey was conducted in order to analyze the number of visitors and people's interest in Museums (Bounia et al. 2012). Additionally, another study done by Jeon and Lee focused on analyzing the impact of the Physical Environment on the user's or visitors' satisfaction. This survey was distributed to over 760 visitors located in Soul South Korea (Jeong & Lee 2006). Moreover, ICOM has conducted a Survey in order to study the impact of COVID-19 on the Museum sector. As the COVID-19 forced around 95% of institutes to close in order to protect their staff and workers (ICOM 2021). Also, in the research done by Qiong Dang focused on analyzing the Visitor Satisfaction towards Digital Museums using surveying in order to analyze how much visitors would enjoy a digital Museum (Dang & Segers 2019). All of these studies focused on analyzing the Museums based on the users' satisfaction and understanding. But this paper will focus on analyzing the Museum from an Indoor Environmental Condition aspect focusing mainly on Lighting. Additionally, in 2011 Jim Duzik and Stefan Michalski created a guideline to assess Solid State Lighting or SSL in Museums, and in 2014 some Museum organizations such as the U.S Department of Energy or DOE and the Canadian Conservation Institute or CCI. A Questionnaire was prepared in order to analyze the use of LED lighting in Museums. Thie questionnaire was planned to be sent to most of the Organizations or Individuals who requested the Guidelines which are a total of 1113 individuals. But a pilot study was conducted to evaluate the suggested questions and 55 was selected from 1113 these 55 individuals was sent the trial version questions to test the setup and content of the questionnaire. The remaining 1058 individuals were sent the final format or version and out of that total of 46 completed the questionnaire with a total of 4.7% response rate. The responses indicated that around 68% are I am putting energy saving as a priority. However, the response indicated that the museum owners are not willing to risk the quality of their museums in order to save energy. All responses are indicated in the Figure 3.1 (Perrin, Druzik & Miller 2014).



Ranking					
Mean	1.9	2.3	2.9	3	3.4
Mode	1	3	1	4	5
Min	1	1	1	1	1
Max	5	5	5	5	5
Mean rank	**1**	**2**	**3**	**4**	**5**

A Use a lighting source with equal if not lower damage potential

B Save energy and reduce cost/maintenance

C Improve color quality compared to standard

D Match color quality of standard museum lighting

E Inconspicuous transition from incandescent to LED lighting

Fig 3.1. Museum Owners Survey Response on ranking Lighting Goals in Museums *(Perrin, Druzik & Miller 2014)*

3.1.3 Field Visits

Conducting site field visits in order to analyze the selected case study based on indoor quality conditions. This will help in analyzing all the space challenges and will suggest the first understanding of potential answers. In the study done by Raul Fernando et al., they concluded from multiple site visits to the selected case study, which is an archeology museum, that most displays were not well illuminated (Ajmat et al. 2011). Also, as demonstrated by Phillips and Gardner after conducting multiple field visits to different locations, daylight has a huge impact on the visibility and clarity of the space (Phillips & Gardner 2012). Furthermore, conducting field visits in order to analyze the type of lighting monitoring and control systems in the space, as demonstrated by Melendez et al. (Del Hoyo-Meléndez, Mecklenburg & Doménech-Carbó 2011), Much other research has demonstrated the impact of field visits on the visibility of research, such as the studies done by Perrin, Druzik & Miller (2014), Bounia et al. (2012), and Jeong & Lee (2006). Furthermore, all of these studies conclude that having a field visit would enhance the quality of the research and help achieve the goals and objectives of the research. All of the field visits were conducted after sending the Louvre Museum in Abu Dhabi a request explaining the main aim and objective of the research, as they provided the chance to visit all the facilities and exhibition areas in order to get the whole perspective of all the space from all angles.

3.1.4 Simulations

focusing on simulation to help with the findings where it will assist in finding an obvious and accurate outcome and result. Multiple studies have demonstrated the importance of simulation when studying energy consumption. Foolady showed in her study that the use of simulation while studying the daylight impact in the museum space was the most significant tool. Foolady focused on using four main simulation tools: Honeybeey, Daysim, Radiance, and Opensudio. Using all of these simulators makes sure that the findings are clear and transparent (Filters 1988). Also, in the paper done by the use of Radiance Simulation in order to study, focusing on suggesting a light method that focuses on balancing the daylight in the space and applying it to the selected case study, Seoul Museum of Art in Korea (Kim & Seo 2012), Furthermore, Huang and Zhu demonstrated the importance of simulations in their study of daylight impact on sculpture museums. They focused on analyzing the impact of daylight based on window size and placement with the use of Ecotect for Modeling the Daylight Prototype, and Radiance was used to estimate the space of daylight (Huang & Zhu 2021). Additionally, more researchers made sure to demonstrate their theories in relation to lighting in museums using different simulation methods (Gao et al. 2020). They made sure to analyze the impact of different lighting modes and CCT changes on the museum experience. (Fathy et al. 2020) also studied the performance of daylight in the layout design of the building and the human awareness of lighting in museums. This illustrates the importance of simulation when studying the lighting impact on museum design. This paper will focus on studying both natural and artificial lighting using mainly two simulation programs and two modeling programs to support the simulation.

A) Modeling

This phase will focus on modeling the selected area of the museum that will be simulated in order to get a transparent outcome. Usually, this phase is done before the simulation process so that the space can be accurately described before starting with the process of simulating.

- **Autodesk 3D Max** will ensure an accurate modeling of the selected space and will also help in dividing the suggested lighting solutions according to the space function. Therefore, when the model is transferred to the simulation program, the findings will be precise.
- **Vary for 3D Max Plugin** will support the lighting analysis with 3D Max. Also, this will give an accurate and more realistic interior shot after applying the suggested solutions and treatments in order to have an image of the expected outcome concerning the function of the space.
- **Sketchup** will support the process of modeling as it will provide a variety of materials and furniture selections. This will make sure that the simulation program gives an accurate diagnosis and analysis, as all of these aspects have a huge impact on lighting when it comes to interior design.

B) Simulation

This process of research will focus on studying different aspects of lighting and their impact on energy consumption. This will be done by comparing the actual museum energy consumption with the new energy consumption that will be simulated using mainly one program or plugin.

- **Integrated Environmental Solutions IES** will help with the Daylight analysis to get an accurate illustration of how Much does the Louvre Museum in Abu Dhabi receives Daylight and how to harness and exploit this Daylight to service the space based on the existing arrangement.

CHAPTER 4

Case Study Analysis

4

C H A P T E R I V

4. Case Study Analysis

4.1 Introduction

This part of the paper will focus on the analysis of different case studies related to museum design to help in the investigation and understanding the aspects of the paper. The focus and awareness of designing a museum with a green and environmentally friendly background have flourished throughout the years due to the huge spread of awareness. Moreover, an institute and an organization have been created called green museums. This organization focuses on the study of green design and sustainable design of museums to help improve and protect the environment due to the huge impact of museums (Pope, 2010). Another aspect that shows the spread of awareness and recognition of green museum design would be the spread and increase of journals and literature focused on green museum design. “Green Museum Design” was even a cover story by the American Association of Museums Publication which is a huge association in museum design (Brophy & Wylie, 2006, & Wylie & Brophy, 2008). Moreover, some studies show that the huge recognition and spread of green museum awareness would imply that in the coming years for a museum to be recognized and accredited it would have to follow a green and sustainable background.

4.2 Case Study 1

The first case study focuses on an analysis of the largest museum dedicated to one civilization that was first started or recognized in 1992. The Grand Egyptian Museum, or GEM, was constructed to create a space where all of the Egyptian civilization met, which was a huge challenge due to the size of the civilization. In 2002, a competition was carried out by the Egyptian government with over 1550 companies participating from different countries around the world to obtain the most innovative design supporting the magnitude of the project (Grand Egyptian Museum Gives Historic Artifacts a Modern Context | ArchDaily, n.d.). The competition was divided into three main categories: architecture design, exhibition gallery design, and construction work. The Irish company Heneghan Peng was announced as the winner in 2003 for the architectural category, while the German company Atelier Brueckner was announced as the winner for the exhibition gallery design category, and for the construction work, both Orascom Construction and Besix were announced as winners (Grand Egyptian

Museum... Egypt’s gift to the world-SIS n.d.). Alongside these companies, multiple firms have participated in achieving the ultimate design. It is worth mentioning that this project is estimated to cost approximately 1 billion dollars, with 70% funded and supported by the Japan International Co-Operation Agency (JICA) (Grand Egyptian Museum | more details ahead of 2021 opening | blooloop n.d.). The location of the project is the key factor for its success. The 500,000 sq. mi GEM is located west of Cairo, close to the Giza Pyramids, as to have a relationship between the Pyramids and the museum. The Pyramids' visibility and proximity to the museum would allow visitors to have a view and understanding of the whole culture. It would also allow them to visit the Pyramids if desired (Khaled 2009). Additionally, the museum is also located a few kilometers from the airport, which will make it easier for tourists to reach the museum with a connected tunnel that connects the 2 km distance to the Pyramids (Egypt’s Grand Egyptian Museum construction work is about 97% complete - EgyptToday n.d.). The main concept of GEM was inspired by the three main pyramids of Egypt. The three pyramids were built approximately 2550–2490 B.C. These pyramids were named after their creators. The tallest was built by Khufu Pharaoh, the second was built by Kahfre Pharaoh, and the smallest was built by Menkaure Pharaoh (Pyramids of Giza | National Geographic n.d.). The process of design and concept analysis is defined and influenced by multiple and different environmental, sociocultural, regional, and climate conditions. All of these aspects were taken into consideration while analyzing and designing the GEM (Finaeva 2020). The first and most important aspect that the designers ensure to accomplish is staying within the level of the plateau, meaning that the museum never exceeds the plateau level. Therefore, the museum lies between the Nile and the Plateau Level (heneghan peng architects - The Grand Egyptian Museum | Giza, Egypt n.d. a). This analysis has significantly influenced the development of the concept in GEM, as the designer ensured that the visitor would live the experience when visiting the museum, which is going through different levels within the museum, and the end level is the plateau where he can clearly see the three pyramids from the museum, as seen in Figure 4.1. On this level is the main gallery where most of the artifacts are showcased. Additionally, the main concept was developed by creating an imaginary axis that connects the museum with the three pyramids this will create a new relationship between both the old and new Egypt (*Grand Egyptian Museum, Cairo, Egypt* -

Verdict Designbuild n.d. a). As seen in Figure 4.1 the imaginary axis points that connect the museum to the Pyramids are shown with three axis lines A, B & C (*Grand Egyptian Museum Gives Historic Artifacts a Modern Context | ArchDaily* n.d.). This clearly shows the huge relation that the design team intended to illustrate (*Grand Egyptian Museum Gives Historic Artifacts a Modern Context | ArchDaily* n.d.). which will help enhance the main concept, which is the relationship between old and new Egypt. The whole theme and concept that the designer clearly tried to emphasize and illustrate is the use of triangles in relation to the three main pyramids, as illustrated in the Figure 4.3 which was taken in 2019 (*A glimpse behind the scenes of Giza's Grand Egyptian Museum | Cairo holidays | The Guardian* n.d. a)

Another main factor of the museum's design is the use of alabaster stone walls that cover the whole front façade, as seen in Figure 4.2. The main idea of this stone is that it's translucent, so it can radiate sunlight into space, increasing the inner daylight (The Grand Egyptian Museum: opening in 2020 - THE Stylemate n.d.). It is worth noting that most of the museum is built underground so that it doesn't interfere with the topography of the site. This also gives visitors a dramatic experience as they traverse the levels: they would move throughout the structure system and levels of the space as seen in Figure

Fig. 4.1 Imaginary Axis with the 3 Pyramids
(*Grand Egyptian Museum Gives Historic Artifacts a Modern Context | ArchDaily* n.d.)

Fig. 4.2 Translucent Alabaster Stone *(The Grand Egyptian Museum: opening in 2020 - THE Stylemate n.d.)*

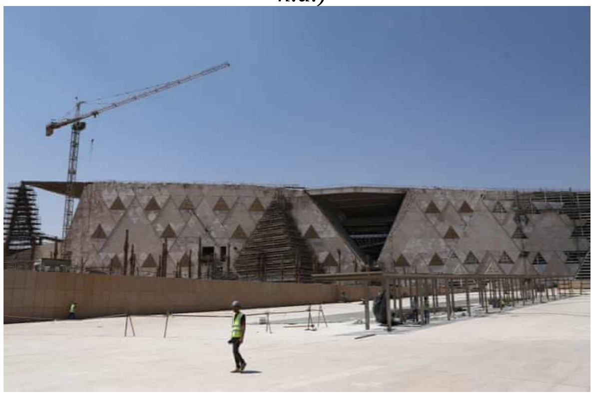


Fig. 4.3 Triangles Concept Implementation in the building Façade *(A glimpse behind the scenes of Giza's Grand Egyptian Museum | Cairo holidays | The Guardian n.d. a)*

4.4, and on the last level, or the highest level of the space, the visitors would be able to directly see the Pyramids from the museum on the same level as seen in Figure 4.5 (Grand Egyptian Museum Gives Historic Artifacts a Modern Context | ArchDaily n.d.)

Fig. 4.4 Structure system in relation to the Movement
(Grand Egyptian Museum Gives Historic Artifacts a Modern Context | ArchDaily n.d. b)

Fig. 4.5 Pyramids View from the Museum
(The Grand Egyptian Museum: opening in 2020 - THE Stylemate n.d.)

4.2.1 *Phases of the Project*

GEM started with two main phases that took part from 2005 to approximately in 2008 based on the Design-Build Network *(Grand Egyptian Museum, Cairo, Egypt - Verdict Designbuild n.d. b).*

A) Design

The First Phase of the project was to clear the building area and begin all the schematic design work, which is when they came up with some innovative design to highlight the triangles of the Pyramids as seen in Figures 4.6 focusing on the use of triangles to help promote the relationship between the Pyramids and the location of the museum (*Grand Egyptian Museum* - *BESIX* n.d. b). Another important part of this phase was the creation of the Grand Egyptian Museum Conservation Center or GEM-CC, which was used to store and reserve some of the artifacts that were planned to be exhibited and stored in GEM due to limited space in the Egyptian Museum (Arab Republic of Egypt Grand Egyptian Museum Joint Conservation Project Project Completion Report (Term1) 2020).

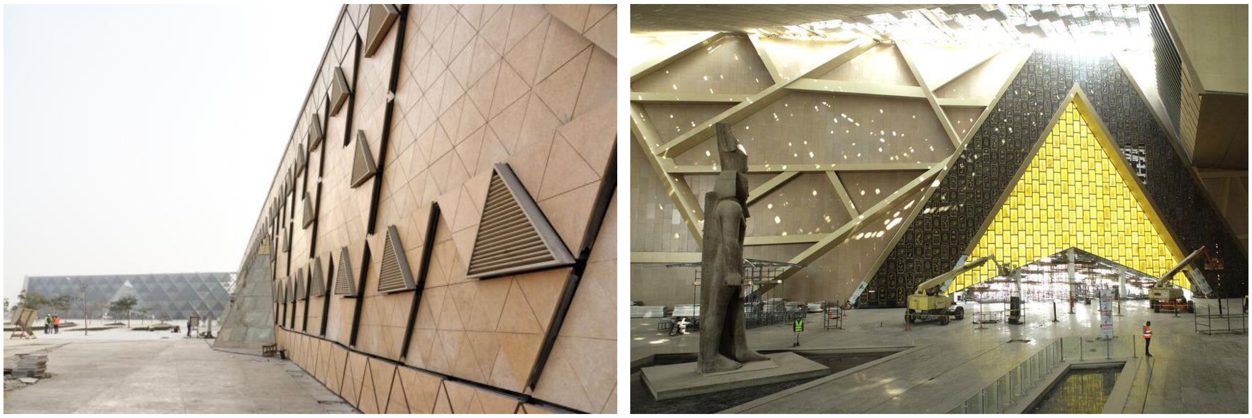


Fig. 4.6 GEM Exteriors and Interior Design with the use of Triangles (*Grand Egyptian Museum - BESIX* n.d. b)

The Second Phase was the construction of the energy and firefighting systems and also the manufacture of the tunnel between the Pyramids and the museum (*Grand Egyptian Museum, Cairo, Egypt - Verdict Designbuild* n.d. b). This stage was divided into three main security zones (*The Grand Egyptian Museum* n.d.):

Zone 1 - Inspecting zone.

Zone 2 – Labs Zone.

Zone 3 – Archaeological Warehouse.

The Third Phase took part from 2008 to February 2009 and included leveling the ground and removing sand from the site as the location of the museum has a nature of contour levels reaching almost +45 meters. Also due to the concept of the project and the main goal which is having an open view of the pyramid, a total of 2.25 million cubic meters of sand was removed so as not to block the view from the museum towards the pyramids as seen in Figure 4.7 (*The Grand Egyptian Museum* n.d.).

Fig. 4.7 Sand Removal Process from

The Fourth Phase was the implementation of the design, mainly focusing on the main atrium where a huge statue of Ramses II greets the visitors at the entrance as seen in the Figure 4.8. This phase also focused on the entrance façade that is covered by an 800 m long with a 40 m high translucent stone wall in front of sheltered space for visitors

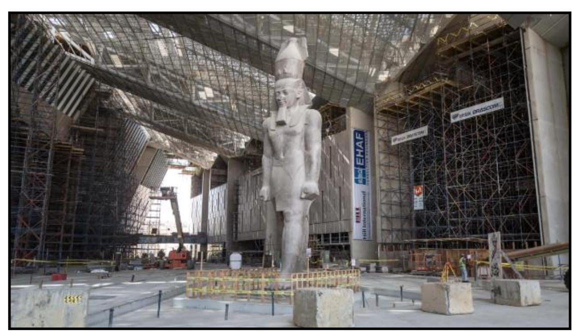


Fig.4.8 Ramsees II Status in the main Atrium

which is designed in a triangle shaped movement as to emphasis the concept as seen in the below Figure 4.9 (*A glimpse behind the scenes of Giza's Grand Egyptian Museum | Cairo holidays | The Guardian* n.d. b). Additionally, another important aspect that can be seen in GEM is the first-ever hanging obelisk that greets visitor as they are entering the main entrance. Eissa Zidan, executive affairs for restoration and transportation of antiquities for the museum, said that the construction for the world first obelisk is almost done (*Egypt's Grand Egyptian Museum to be inaugurated on June, 2021 - EgyptToday* n.d.). Also, the design of all the different zones that are included in the museum such as the exhibition galleries with a total of five galleries to host the massive number of artifacts, a conference centre, an auditorium that hosts around 1000 guests, seminar rooms with over 200 seats, and educational research centers. The Grand Museum consists of multiple zones and areas as follows:

Fig. 4.9 Translucent Stone Wall at the

- More than 100 galleries that illustrate some of the main sculptures and tombs (Khaled 2009):
  - A large statue of King Tutankham Amon in the middle of the gallery.
  - Hanging of King Ramses II obelisk in the ceiling so people can see the King Ramses II Cartouche (The Grand Egyptian Museum: opening in 2020 - THE Stylemate n.d.).
  - The Throne of the King Tutankham Amon.
  - The famous Majestic Mummies (Ramses II, Tuthmosis the Third, etc.).
  - King Ramses' Huge Statue in the middle of the foyer after the entrance as seen in Figure 4.10 (*Heneghan Peng Architects-designed Grand Egyptian Museum to open at end of 2020 | Architecture and design news | CLADglobal.com* n.d.).

Fig. 4.10 King Ramses Statue Centre of the Atrium *(Heneghan Peng Architects-designed Grand Egyptian Museum to open at end of 2020 | Architecture and design news | CLADglobal.com n.d.)*

- Conference center
- Multimedia center
- A huge movie theatre
- The biggest library devoted to Egyptology
- Some shops and restaurants
- Multitasking rooms and halls
- Operational facilities

After passing King Ramses II, there is a Grand Staircase and on the left of the staircase, there is the main galleries that are divided into four main eras: pre-dynastic (this is the period of 3100 B.C), the Middle Kingdom, the New Kingdom, and the Greco-Roman civilizations. While on the right of the staircase there will be the Tutankhamun Tomb showed for the first time (*The Grand Egyptian Museum: Everything We Know, From the Architecture to the Must-See Collections | Condé Nast Traveler* n.d.). Also along the stairs, the different Pharaohs of the Egyptian era are arranged along the stairs as seen in the Figure 4.11 (*Gallery of Grand Egyptian Museum Gives Historic Artifacts a Modern Context - 4* n.d.).

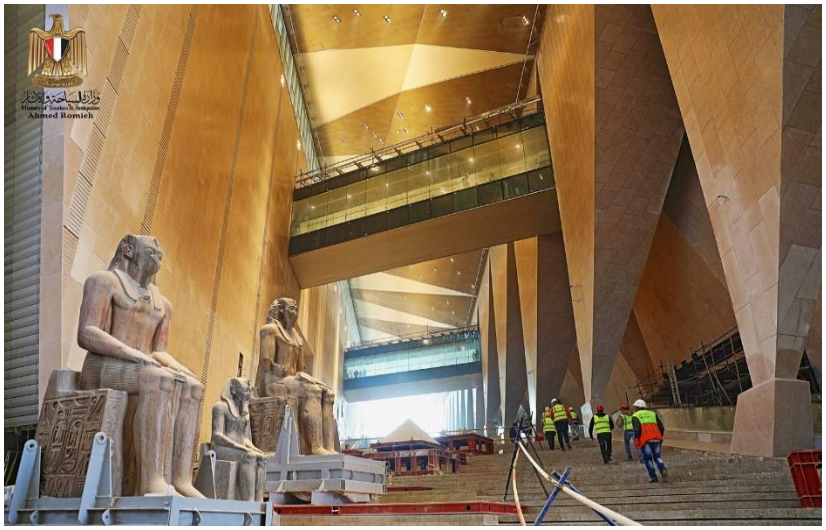


Fig.4.11 Staircase Pharaohs arrangement

The Fifth Phase of the project was the transportation of the famous exhibits to the main halls in GEM. The first part of this started with the moving of the Ramses II Statue, which is 3000 years old as he ruled between the periods of 1279 and 1213 B.C. The Statue is 83 tons and

Fig.4.12 Ramses II Transportation and all taken precautions

over 10 meters high. This statue was one of the first artifacts to arrive in the museum area (*Ancient Ramses II Statue Moved to Grand Egyptian Museum* n.d.). The transportation took place on the 25th of January 2018 with the participation of the Egyptian military, which took huge precautions while transporting the huge statue to keep it as safe as possible as seen

Fig. 4.13 Mummies Transportation Vehicle

in Figure 4.12 (*Egypt moves Ramses II statue to Grand Egyptian Museum's atrium for later soft opening - Xinhua | English.news.cn* n.d.). Additionally, part of this phase was the transfer of approximately 22 mummies from their main location which is the Egyptian Museum located in front of Tahrir square to the Grand Egyptian Museum. The transfer of the mummies was accomplished in a huge ceremony that was held on the 3rd of April 2021, where the mummies were placed in a vehicle representing the Egyptian culture as seen in Figure 4.13 (*Egypt Holds Parade to Move Royal Mummies to New Museum* n.d.).

The main concept behind the whole theme of GEM is the pyramids shape as mentioned before. Additionally, the shape of the museum was a combination between the pyramids and the spiral shape and the reason for that is when focusing on a spiral it is possible to add multiple layers within the museum and this was the main target of the designer as to add multiple layers and levels within the museum. As seen in the Figure 4.14, the layers of the museum define different functions which are illustrated with different colors in the below Figure 4.15 (*JDS Architects | Grand Egyptian Museum* n.d.).

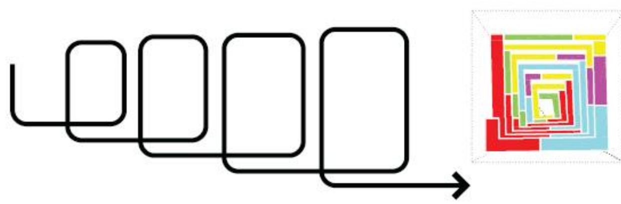


Fig. 4.14 Spiral Shape of the Museum *(JDS Architects | Grand Egyptian Museum n.d.)*

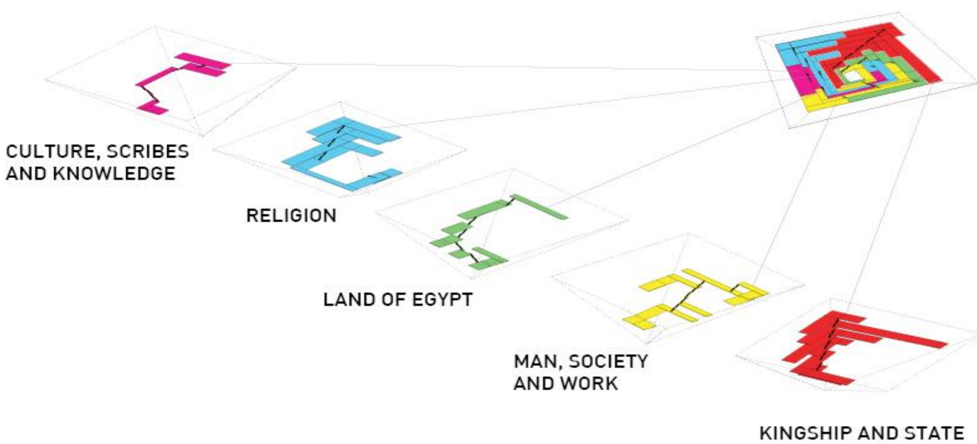


Fig. 4.15 Spiral Shape different Functions Illustration *(JDS Architects | Grand Egyptian Museum n.d.)*

The shape of the whole museum is following the pyramids shape with half of the pyramid shape is underground as illustrated below Figure 4.16. The main reason for that is to preserve and ensure that the typography of the site is not affected or changed as this site which is Giza (Memphis and its Necropolis) was declared by UNESCO as a World Heritage (*UNESCO World Heritage Sites in Egypt | Egypt Online Visa* n.d.).

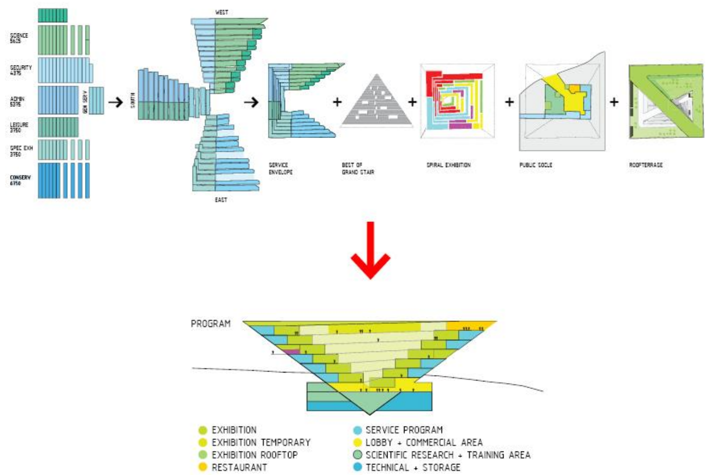


Fig. 4.16 Half of the Museum Lays underneath the Ground *(JDS Architects | Grand Egyptian Museum n.d.)*

Another important goal of the designer is to help the visitor view the artifacts from different angles in the museum. For instance, if the artifact is on the first floor and the visitor is on the 3rd floor, the artifact would be visible because the designer made sure that all the levels are visible from within as seen in Figure 4.17. This is also related to the size of the artifact.

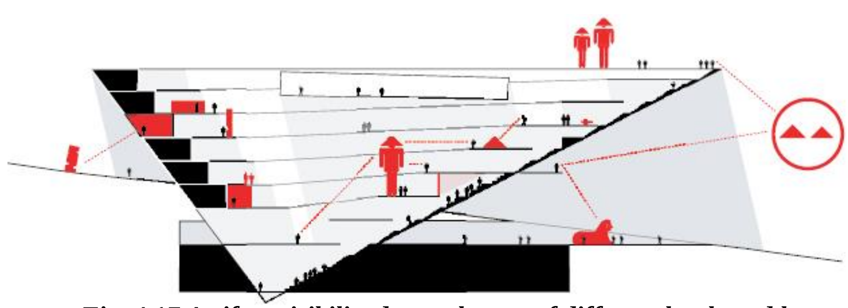


Fig. 4.17 Artifact visibility due to the use of different levels and layers Ground *(JDS Architects | Grand Egyptian Museum n.d.)*

The whole stairs run along with the museum in an angle that allows the viewers to view all of the artifacts that run along with the stairs as visible in the Figure 4.18.

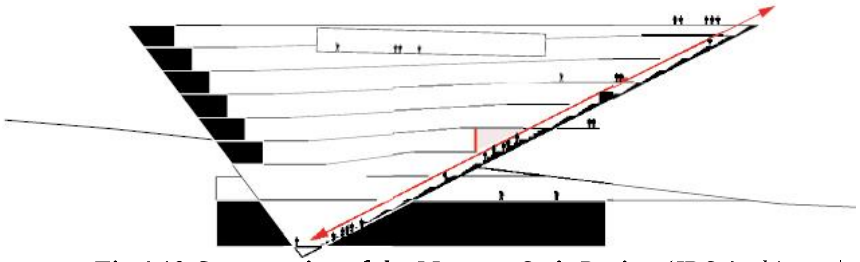


Fig.4.18 Cross-section of the Museum Stair Design *(JDS Architects | Grand Egyptian Museum n.d.)*

Having levels and layers has a huge positive impact on the artifacts and the exhibited pieces, though having too many layers or ramps within the space can have several limitations. Having such levels and ramps would reduce the amount of available space and usually all museums try to use as much space as possible devoted for the artifacts and pieces. Similarly, the use of multiple layers would require enhancing the lighting system due to the increased number of shading that such ramps or stairs would provide, this will on the other hand increase the energy consumption. These points take us to another important element which is lighting in space.

B) <u>Lighting</u>

The lighting in a museum is one of the challenges that the designer faces. Additionally, in a space as huge as the GEM, lighting will be a challenge to the designer as it would require a huge amount of lighting fixtures in order to make sure the space is efficiently controlled with enough lighting for the specific function.

- *<u>Natural Lighting</u>*

The Grand Egyptian Museum's main lighting factor that will help generate and produce daylighting for the space is the translucent stone wall which is 800 m long. This wall will rise 40 m in height where it will separate the spaces from the outdoor area also providing a dramatic type of daylighting for the space. Another aspect that was studied by the designer is having a floated ceiling that would allow daylighting to the space also adding a theatrical experience and feeling to the visitor as shown in

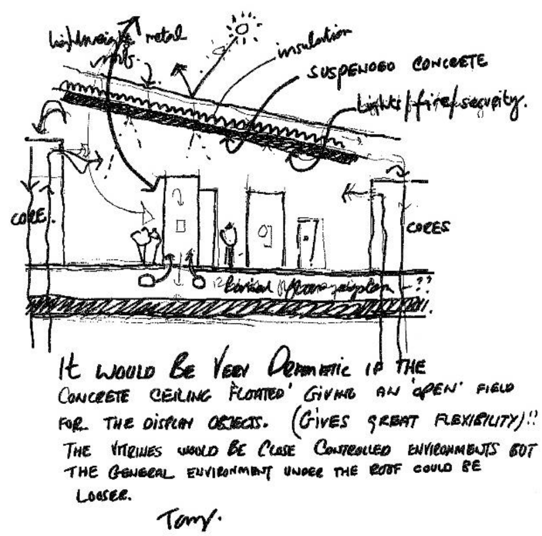


Fig.4.19Sketch done by the Designer Heneghan Peng that illustrates the impact of floating Ceiling *(heneghan peng architects - The Grand Egyptian Museum | Giza, Egypt n.d. b)*

Figure 4.19 (heneghan peng architects - The Grand Egyptian Museum | Giza, Egypt n.d. b). Additionally, as seen in Figure 4.20, the use of natural lighting was the main aim of the designer, by adding an opening in the ceiling in the main hall to allow daylight into the space (*Grand Egyptian Museum - BESIX* n.d. c).

Fig. 4.20 Daylighting application within the space *(Grand Egyptian Museum - BESIX n.d. c).*

- *Artificial Lighting*

Due to the size of the space and the high ceiling, the need for a huge number of artificial lightings was essential. The designer made sure to use LED lighting, due to the factor that LED is best used for museums due to the multiple factors as discussed before. Figure 4.21 shows the use of LED lighting.

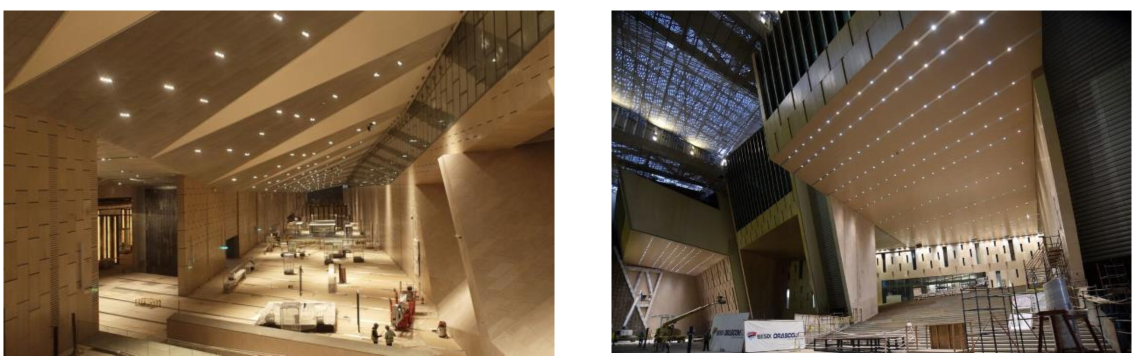


Fig. 4.21 Artificial Lighting in the Main Halls *(Grand Egyptian Museum - BESIX n.d. c).*

C) Environmental Aspects

Another important aspect that the GEM analyzed during the process of the project was different environmental characteristics. Due to the use of the translucent stone wall, the indoor temperature of GEM remains 23°C while the temperature of the wall and roof might reach 70°C (*Grand Egyptian Museum - Buro Happold* n.d.). Additionally, having a water feature that surrounds the space of the museum improves the indoor air quality by adding a feeling of coolness in the space. Most of the artifacts and objects in the museum benefit from the dry weather of Egypt. But some delicate and sensitive objects require the creation of a microclimate. Figure 4.22 illustrates GEM's exterior façade design.

Fig. 4.22 GEM Translucent Stonewall Façade *(Grand Egyptian Museum - Buro Happold n.d.)*

4.3 Case Study 2

Another important case study is the California Academy of Science located in San Francisco, California, United States as seen in Figure 4.23 (Pallowick 1985). This institute was first founded in 1853 as a facility to perform experiments. It also had a museum where visitors could learn about the ecological world. After years of work as a research facility, in 1999 the owners had the idea that this facility could be the most recognized museum that focuses mainly on sustainability (Kociolek 2006). This idea came after the hazardous earthquake that resulted in huge damage to some of the structures and facilities of the museum. Importantly, as a museum that focuses on natural history, this type of museums needs to have a

Fig. 4.23 Museum Location in San Francisco *(Pallowick 1985)*

goal and objectives towards the environment to help spread awareness regarding sustainability and the safety of the environment.

4.3.1 Phases of the Project

"A lot of natural history museums are good at telling what was, but we were trying to shift to telling what could be or what should be" – this was a saying by one of the members of the museums (Pallowick 1985). The original facility had been a campus located in Golden Gate Park that was originally built in the middle of 1916 and 1976. But due to the Loma Prieta Earthquake, most of the building structures were demolished.

A) Design

Multiple designers applied to the project but Renzo Piano was the one who impressed the owners with his well-designed INK sketches that represented the aim of owners. Most of the other designers and architects came with multiple models and 3D work but Renzo only came with a sketchbook in his hand. Renzo also impressed the owners in his interview: one employee said that this interview was the reason for hiring Renzo due to the conversation he had with the owners (*California Academy of Sciences by Cal Poly Citizen Architects - issuu* n.d.). Renzo had never worked on a fully green and sustainable project except for the museum that he designed in Switzerland. The design process started by studying the location and surroundings of the museum; Renzo was inspired by the geological and hills of San Francisco nature as illustrated in Figure 4.24 – this sketch and image was captured by the artist Renzo himself (*California Academy of Sciences by Cal Poly Citizen Architects - issuu* n.d.). The design's concept was mainly illustrated in the roof of the building, to so-called *living roof* as seen in Figure 4.25. The designer described

Fig. 4.24 Renzo Concept and Sketch of the Museum Concept *(California Academy of Sciences by Cal Poly Citizen Architects - issuu n.d.)*

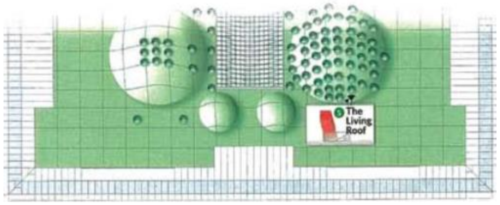


Fig. 4.25 The Living Roof Top View

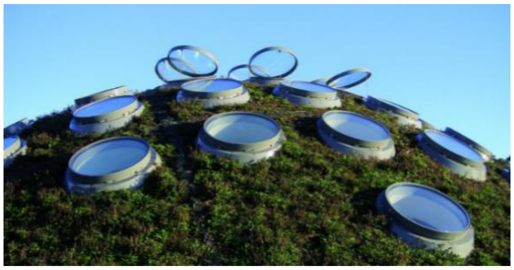


Fig. 4.26 Roof Top Openings Design *(California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture | ArchDaily n.d.)*

it as "Lifting a piece of the park and putting a building underneath it" (Pallowick 1985), as it included around 2.5 acres of native plants.

B) Lighting

The innovative and smart curved design that is illustrated in Figure 4.26 and represented in the living rooftop is designed to capture the wind, and also allows natural light to enter the space through the available openings as seen in Figure 4.27 (*California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture | ArchDaily* n.d.).

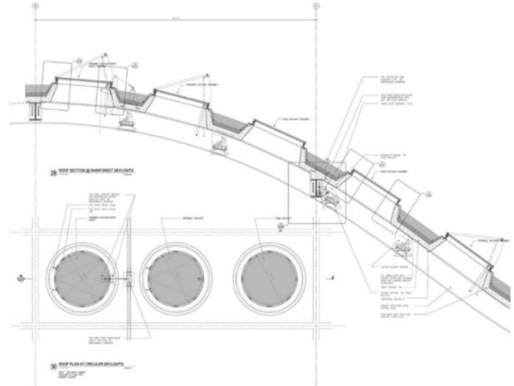


Fig. 4.27 Roof Top Openings System *(California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture | ArchDaily n.d.)*

- *Natural Lighting*

Additionally, as shown in Figure 4.28 the use of the openings to provide daylight to the space will help with the lighting of the space. These openings unfold and fold throughout the day as illustrated in Figure 4.29, which allows control over the amount of daylight that enters the space (*California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture | ArchDaily* n.d.). As seen in Figure 4.29, the amount of natural light that these openings provide is huge. Also having a floor-to-ceiling glass with low iron content to have more clarity allows more natural lighting to enter the space.

Fig. 4.28 Atrium daylight

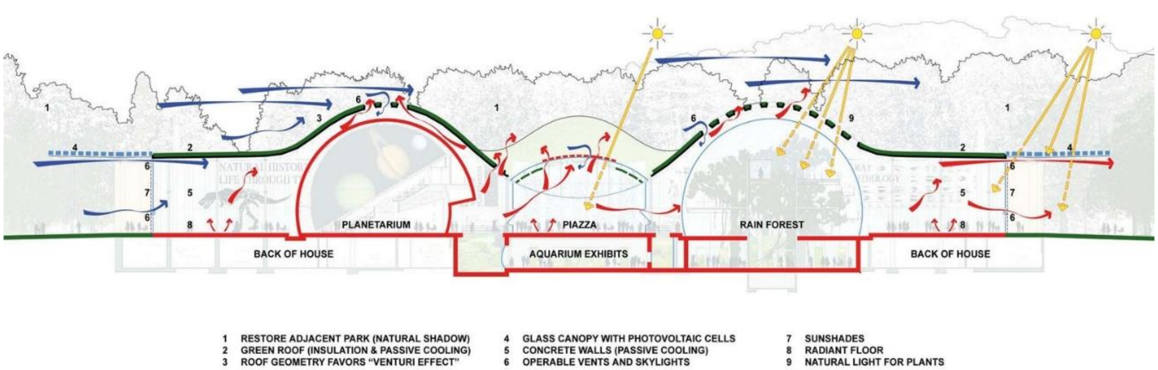


Fig. 4.29 Roof Top System and Design Functions *(California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture | ArchDaily n.d.)*

Artificial Lighting

This museum mainly focused on the dependence on natural lighting, but the use of artificial lighting in museums is a necessity. Additionally, the use of 60,000 photovoltaic cells are divided on a glass canopy around the parameter of the building. This PV system helps in providing approximately 213000 kWh of clean energy which is 5 percent of the museum's annual requirements based on one study (*Efficient Building Design | California Academy of Sciences* n.d.). Another study indicates that it might reach around 10 percent of the annual requirements (*California Academy of Sciences by Renzo Piano Building Workshop | Dezeen* n.d.). This also prevents the release of more than 405,000 pounds of greenhouse gases annually to the environment. This PV system helps with the production of artificial lighting within the space. Since the building is an old building that has been renovated, some traditional lighting was available. CFL was highly used with LED lighting for the indirect light as seen in Figure 4.30 (*Gallery of California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture - 9* n.d.).

Fig. 4.30 LED Indirect Lighting *(Gallery of California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture - 9 n.d.)*

C) Environmental Aspects

Furthermore, the system of the openings allows fresh air to enter the space while also allowing unwanted heat to escape from the openings. This reduces the need to use HVAC systems (*California Academy of Sciences by Cal Poly Citizen Architects - issuu* n.d.). Additionally, the green roof is more insulating than a traditional roof due to the vegetation and greenery available; this roof also helps by collecting rainwater and any additional water created from the humidity and mist in the air,

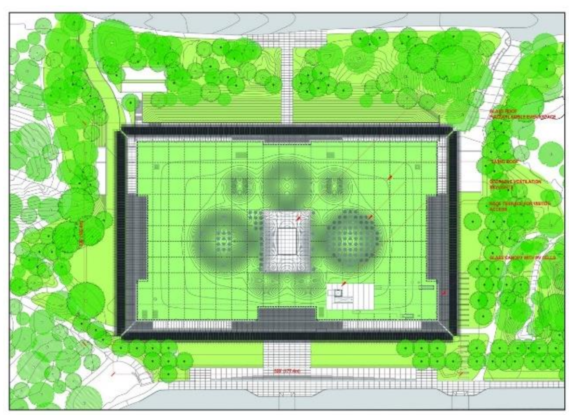


Fig. 4.31 Fresh Air from Golden Gate Park *(California Academy of Sciences by Cal Poly Citizen Architects - issuu n.d.)*

which can then be used as a gray water system. (*California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture | ArchDaily* n.d.). The shape and movement of this roof takes advantage of the natural air current generated from the location of the museum beside the Golden Gate Park as seen in Figure 4.31. Moreover, having space where users and visitors can observe and learn about sustainability through the available roof design will help in spreading awareness about green design and sustainability. Providing cross-linked polyethylene tubes or PEX tubing in the flooring of the building helps to control temperature and supports the cooling and heating of the space as seen in Figure 4.32. This will result in a reduction in the annual energy consumption by approximately 10% (Gallery of California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture - 9 n.d.).

Fig. 4.32 PEX Tubing in the Museum Flooring can provide heat for the space *(California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture | ArchDaily n.d.)*

Another important aspect is the materials used, which were recycled materials from the previous building such as stones, glass, and wood (Kociolek 2006). The use of glass for the façade and exterior walls of the building allows a connection between the park and the indoor space as seen in Figure 4.33. Furthermore, as Piano indicated that museums are usually dark spaces that can make people feel stuck, but this space is a museum of natural history that is located in the middle of the park so it is important to link both of these spaces

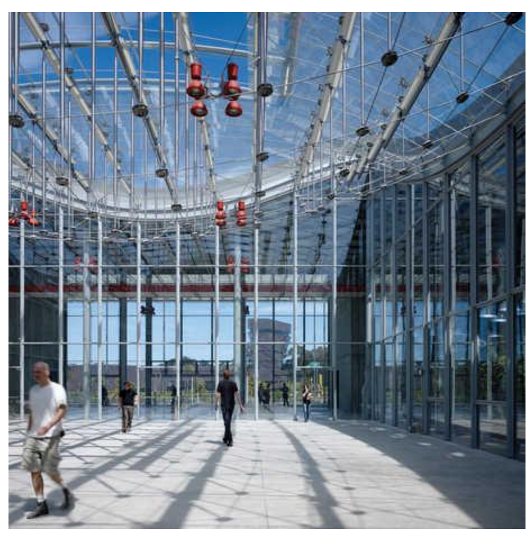


Fig. 4.33 Glass Façade Design *(California Academy of Sciences by Renzo Piano Building Workshop | Dezeen n.d.)*

together (*California Academy of Sciences by Renzo Piano Building Workshop | Dezeen* n.d.). Furthermore, this museum has multiple functions and zones that are divided into levels in the space The museum is divided mainly into five main halls:

- The rainforest is designed under the main dome in the museum as seen in Figure 4.34. This reflects the rainforest, where most of the light from the roof design enters this space.

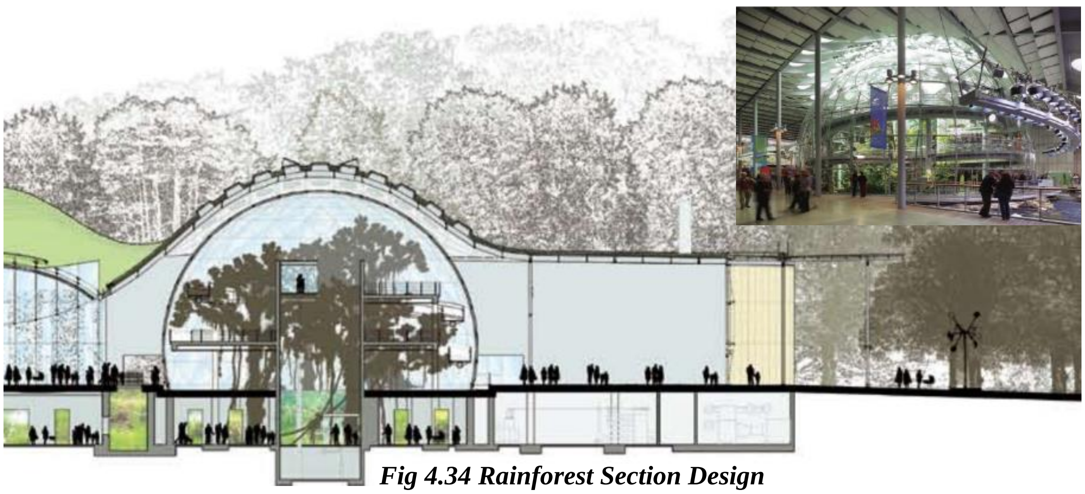


Fig 4.34 Rainforest Section Design

- The planetarium indicated in Figure 4.35 is built under the second main dome which includes an area to study different space, planets, and stars-related studies.

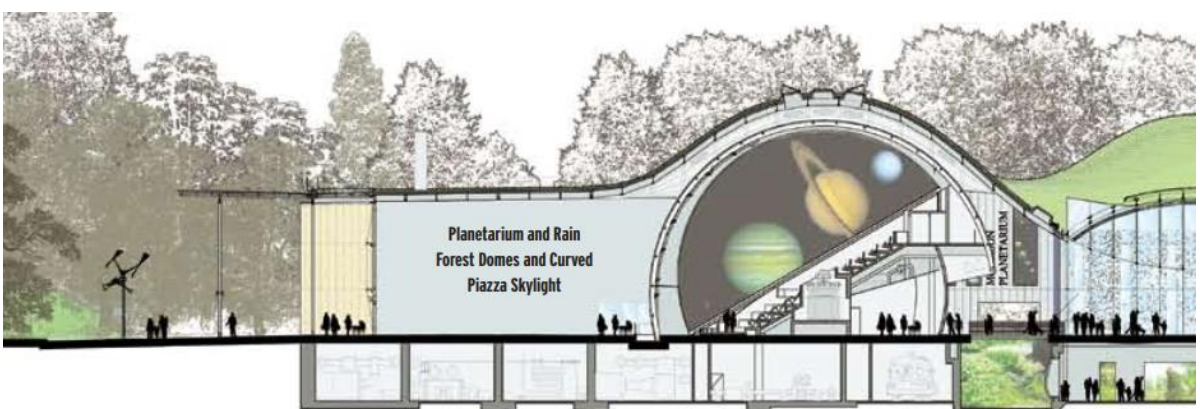


Fig 4.35 Planetarium Section Design

- The planetarium and rainforest spaces are the museum's main exhibit areas, which is illustrated in Figure 4.36. This area has an obvious airflow as seen in the Figure which allows air circulation through the space. Also, the yard is fully covered with a glass roof and glass walls, which was a tremendously complex and challenging undertaking for the designer. The roof is covered with a double net of steel beams, and the size of this hall space is around 660 sq. mi, which is quite big when talking about a full glass space. This was one of the challenges that the designer was ready to encounter and the particular reason for that is due to the importance of this aspect to the success of the project (*renzo piano's california academy of sciences* n.d.)

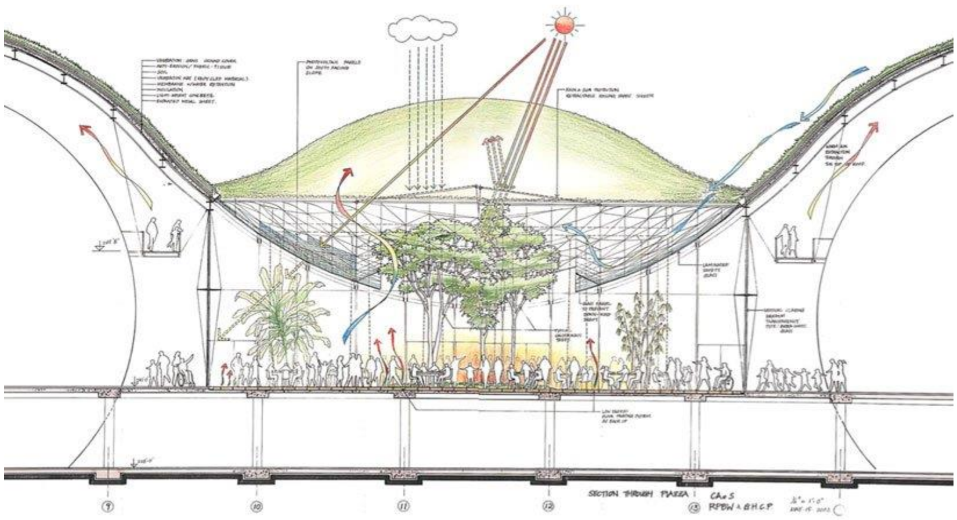


***Fig 4.36 The Exhibition Court between the Planetarium and the Rainforest** (Renzo Piano's California Academy of Sciences n.d.)*

Figure 4.37 illustrates the levels of the museum (Pallowick 1985):

- The basement includes an aquarium, while the back of the house provides space for administrative functions.
- Level one includes the earthquake hall, the African hall, rainforest, and the planetarium.
- Levels two and three include the rest of the rainforest and the planetarium.
- The roof or the living roof includes all the functions mentioned before from having PV solar panels to help produce energy to space where users or visitors can observe all the vegetation and learn about sustainability.

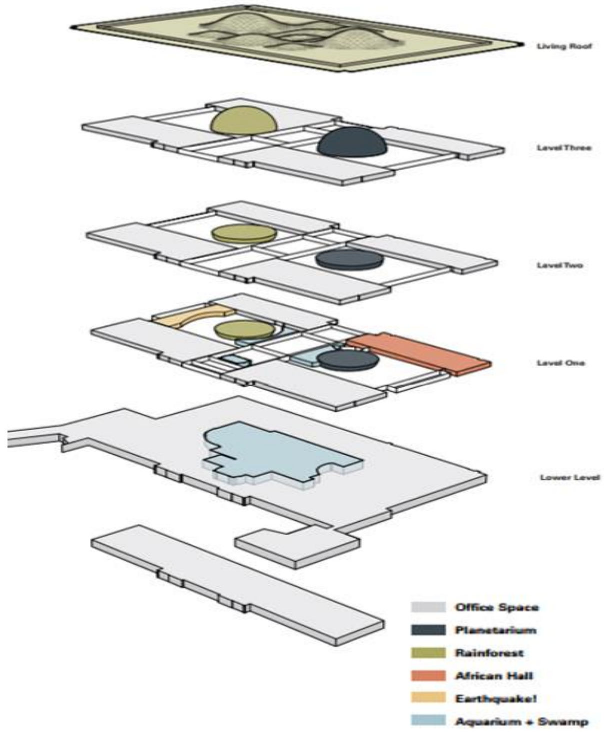


Fig 4.37 Levels of the Museum *(Pallowick 1985)*

Furthermore, the financial aspect of this project had a huge effect on the quality and results received. After the earthquake hit San Francisco and damaged multiple areas and structures of the museum, a decision had to be made about whether to remove the museum from its location in the park or leave it. The question was put to a vote and 70% of the San Francisco community voted that it would stay in the park (Kociolek 2006). This museum has cost approximately around 488 million dollars to accomplish, which is a huge amount for a museum re-design. The high cost was due to the sophistication of design and the high goals that the designer and the community aimed to achieve from this project. The funds of the project came mainly from local bonds by the voters. The living roof (green roof) has cost approximately around 28$ to 35$ per sq.ft. while the regular roof costs around 15$ to 20$ per sq.ft. This illustrates the level of sophistication and effort put into the design of the roof (*Three Years Later: California Academy of Sciences' Living Roof Also Educates the Design Community – THE DIRT* n.d.).

The New California Academy of Sciences is the greenest museum in the world, having been awarded the US Green Council's highest certification, LEED, in 2008. The museum earned this certification due to the following conditions:

1- Material selection

- Most of the materials used including glass, bricks, stones, steel, and concrete are reused and recycled from the old building (*Choosing Sustainable Building materials for the Academy* n.d.)
- Most of the materials used for AC and ventilation are environmentally-friendly and have low CO_2 emissions.
- Around 65% of the waste is transformed from the landfills into recycling.
- Around 50% of used woods were planted and used in the most sustainable way. (*Academy of Sciences in California - Data, Photos & Plans - WikiArquitectura* n.d.).
- The insulation used in the building was extracted from leftover denim jeans (*California Academy of Sciences // Renzo Piano Building Workshop - Architizer Journal* n.d.)

2- Water-saving due to the available living roof the use of rainwater is visible and useful. The facility also uses waterless urinals and tanks (*The California Academy of Sciences Receives Second LEED Platinum Rating From U.S. Green Building Council | California Academy of Sciences* n.d.).

3- Lowering the green gas emissions by installing CO_2 gas monitor and by limiting the use of materials that are low in VOC.

4- Spreading awareness and understanding about sustainability by doing the following:

- The green roof or living roof is a place where people can learn about sustainability and green design. Also, this space is used weekly for different programs and research projects related to sustainability (*The California Academy of Sciences Receives Second LEED Platinum Rating From U.S. Green Building Council | California Academy of Sciences* n.d.).
- Some educational programs and institutions such as The Academy's Teacher institute use the museum as part of their curriculum.
- Given the high traffic of this museum, with millions of visitors yearly, there is a very large audience to learn about sustainability and green design.
- A fully green and sustainable museum like this one has the power to influence other museums to follow suit, spreading the concept and practice of sustainability.

5- Energy efficiency through the use of sustainable materials, the use of PV panels to produce energy, and reduce energy consumption.

4.4 Case Study 3

The third case study that is analyzed is located in Hague in the Netherlands. This was a conceptual project consisting of two buildings attached to each other. This project studied the impact of using different shading elements and devices to compare the amount of daylighting that would be ideal for the museum Project.

4.4.1 Phases of the Project

The first phase of this project was the site selection for the museum. As it is located in the Central Park of the city as seen in Figure 4.38 (Filters 1988), which is indicated with the yellow shape. This city is the third largest city in population in the Netherlands and the number of visitors that the museum expects is indicated with the red shading in the below Figure 4.39 (Filters 1988). This is also one of the main reasons for the selection of this site as a location for the museum. Additionally, when selecting the project site, it's important to study the different aspects of weather and different possible orientation for the building.

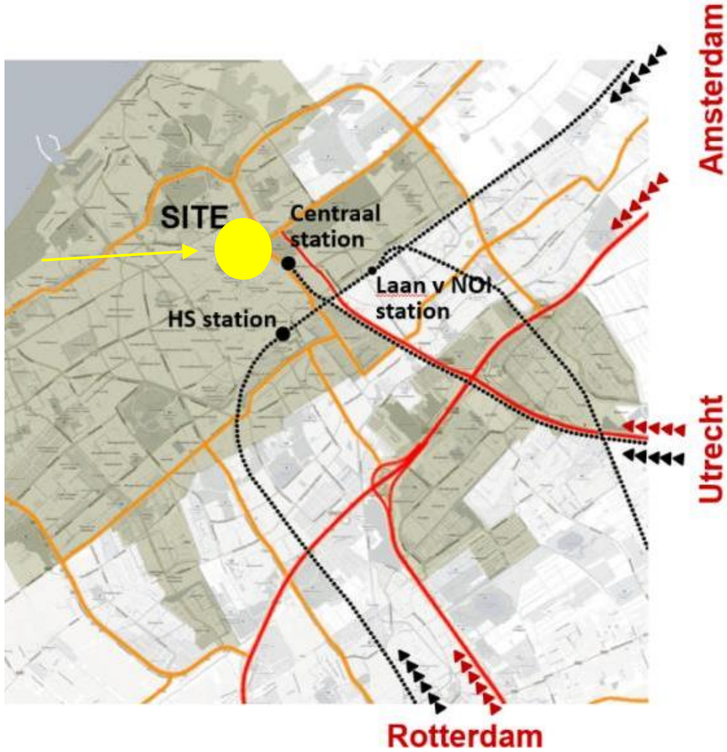


Fig. 4.38 Third Case Study Location Site *(Filters 1988)*

Fig.4.39 Expected Number of Visitors (*Filters 1988)*

A) Design

The exhibition area had three main levels, where the exhibition area was divided into the first and third floors (Basement Area) and a small zone for collection also in the basement area, The ground floor of the building is an elevated area where visitors can enjoy outdoor seating without being affected with the sun's heat due to the building providing a shading element as indicated in Figures 4.41 and 4.42.

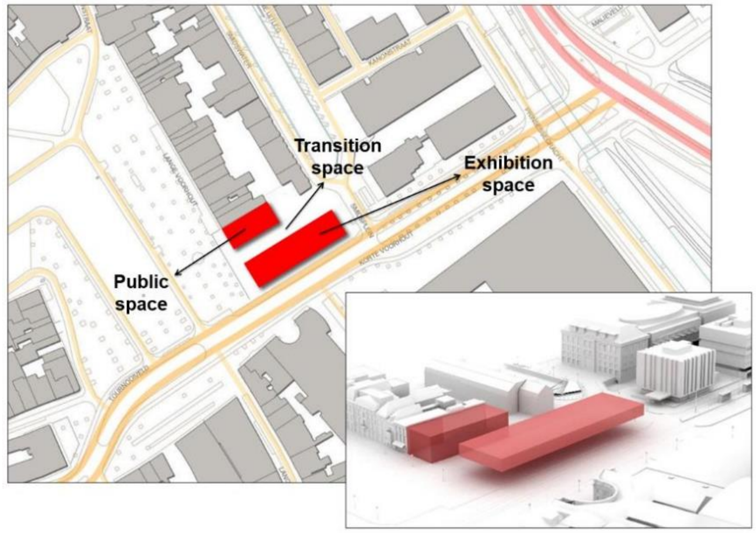


Fig.4.41 Museum Different zones and Levels *(Filters 1988)*

Furthermore, after adding and analyzing the shading elements, another important aspect is material analysis. Building materials consume around 38% of the total energy consumption of the world (*IAP | InterAcademy Partnership* n.d.). A study was done using a space located in Delhi which is composite weather the size of the space is 3m X 3m X 3m. The study compared two different materials – ash blocks and fireclay bricks – and their effects on energy consumption. The price of ash block is much higher than the fireclay but due to the low density of the ash block which is 600 kg/m3 when compared to fireclay with 1600 kg/m3 in density, it is a better choice as it reduces the amount of structure that would be required. Additionally, the study has shown that the use of ash block reduces air conditioning requirements by 59%. This is illustrated in the chart below which also shows that the ash block also reduces the heat load when compared to the fire clay bricks (Buddhi & Energy 2015).

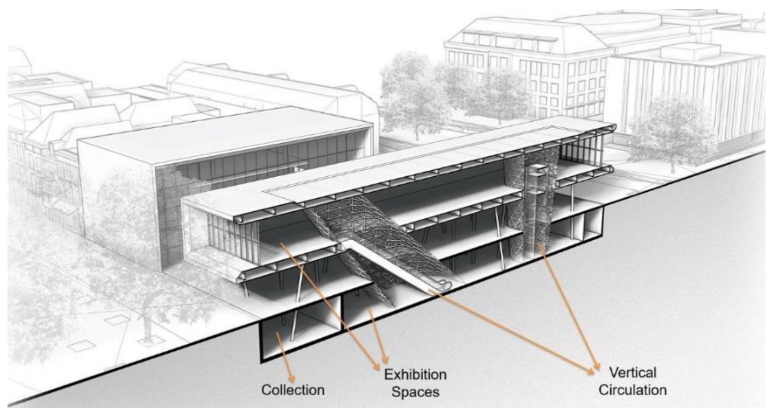
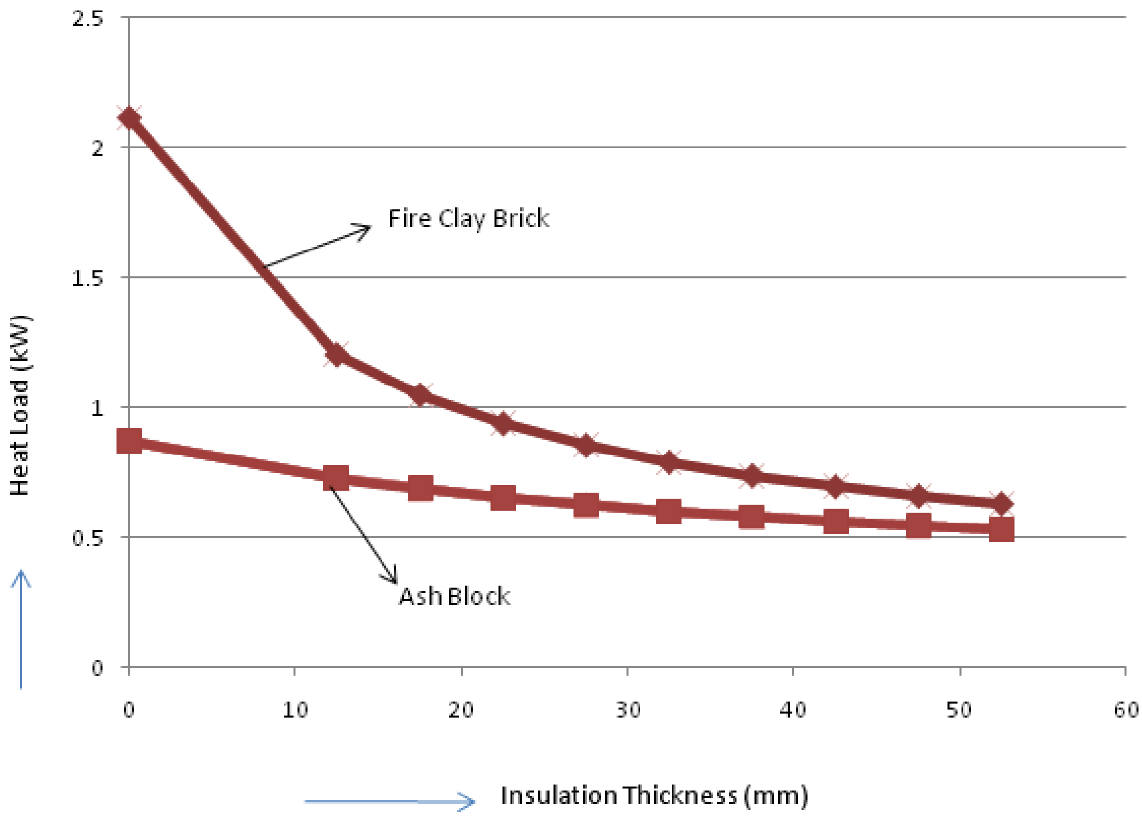


Fig 4.42 Museum Different zones and Levels *(Filters 1988)*



This illustrates the change in materials has a huge impact on energy and electricity consumption. Therefore, in the analyzed case study, the designer ensured the study of different elements and their impacts on the building using the IES simulator. Each transmittance, specularity, roughness, and refractive value was defined to get the ultimate energy consumption in the space. The building was divided into multiple layers.

B) Lighting

The Figures below demonstrate the sun's path; what is visible in the Figure 4.43 is that the museum will be exposed to sun from several directions, which will have a huge impact on direct daylight. Therefore, adding and providing enough daylight in the space has multiple positive impacts on the space (Pavlogeorgatos 2003).

Fig. 4.43 Building Orientation and Exposure to the Sun *(Filters 1988)*

Natural Light

The use of daylight reduces dependence on artificial light, which will reduce energy consumption by 15–40% (Mousavi Asl & Safari 2021). Furthermore, using daylight has a huge impact on the health and well-being of the user and enhances the overall user experience in the space (Vathanam et al. 2021). The use of balanced daylight for interior space also reduces the use of the HVAC system because excessive artificial light produces more heat than controlled daylight (akir 2009). Several studies have found that having too much light in the space can also have negative effects. For instance, excessive daylight might cause some undesired glare, which might decrease the productivity of an individual. Also, having excessive uncontrolled daylight might cause unwanted reflections and shadows, as illustrated in the Figure 4.44 which shows bad daylight control in schools (*Daylight Glare: How Does it Affect Health, Well-being, and Performance | SageGlass* n.d.).

***Fig. 4.44 Unwanted Daylight interfering with Teaching process in schools** (Daylight Glare: How Does it Affect Health, Well-being and Performance | SageGlass n.d.).*

Excessive daylight in the space also adds to the load on the air-conditioning system as a result of increased indoor temperatures due to the sun's heat. That being said, the daylight effect on heating and cooling loads is much lower than that of artificial light sources as the thermal energy per lumen of daylight is much lower than that of most artificial sources (Johnson et al., 1986). A study in Malaysia indicated that high-rise buildings consume around 46% of the total energy for cooling due to the amount of sunlight that enters the space (Lau et al. 2016). Another aspect is that daylight is a non-controllable factor, which indicates that the designer cannot control the amount of light for multiple different natural factors like clouds, weather, fog, etc. As a result, predicting the amount of light that will enter the space based on the function is difficult (Gay Hunt 2009). Therefore, all of these aspects and impacts illustrate the importance of building orientation. Sometimes the orientation of the building is uncontrollable due to different reasons, therefore having some shading solutions can help decrease or even cancel the negative impacts that might occur from excessive daylight. In Hague, the city receives direct sunlight mainly from the north-west and south-east directions. As illustrated in Figure 4.45 (Filters 1988).

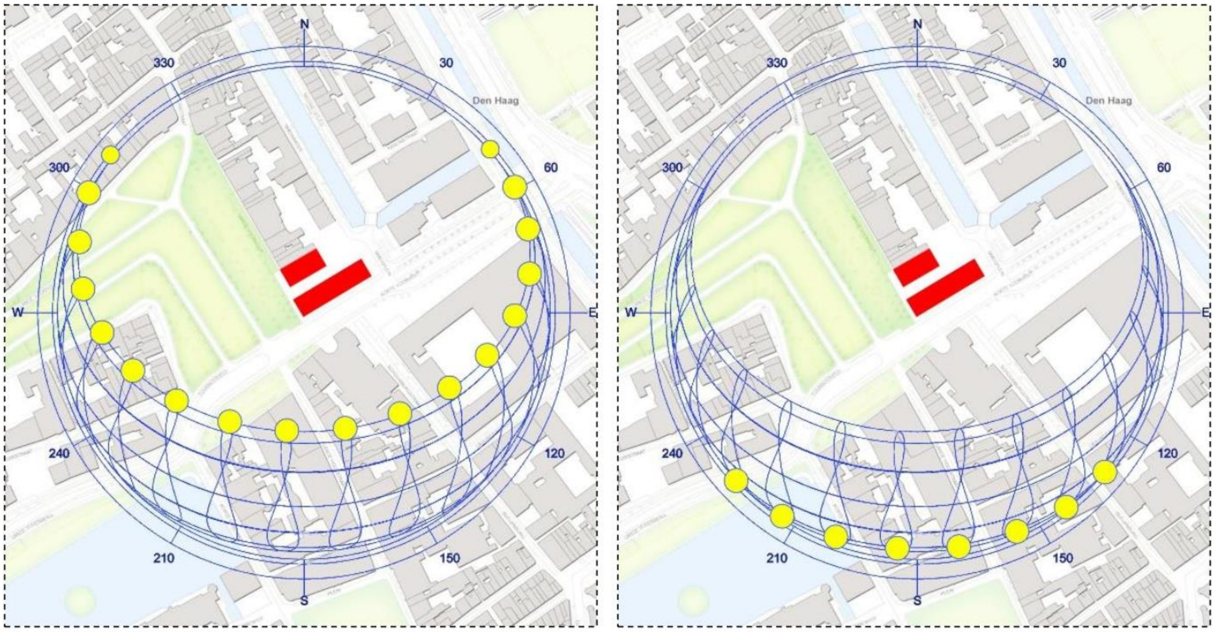


Fig. 4.45 Museum Orientation in relation to sun movement in Both Summer and Winter seasons *(Filters 1988)*

When a huge amount of daylight will be entering the space, it is important to find a solution that can help reduce tit. The use of shading elements is usually the solution when a building is penetrated by a huge amount of sunlight. The use of some shading elements has multiple positive impacts on the building. A study has shown that a building with good insulation or shading consumes 20% to 40% less energy than a poorly insulated or shaded building, as it prevents solar radiation from entering the space (Balaras et al. 2000). Additionally, there are a variety of designs and ideas when it comes to shading devices. For instance, a study was done in Malaysia, Penang, at the University of Saints Malaysia using a plant-based shading device or vertical greenery system (VGS). Usually, the VGS is a concept of adding plants on the façade or as an external insulation, as this will help as a solar radiation absorber. The study was held at the ground level as a test sample before implementing it on a taller building. As seen in Figure 4.46, the studied space is 4.2 m X 4.8 m X 3.3 m. Moreover, the study sample used indoor plants placed on an MDF frame with a small gap between the opening and the VGS, which is around 150 mm, as shown in Figure 4.46. The type of plant used is phosphorous tetragonolobus, which helps in thermal heat reduction and also provides a food source for the users. Additionally, the simulation was done in two different levels: upper and lower. In the lower level, there was an average of 2.4 degrees C decrease in temperature, while in the upper level, there was an average of 1.1 degrees C decrease. The maximum temperature drop was approximately 6.4 degrees C. This indicates that adding some sort of insulation helps in the reduction of the indoor temperature (June 1823).

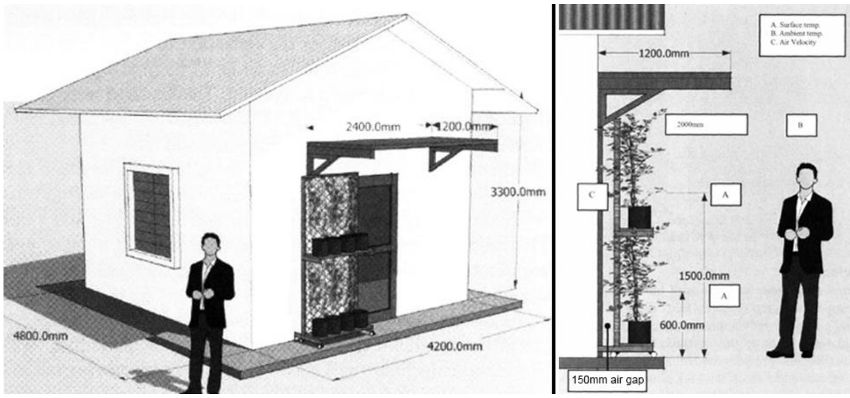


Fig.4.46 Studied sample space *(June 1823)*

Another study was done using different types of shading elements, as shown below Figure 4.47. The study focused on analyzing different shading elements in a school and the total reduction in energy consumption. In the table below, a small comparison is done using the Revit simulation to compare the energy consumption of different shading elements. As visible in the table, with adding layers to the shading elements, a reduction in energy consumption is visible. Therefore, the egg-crate design, which is option 8, shows a 49.63% reduction in energy consumption (June 1823).

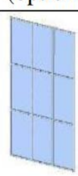
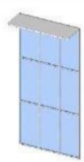
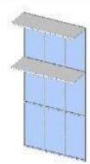
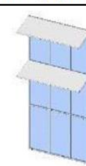
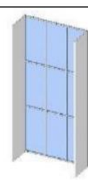
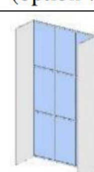
No shading device (option1)	Horizontal single panel (option 2)	Horizontal double panel (option 3)	Horizontal inclined double panel (option 4)
			
Horizontal louvers (option 5)	Vertical fins (option 6)	Vertical slanted fins (option 7)	Egg-crate (option 8)
			

Fig. 4.47 Different Studied Shading Elements *(June 1823)*

Table. 4.1 Energy Consumption Comparison between different Shading Elements Design *(June 1823)*

Types of shading devices	Electricity used for cooling (kWh) in March	Electricity used for cooling (kWh) in Sept	% of reduction in Sept from March
None (base case)	45,337	42,898	5.38
Horizontal single panel	43,882	41,392	8.70
Horizontal double panel	33,433	31,491	30.54
Horizontal inclined double panel	32,204	29,542	34.84
Horizontal louvers	40,725	38,399	15.30
Vertical fins	41,808	39,259	13.41
Vertical slanted fins	40,000	37,476	17.34
Egg-crate	25,475	22,834	49.63

Bellia, DeFalco, and Minichiello (2013) targeted the shading concept from a different direction. Their study that was done on an office building is seen below in Figure 4.48. After doing several tests and exams, they found that the use of different sizes of overhang louvers results in different outcomes. The simulation was done in four main factors: electricity, lighting, heating, and chillers. As seen in the chart below, the saving results differ with the change of the overhang depth, having an overhang with a 0.5 m depth saves around 12% while having an overhang with a 1.5 m depth saves around 9%. The depth that resulted in the most saving, around 15%, was the 1 m depth overhang. The use of louvers or any shading elements may also have negative impacts on the building, which is also visible in the chart. For instance, the lighting in the building without shading consumes around 4800 kWh while in an overhang with 1.5m depth the consumption reaches approximately 5200 kWh as seen in Figure 4.49 (Bellia, De Falco & Minichiello 2013).

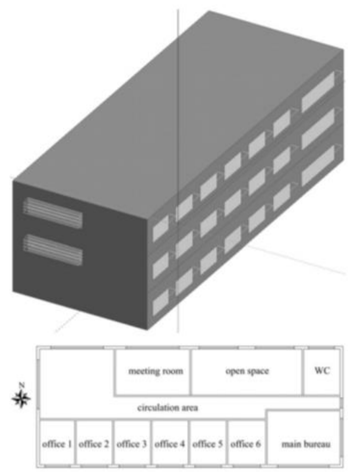


Fig.4.48 Studied Building

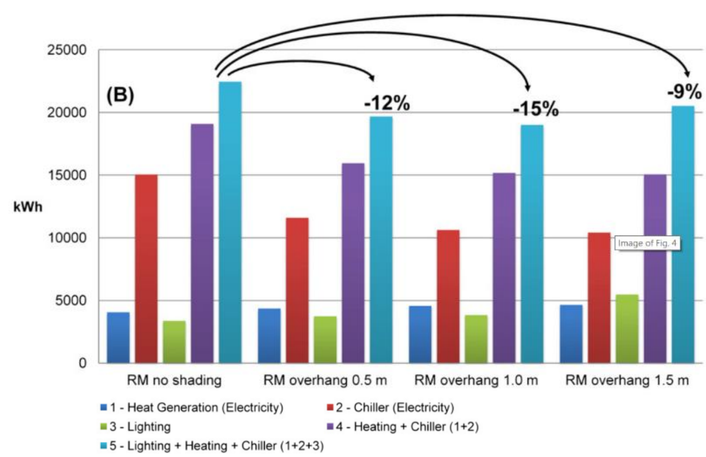


Fig. 4.49 Different Louvers Depth effect on different consumption values *(Bellia, De Falco & Minichiello 2013)*

Therefore, sometimes the use of some shading elements might have a negative impact on the building. In order to overcome the massive heat, gain due to the orientation of the building, the designer fixed dynamic louvers on the main two facades that gain heat, which are the northwest and southeast facades, as seen in the below Figure 4.50.

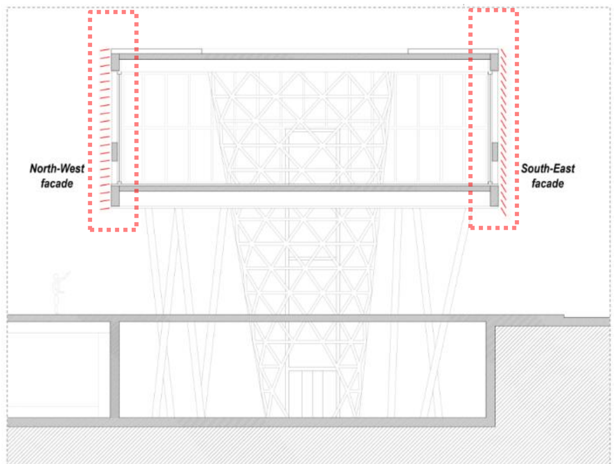


Fig. 4.50 Cross Section demonstrating the Fixed Louvers on main 2 Facades to ensure maximum reduction in Energy consumption

Dynamic louvers, those that move according to the requirements, were used for this, as shown in Figure 4.51. The size of the louvers as mentioned before has a huge impact on the amount of consumption reduction. Moreover, the dimensions of the louvers are quite important when trying to get the ultimate reduction of energy. For the selected case study, the height of the louver is 700 cm, the depth of each panel is 40 cm, the space between each panel is 35 cm and the total number of panels on each façade is around 20 panels. These dynamic louvers had a range of motion, allowing them to adapt to requirements based on the amount of light needed. The maximum angle of the louver is 28.95°. The Figure illustrates that the variable β_{max} is the changeable variable as it changes based on the requirements.

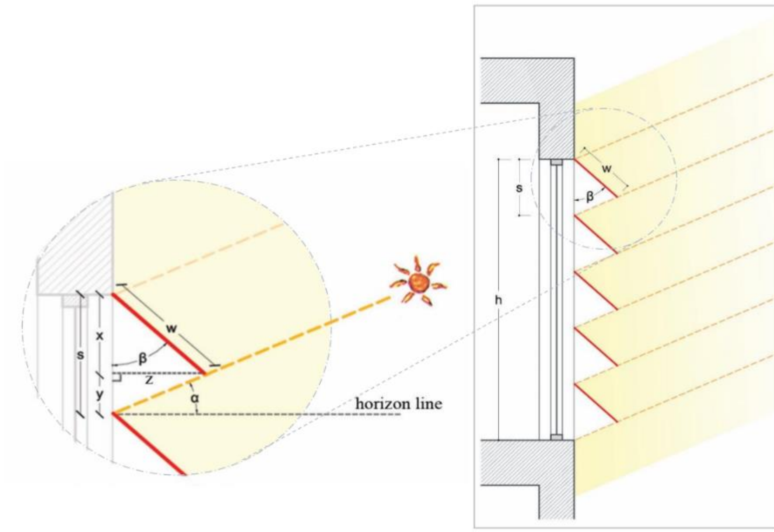


Fig.4.51 Cross Section demonstrating the Movable Louvers based on requirements

The variable β_{max} was found using the below equation as α which is illustrated in the Figure was defined as 0 to get the ultimate protection from the sunlight all year long. Most museums need to be protected from direct sunlight throughout the full year. The β_{max} was found using the below equation:

$$\beta_{max} = \alpha - \cos^{-1}(s\cos(\alpha)/w)$$

$$\beta_{max} = 0 - \cos^{-1}(35\cos(0)/40)$$

$$\beta_{max} = 28.95°$$

$$\beta_{max} = 28°$$

The max angle that the louver can obtain to allow indirect lighting is 28°. Mainly the museum was divided into two main spaces, the public space and the exhibition space as illustrated in Figure 4.52. The transition space is the transformation area from the museum surroundings to the main street.

After doing multiple simulations, the optimum daylight value was 43.6% and 51.31% in June and December, meaning that 43.6% and 51.31% of the exhibition receive enough daylight while using the designed shading elements. Changing the angle of β will result in different results, which will on the other hand decrease the amount of daylight if required.

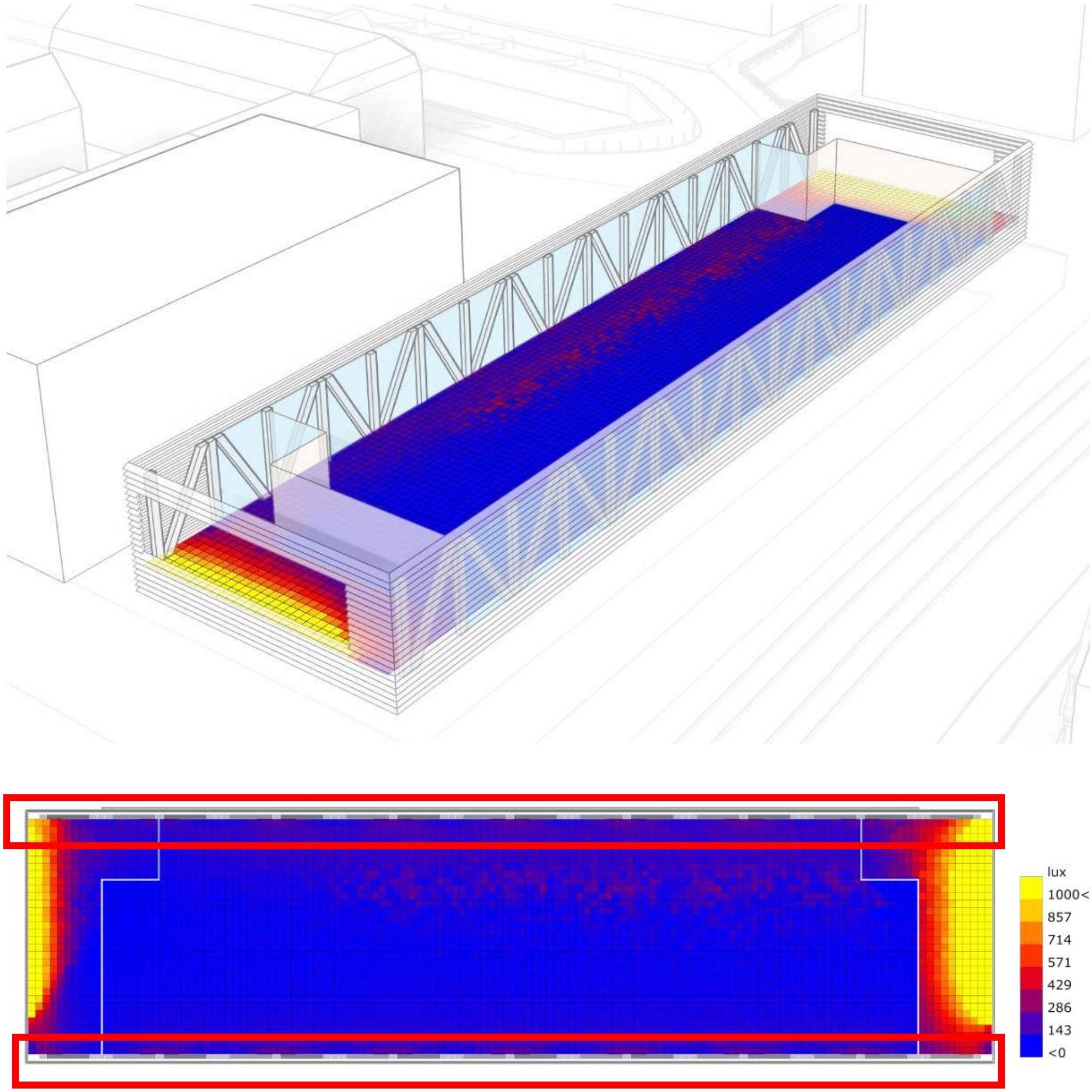


***Fig. 4.52 Plan & Perspective view of 2 simulation illustrating the impact of Shading element in 2 different facades** (Filters 1988)*

Furthermore, as seen in Figure 4.52, a simulation was done in December at 2 pm. The Figure illustrates the implementation of the shading element at 8° and 66° in two facades as illustrated with red, the northwest and southeast, showed a huge reduction in the penetration of daylight within the space. This illustrates that most of the space does not receive enough amount of daylight, which indicates the importance of using artificial lighting in this space (Filters 1988).

Artificial Lighting

The use of artificial lighting isn't highly illustrated in the study, as the main reason for this study is to demonstrate the huge impact of shading devices on the amount of daylight that penetrates the space using different simulations method which is similar to the aims and objectives of this research.

Each element illustrated in Figure 4.53 refers to a type of material used in the project, for instance, glazing materials, which are level C, have a transmittance value of 0.45 and a refractive value of 1.52. The structure elements, which are layer C along with the glazing, was given the materials of metal with reflectance value of 0.4 and secularity value of 0.9 with 0.05 roughness.

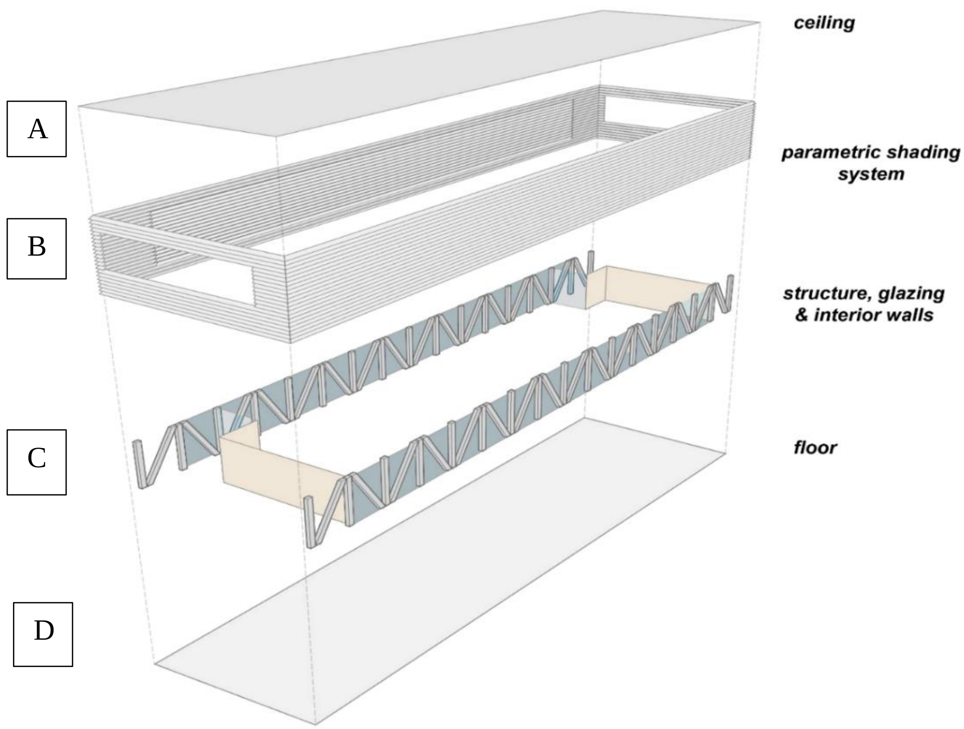


Fig. 4.53. Different Layers of the Exhibition defining different Material Types *(Filters 1988)*

The interior walls, also in level C, had a transmission value of 0.10 and a specular value of 0.04 with 0.05 of diffused reflectance. The reason for analyzing all of this materials data is to get an accurate consumption value when modeling and simulating the building on Grasshopper and Radiance.

CHAPTER 5

Selected Case Study

Analysis

5

C H A P T E R   V

5. Selected Case Study Analysis

5.1 <u>Louvre Museum</u>

In 1546, Francis I used his castle, called the Louvre, to collect art. The architect Pierre Lescot made sure to keep the foundation of the castle and preserve the concept of Renaissance without changing it but rather by adding some elements to enhance the concept of the museum and Renaissance in Francis I's period. This section, designed by Lescot, only covers the southwestern part of the Cour Carree. The Louvre Museum or The Musée du Louvre was built in the location of a medieval castle where kings from several generations have lived including King Henry IV, Louis XIII, and Louis XIV. In the 18th Century the Louvre was fully devoted for art as a museum as seen in Figure 5.1 (*Louvre | History, Collections, & Facts | Britannica* n.d.).

Fig 5.1. Colonade Eastern Façade of Louvre Museum 19th Century
(Louvre | History, Collections, & Facts | Britannica n.d.).

In the 1980s and 1990s, the Louvre went through major remodeling to make it more manageable and accepting for visitors, since the museum's annual attendance rate reach approximately 8 million visitors. New facilities such as offices, shops, exhibitions, and cafeterias were built underground as not to disturb the existing history of the castle. The Louvre is the most famous art museum in the world; both people who know art and people who don't know art are aware of this museum. It is most famous for being home to the great Mona Lisa painting and the statue of Venus de Milo. In 1989 the opening of the new reception and entrance area was designed by the Chinese American Architect Ieoh Ming Pei. The glass-shaped pyramid has become the most famous part of the modern Louvre Museum.

5.2 Louvre Abu Dhabi

The impact of the museum on the cultural and economic aspects of the U.A.E is highly recognized as mentioned before in Chapter 1. This is due to the high impact of museums on users and visitors. The recognition of museums in the Gulf region has grown greatly in the past years. Al-Ain Museum is the first museum to be founded in U.A.E, having opened its doors in 1969 under the leadership and direction of his Highness Sheikh Zayed bin Sultan Al Nahyan (May he rest in Peace). In 2007 a partnership was formed between France and the United Arab Emirates to exchange culture through art and heritage. This was done with the opening of the Louvre Museum located in Abu Dhabi. The museum opened its doors officially in 2017 as the largest ever museum cooperation in France history. This museum is part of a 30-year agreement between France and the U.A.E. Covering around 24,000 sq. m of the area with 8000 sq. m of galleries where 6000 sq. m is permanent galleries and 2000 sq. m is temporary galleries. The main target of this museum is to take the visitor through a journey of 12 chapters from different civilizations and eras until they reach the present time as demonstrated in Figure 5.2 (Langdon et al. 2021). The Louvre Abu Dhabi represents the lively nature of the classical modern Arab world. Moreover, Agence France, a French cultural institute, has provided a loan with different artworks to the UAE to be presented in the museum.

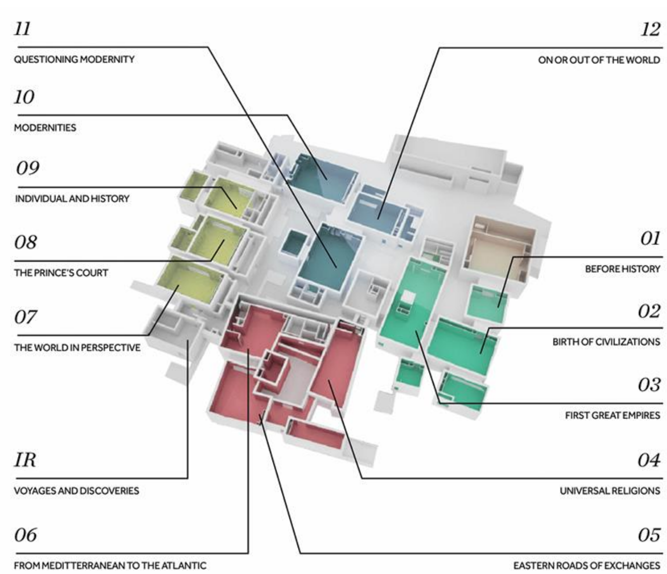


Fig 5.2. Chapters tour in Louvre Museum *(Langdon et al. 2021)*

5.2.1 Louvre Museum Selection Criteria

The selection of this case study was based on multiple criteria explained in Chapter 1. One of these criteria was the modern and contemporary design of the Louvre Museum, which has a huge impact on the lighting quality and quantity that the space receives. The selection of the museum was based also on establishment factors, as museum could be either redesigned or reprogrammed or a new project. A redesigned project is a museum that was a museum but had to renovate, such as the

Louvre Museum in Italy. A reprogrammed project is a space that was meant for a different program but the owner has decided to change the program or function of this project to something else. A new project is a space that is done from scratch and devoted to a specific goal, such as Louvre Museum in Abu Dhabi. Also, the value of museums in the U.A.E is huge due to the factors mentioned before therefore a study that focuses on the analysis of the lighting factor in museums would have a huge influence. Moreover, the size of the impact that Louvre Museum has on the region is massive due to the history of this museum, and having such an agreement and partnership would have a great influence on the region.

5.2.2 Location of the Case Study

The museum is located in Abu Dhabi, specifically Saadiyat Island which is located at 24.5303° N, 54.4452° E. Abu Dhabi is 972 sq. km and it is the capital of the United Arab Emirates. The area of Sadiyaat Island is 27 sq. km with 30 km of coastline. It is located 500 meters away from the Abu Dhabi Island. It is a natural island as illustrated in Figure 5.3 (*Saadiyat Island - Google Maps* n.d.). It is also a tourist attraction, which makes it a perfect location for such a huge project. It has multiple districts such as Sadiyaat Beach, Sadiyaat Lagoons, and Sadiyaat Retreat (*Saadiyat Island* n.d.). One of the designer's aims was to have the museum within a water feature which would enhance the targeted concept which is having a floating object of floating colander which is illustrated in the perforated dome.

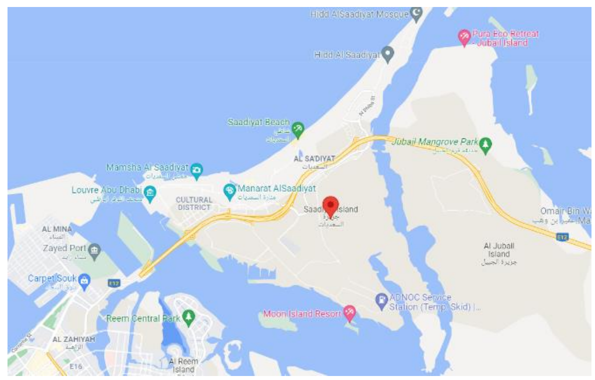


Fig 5.3. Louvre Museum Sadiyaat Island *(Saadiyat Island - Google Maps n.d.)*

A) <u>Weather</u>

The weather of Abu Dhabi is mainly sunny with high temperatures as illustrated in Figure 5.4. The month with the highest temperature is August with a maximum temperature of 43°C and the coldest month is January with a maximum temperature of 24°C. February is the month that usually expects more rain. Therefore, the importance of benefiting from the amount of sun that the location receives in the daylight and was the main aim and target of the Louvre designer.

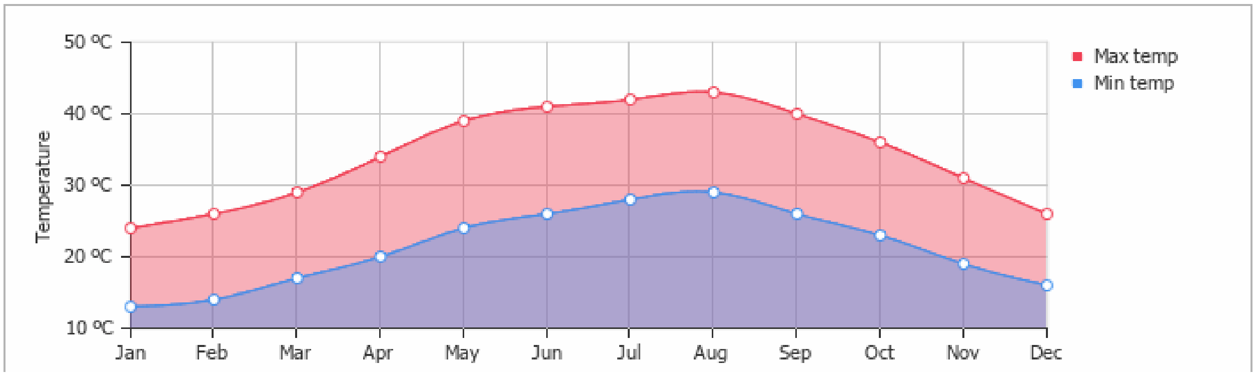


Fig 5.4. Average Min and Max Temperature in Abu Dhabi along 2021 *(Climate and average monthly weather in Abu Dhabi, United Arab Emirates n.d.)*

Another important aspect of the weather is analyzing the sun's path in order to define the ultimate position for the openings, also to define which areas would require more opening treatments, and also which zones would require more or less artificial lighting. The Louvre Abu Dhabi orientation is illustrated in Figure 5.5 which shows the sun path and the wind direction. In the next part of the paper, the author will demonstrate whether this orientation is ideal or it could be improved.

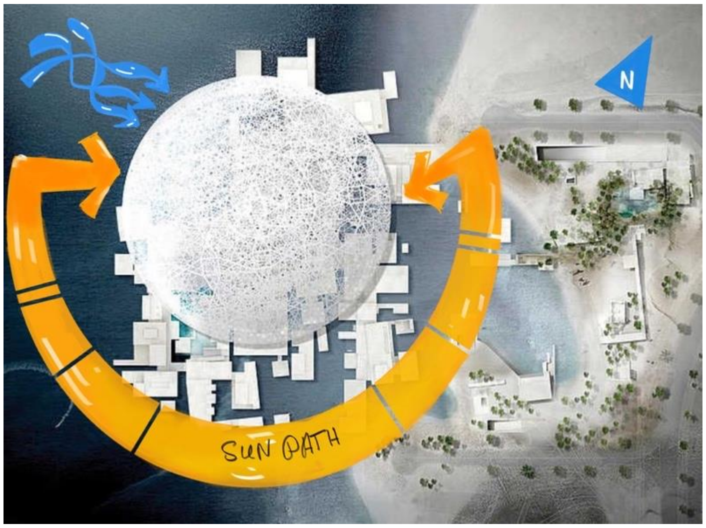


Fig. 5.5 Louvre Abu Dhabi Sun Path and Wind Direction *(Author)*

5.2.3 Design

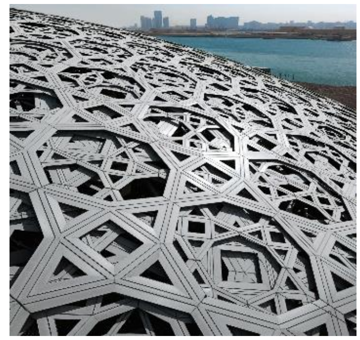


Fig 5.6. Dome Shape *(Louvre Museum, Abu Dhabi - Jean Nouvel | Architecture Viva n.d.).*

The designer behind this masterpiece is the award-winning architect, Jean Nouvel. The main aim of the designer is to design and create a space that feels like it's washed up on the beach. This was represented with a colander shape of a floating dome structure that is constructed from web patterned structure as illustrated in Figure 5.6 (*Louvre Museum, Abu Dhabi - Jean Nouvel | Arquitectura Viva* n.d.). The dome was constructed using an isosceles shape which is rotated and scaled to form different shapes such as squares and hexagons. The shapes were mainly inspired by the Mashrabeya as illustrated in Figure 4.6 (Imbert et al. 2013).

A) Exterior

The whole aim of this dome is to give the effect of in the morning of the sun rays passing through a tree as seen in Figure 5.7 (Tourre & Miguet 2010) and at night it gives the effect of 7850 stars shining which is called Rain of Light (*Louvre Abu Dhabi / Ateliers Jean Nouvel | ArchDaily* n.d.). The developed shape is composed of around 7850 aluminum stars which are shown in Figure 5.8 (*Louvre, Abu Dhabi | Luxhabitat* n.d.).

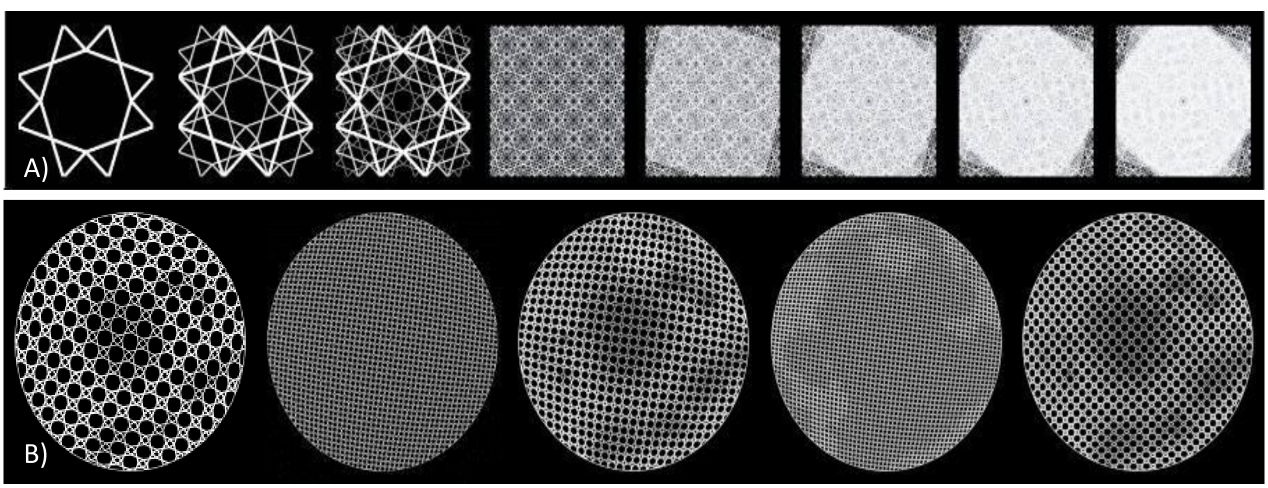


Fig 5.8. A) illustrates the studied pattern that was used to create the Dome pattern *(Louvre Museum, Abu Dhabi - Jean Nouvel | Architecture Viva n.d.).* ***B) illustrates different layers of the dome with different scales and rotations*** *(Louvre Museum, Abu Dhabi - Jean Nouvel | Architecture Viva n.d.).*

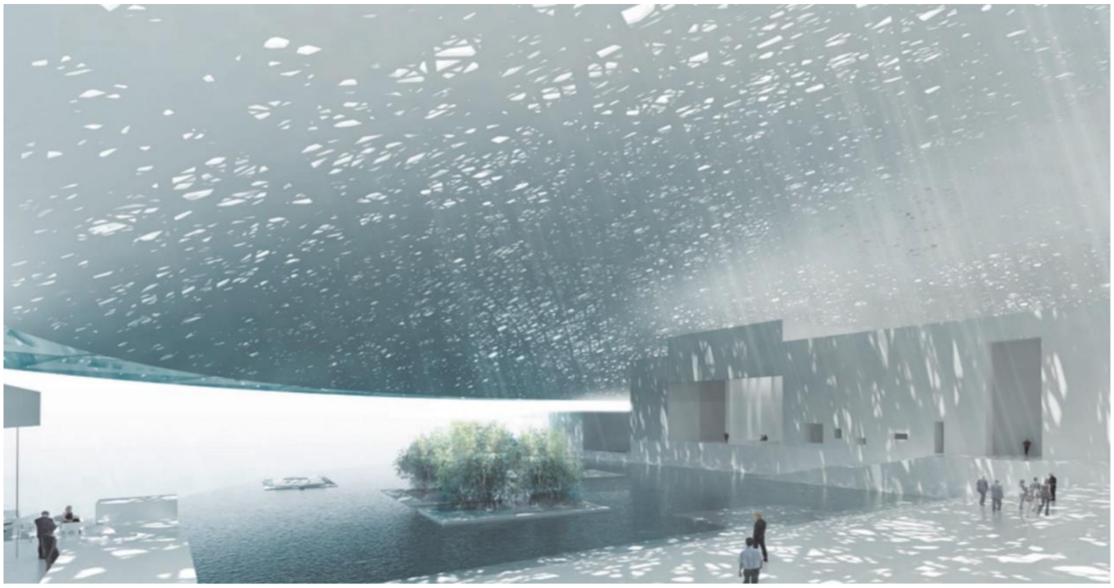


Fig 5.7. Sun Passing through the Pores of the Dome to give the effect of the Sun Ray passing through a Tree *(Tourre & Miguet 2010).*

The dome has a diameter of 180 m and covers the majority of the museum. It consists of 8 different layers: four outer and four inner. This layer consists of different shapes and angles as mentioned before. An important aspect of the dome of the museum is the structure of this star-shaped pattern which was constructed from stainless steel. The structure was constructed of two main layers 6 m apart as demonstrated in Figure 5.9. Additionally, the frame is mainly made of 10,000 structure elements that weigh 50 tons. The façade of the buildings is made of 3900 fiber concrete ultra-high-performance panels as seen in Figure 5.10 (*Louvre Abu Dhabi : inat* n.d.)

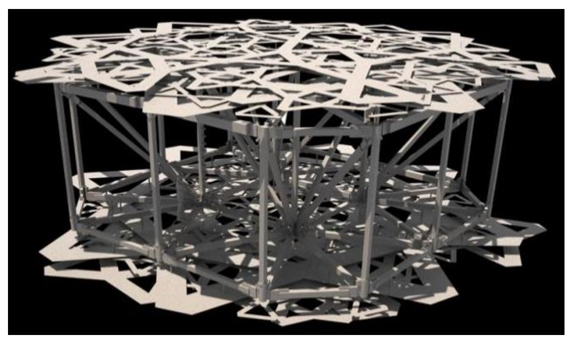


Fig 5.9. Inner Structure 2 Skins with 6 m distance between the Inners and Outer surface *(Louvre Museum, Abu Dhabi - Jean Nouvel | Architecture Viva n.d.).*

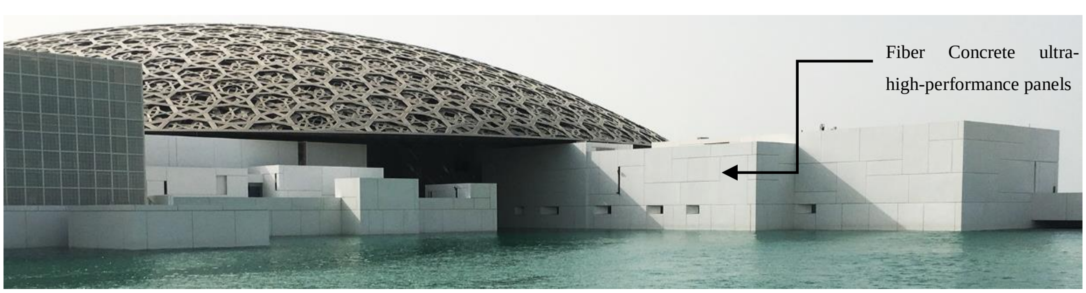


Fig 5.10. Louvre Museum Exterior Façade materials *(Louvre Abu Dhabi : inat n.d.) (Author)*

B) <u>Interior</u>

The interior of the Louvre Museum is focused on minimalist design, like many museums, which allows the visitor to put all the focus on the presented work. In addition to that, the museum focused on enhancing the space by keeping an open area with open circulation so that the visitor would move freely in the space. The flooring of the museum uses raised flooring; around 20,000 sq. m of raised flooring was installed. This raised flooring consists of 1400 X 233 mm panel with 38 mm thickness, covering of galvanized steel at the bottom, and the top finishing consists of marble or natural stone (Black Marquina, Moscato, Red Levanto, etc) as seen in Figure 5.11. Also, the use of different colors of flooring for different zones in order to separate the limits by the flooring to add some sort of meaning and value to the piece.

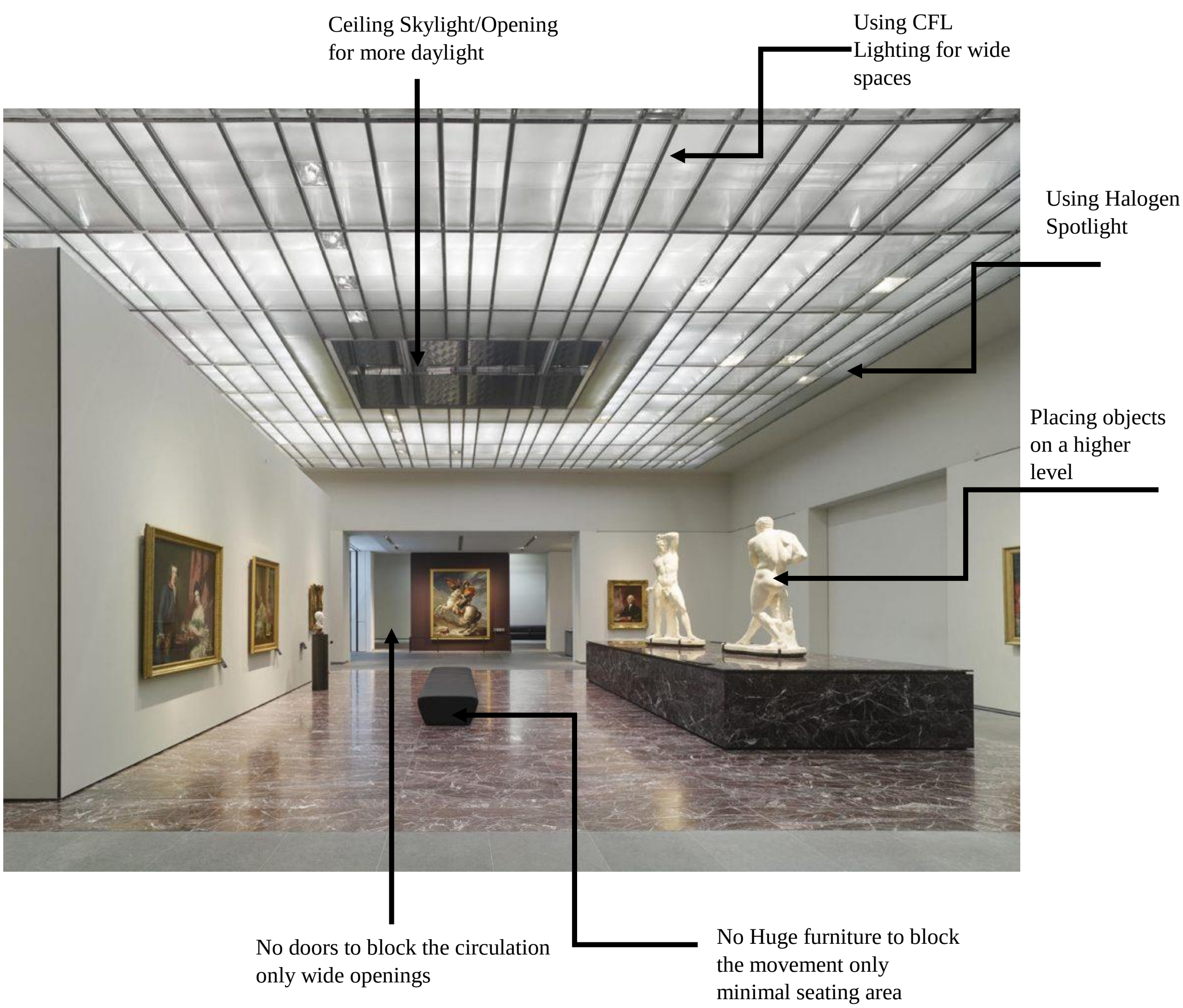


Fig 5.11. Louvre Abu Dhabi Interior specifications

C) *Lighting*

The Louvre Museum Abu Dhabi focused on using natural lighting as a main source of lighting in the space this was reflected in the available pores in the dome which was highly studied by the designer. The weather of the U.A.E, specifically Abu Dhabi, is an important aspect in order to study the amount of daylight the building will receive as seen before in Figure 5.4 that demonstrated the max and min temperature along the year 2021 (*Climate and average monthly weather in Abu Dhabi, United Arab Emirates* n.d.)

Natural Lighting

A study was done to define the amount of solar irradiance that Abu Dhabi receives in three different months – March, June, and December – in specific timings which will help in defining the different amounts of light that Abu Dhabi receives. The results are illustrated in Table 5.1 (Tourre & Miguet 2010).

Table 5.1. Average Global Irradiance during the Day in Abu Dhabi *(Tourre & Miguet 2010).*

	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
March (W/m2)	3,9	150,48	406,7	652	842,7	959,2	998,7	959,8	841,7	649,7	405,2	150,1	3,9
June (W/m2)	79,9	308,9	560,6	786,7	959,9	1067,8	1102,9	1067,8	960,1	788,2	562,7	310	80,2
Dec (W/m2)	0	14,5	174	377,7	546,2	652,8	689,8	655,4	548	377,6	173,2	14,4	0

Multiple studies demonstrated that the maximum illuminance value in the Louvre Abu Dhabi is between 76,000 Lux to 120,000 Lux. Based on Parpairi and Baker, a light source is considered efficient if it has a luminous value of 110 lm/W (Parpairi et al. 2002). Coulter and Happold demonstrated that the dome contributes to a massive amount of shading to the exhibitions that are located underneath it this is illustrated in Figure 5.12. It demonstrates that the amount of sunlight and heat that the space outside the dome is huge when compared to the area underneath the dome (Conand & Reich 2006). Another study resulted in the same outcome: that the dome acts as a huge shading element to most of the museum zones which is illustrated in Figure 5.13 (Tourre & Miguet 2010).

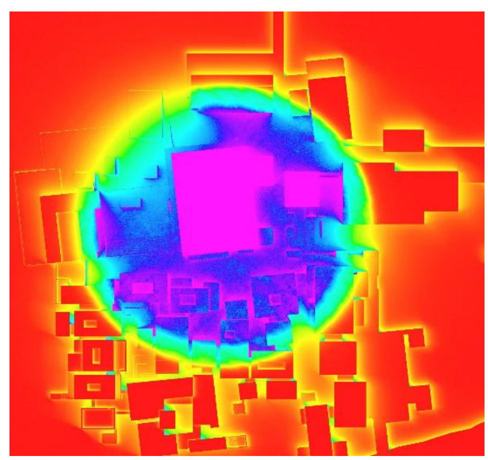


Fig5.12. Dome Contribution to Daylight and Heat Limitation *(Conand & Reich 2006).*

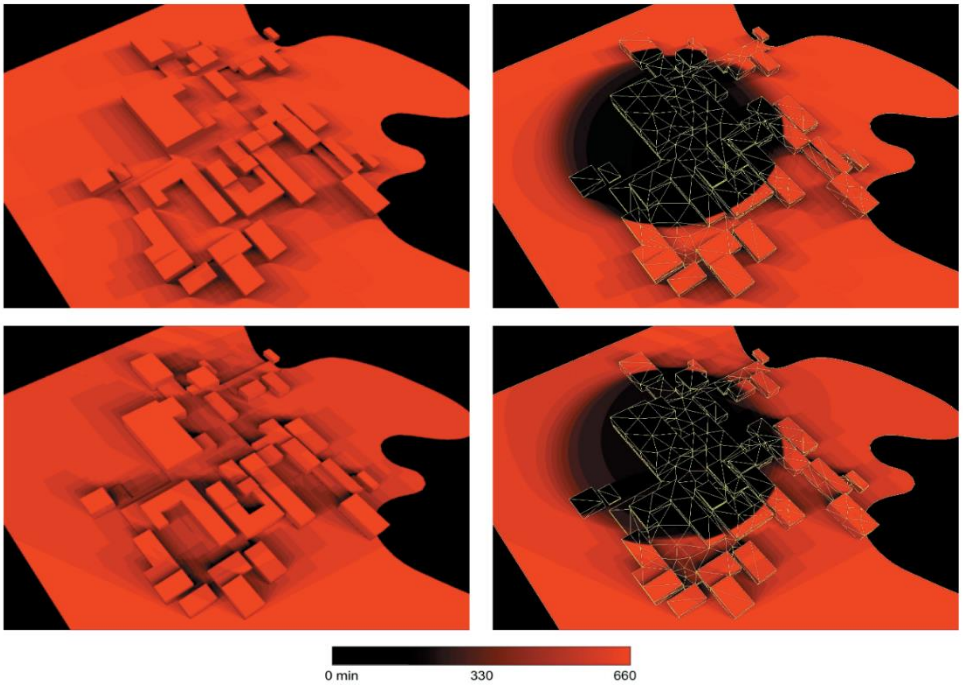


Figure 5.13. Dome Impact on the amount of Sunlight the Building Recieves in both months June and December *(Tourre & Miquet 2010).*

Architect Jean Nouvel made sure to employ the shading element and the natural light to the service of the space and this was done by adding openings and skylights in some zones to allow the daylight to penetrate these spaces. As seen in Figure 5.14, the shapes that are marked with red demonstrates the openings which would allow enough lighting to enter the space (Conand & Reich 2006).

Figure 5.14. Skylight Openings as a source of lighting for the indoor space *(Conand & Reich 2006).*

It's important to identify the glazing qualities and specifications of these openings which were demonstrated by Conand & Reicby are as seen in Table 5.2. Defining the glazing type is a huge part of measuring the amount of natural lighting that the space receives (Conand & Reich 2006).

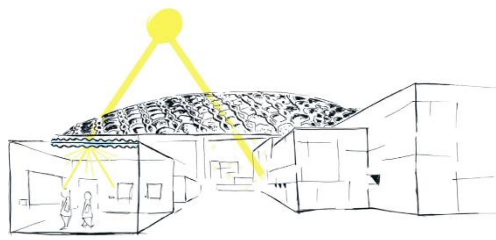


Table 5.2. Skylight Opening Glazing Specifications *(Conand & Reich 2006).*

Opening Name	**Visible** Light Transmittance	**Amount of** Reduced Light by Dome
No. 1	60%	2.3%
No. 2	60%	2.3%
No. 3	60%	100%
No. 4	60%	100%
No. 5	60%	100%
No. 6	60%	4.6%
No. 7	60%	3.9%
No. 8	60%	95.1%

Furthermore, the mentioned two studies illustrated that Louvre lighting system analysis will divide the areas into three main categories which are shown in Figure. The galleries would require daylight illuminance of 10,000 Lux, while the plaza would require illuminance of 100-300 Lux, but for the water and other buildings, an illuminance between 250-300 Lux is expected for the success of the space as seen in Figure 5.15. Based on these categories this paper will focus on analyzing two main zones in the galleries category which will be demonstrated later in the paper.

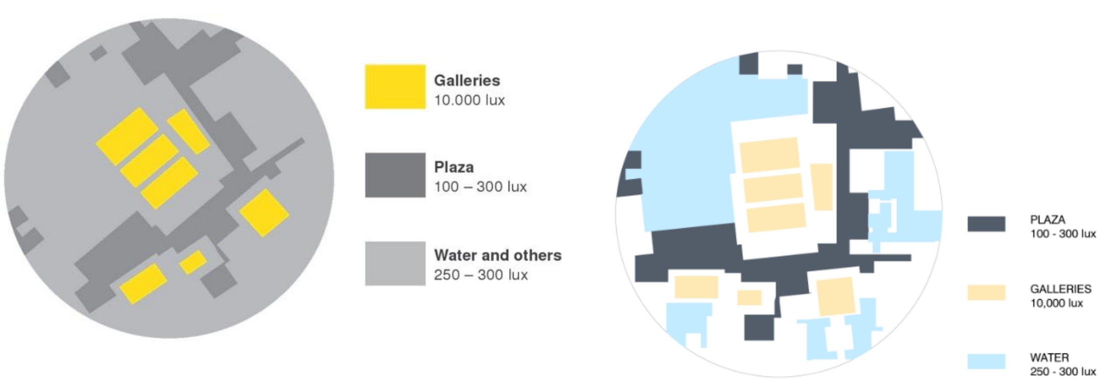


Fig 5.15. Lighting Intention Map for Louvre Museum Abu Dhabi *(Louvre Museum, Abu Dhabi - Jean Nouvel | Arquitectura Viva n.d.) (Tourre & Miguet 2010).*

- *Artificial Lighting*

The use of artificial lighting in the Louvre Museum was defined by Parpairi and Baker based on the type of artwork and artifacts displayed, as summarized in Table 5.3 (Parpairi et al. 2002).

Table 5.3. Illuminance Value of Lighting based on Artifact type in Louvre Museum *(Parpairi et al. 2002) (Author).*

Artwork Type	**Average** Illuminance
Color Paper-based Artwork	50 Lux
Black and White Paper based Artwork	100 Lux
Textile Artifacts such as costumes etc.	50 Lux
Oil Paintings	200 Lux
Objects such as Furniture, Glass, or objects with Paint, or polychromed surface	50 Lux

Additionally, in order to calculate the energy consumption of the lighting system, it's important to calculate its working hours. Therefore, based on the Louvre Abu Dhabi website the museum is open from Tuesday until Sunday from 10:00 am to 06:30 pm and closed on Monday; this is equivalent to approximately 2800 hours per year. See Table 5.4.

Table 5.4. Illuminance Value of Lighting based on Artifact type in Louvre Museum Annually *(Parpairi et al. 2002)*

Artwork Type	**Average** Illuminance hours per year
Color Paper based Artwork	50 Lux X 2800 Hours = **140,000 Lux per Hour**
Black and White Paper based Artwork	100 Lux X 2800 Hours = **280,000 Lux per Hour**
Textile Artifacts such as costumes etc.	50 Lux X 2800 Hours = **140,000 Lux per Hour**
Oil Paintings	50 Lux X 2800 Hours = **560,000 Lux per Hour**
Objects such as Furniture, Glass, or objects with Paint, or polychromed surface	50 Lux X 2800 Hours = **140,000 Lux per Hour**

These values are implemented for both natural and artificial lighting as this space would require this specific amount of illuminance to have a space with efficient lighting.

5.3 Case Study Drawing Analysis

The Louvre Museum mainly consists of one floor with multiple functions distributed along the route the visitor can take to view the 12 main sections representing different eras and ages as shown before in Figure Additionally, the programming of the Louvre Museum is demonstrated in Figure 5.16, where there are seven main zones demonstrated below (*Louvre Abu Dhabi : inat* n.d.)

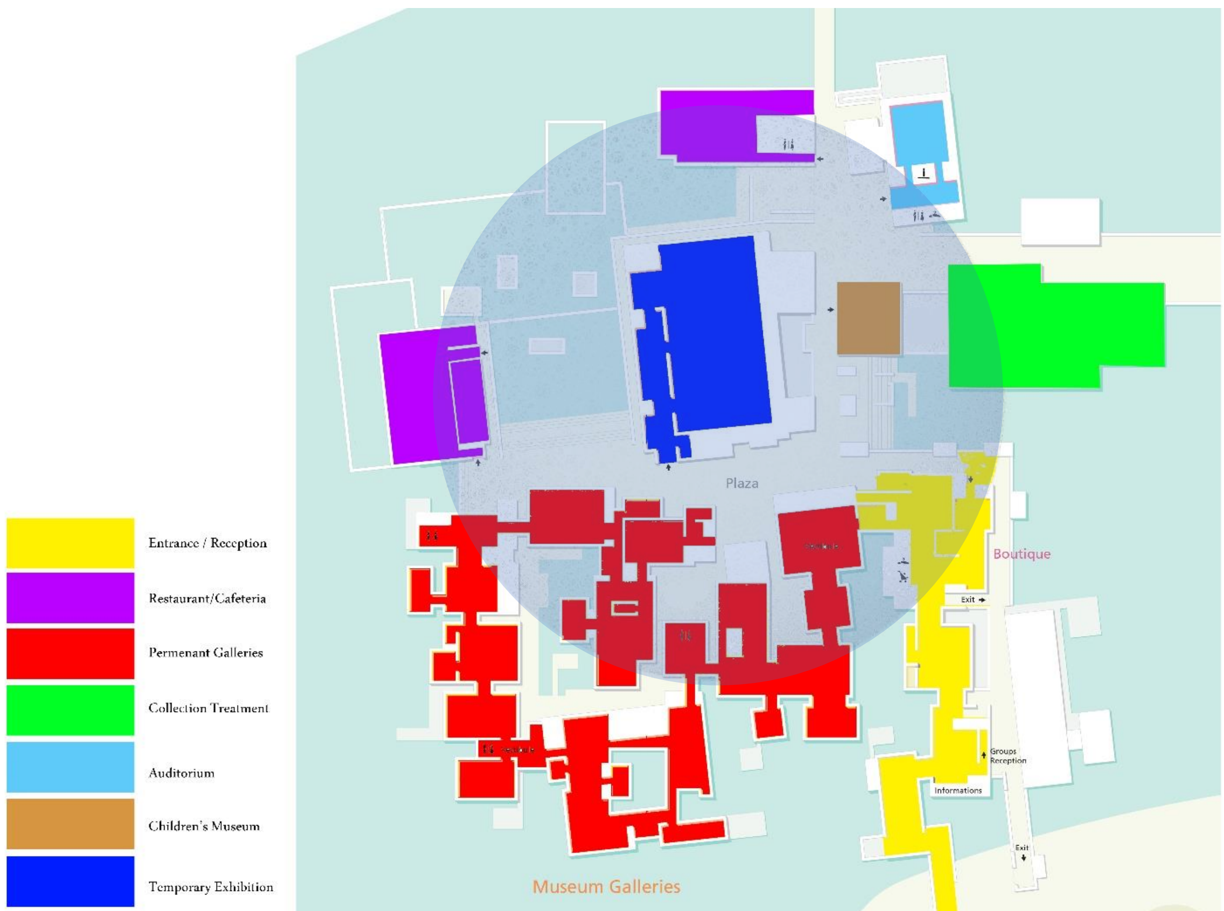


Figure 5.16. Louvre Museum Programming Layout Plan *(Louvre Abu Dhabi : inat n.d.) (Author)*

Another important aspect of the Louvre is the circulation method as mentioned, where the designer aimed to take the visitor through a tour that demonstrates different civilizations from the past up to the present time. This is done by presenting different artworks and artifacts of different nations this is shown in Figure 5.17 (Basar & Goknil 2020)

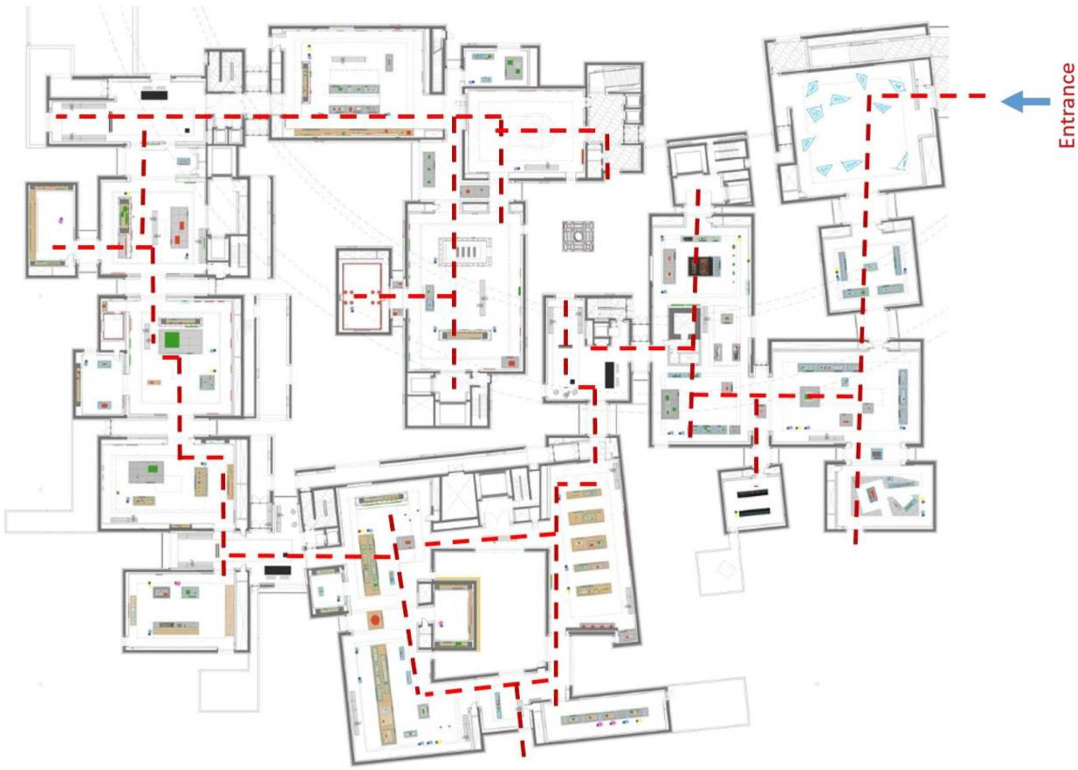


Figure 5.17. Louvre Museum Circulation Plan *(Basar & Goknil 2020)*

The museum has two main entrances from land which are demonstrated in Figure 5.18 (*The Louvre Abu Dhabi Museum - Islamic Architecture by Dxx* n.d.).

Figure 5.18. Louvre Museum Main Entrances from Land *(The Louvre Abu Dhabi Museum - Islamic Architecture by Dxx n.d.)*

CHAPTER 6

Results and Findings

6

C H A P T E R   V I

6. *Results and Findings*

This part of the research will focus on analyzing all of the findings and outcomes that resulted from the study of the Louvre Museum Abu Dhabi. The analysis of these outcomes will be conducted in the following three main stages. These stages are as follows:

The first phase will consist of collecting the data in the selected case study. This data will help in identifying and evaluating the problem. This stage will focus on analyzing the problems that were observed during the field visit to the Louvre Museum. Also, using the surveying tool will be an essential device to help get a whole picture to analyze the existing lighting system based on the user's point of view.

The second phase will focus on suggesting development that might enhance the user's experience and improve energy consumption. These solutions will be analyzed and studied using the simulation tool that was discussed in Chapter 3 in order to find the best solution that fits the project. These problems will mainly focus on two main aspects: the energy consumption of the space and the effectiveness of the lighting.

The third and final phase will be a small comparison between the existing lighting system and the suggested solution in order to indicate whether this solution will help to enhance the user's experience. This will be done using the simulation tool by IESVE, which is described in Chapter 3, having a Base Case, which is the existing light system, and the designed case, which is the case with the new suggested solution. In order to do that, a small region or limit will be selected in the Louvre Museum to help save time. The two selected regions are one of the permanent galleries that are there, which is shown in the Figure. The criteria for this selection were based on multiple aspects:

1. One of the selected galleries is the first gallery that the visitor observes as soon as they enter the Louvre as seen in Figure 6.1.
2. Both of the selected regions have skylights, which will help in assessing the effectiveness of daylight in the space.
3. The selected regions have minimal design features, which will help to focus the analysis on the lighting.

4. The enormous amount of spotlight distribution in the space
5. The difference between the two zones is that one is entirely beneath the Shading Dome, while the other is adjacent but not beneath it. This will help to review the effect of the dome on the amount of daylight that the space receives and the different amounts of daylight that both spaces receive.

Figure 6.1. Louvre Museum Selected gallery for the Analysis

6.1 Stage 1 Facts Assembly (walk through a survey)

The process of gathering information was done using one of the methodologies, which is site visits. The visits helped to analyze the selected space, focusing on the main research question, lighting's impact on the space and how it can be improved. Moreover, the site visit was done after receiving approval from the Louvre Museum. This was done after filling out a form that was provided by the Research Department at the Louvre Museum, which is illustrated in the Appendix. The visit was made on November 29th, 2021, in order to evaluate the existing amount of daylight that the space receives. Additionally, this assessment targeted evaluating the following points as shown in Figure 6.2:

1- Lighting efficiency in the Space.
2- Daylight impact on the Space.
3- Type of lighting System used.

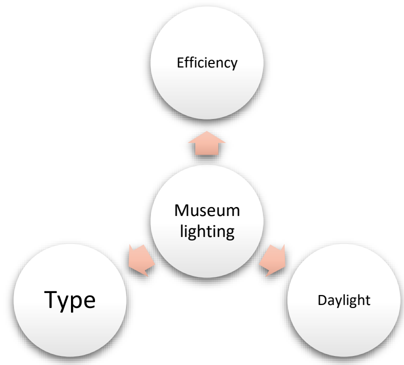


Figure 6.2. Facts Assembly Points *(Author)*

This information was gathered using tools to measure the Lux value in the space in order to compare it with the recommended standards for museums. This was done using the Lux Meter, which was provided by the British University in Dubai.

The field visit was conducted on the 30th of November, where the visit started at around 12:00 pm and ended by 5:30 pm. This was done in order to determine daylight and artificial lighting impacts at different timings of the day. Additionally, the field visit was done in order to determine the effectiveness of the used lighting, both natural and artificial. As demonstrated before in the Figure, the evaluation was conducted in two different areas or zones of the museum. The first zone, Hall 1 or Gallery 1, is the first permanent gallery that the visitor finds. This gallery is unique due to multiple factors. The materials used for this gallery, specifically for the flooring, are semi-glossy with some reflectance. This was done in order to reflect some of the natural light that penetrates through the 4 x 4 m skylight. This skylight is located underneath the dome to help minimize the amount of natural light that penetrates the space. In addition to that, Gallery 1 has a total of 86 Quintessence round Directional Lights with a 3000 K light color, and it has a wattage value that varies from 24 W to 32 W with a Luminous Flux of 3170 Lumens. This is an LED light with a CRI value of 97, which makes it high-quality lighting. The criteria for choosing this zone are demonstrated below:

- Close to the entrance, which will allow an evaluation of the amount of glare that a visitor might comprehend as soon as he enters the gallery.
- Available skylight which is covered by the dome which will allow an evaluation of the impact of the dome on the space.

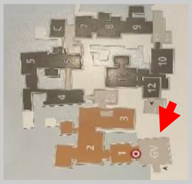
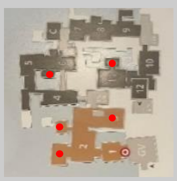
The second zone, or Gallery 7, is shown in the Figure. This gallery is located far from the dome. This was done in order to compare the effectiveness of daylight in both galleries. The flooring of this gallery is more reflective when compared to that of Gallery 1. The reason for that is to enhance the quality of the space by increasing the amount of light in the space, as the light will be more reflected in the space. Also, having reflective materials would help in enhancing the quality of light in the space. Additionally, the available skylight is somewhat sealed, which was done to limit the amount of daylight that the gallery receives as it's not located under the dome. Gallery 7 has a total of 35 Quintessence round directional lights with the same specification mentioned before. The criteria for choosing this gallery are illustrated below:

- The gallery is located far from the dome, which will allow comparison between the two galleries to determine the dome's effectiveness.

- Gallery 7 has two openings and a skylight. All of these were completely blocked-in order to limit the amount of natural light that the space receives. A small comparison will be made to enhance the space by allowing more daylight through these openings.

Furthermore, the museum focused on four major types of lighting, the first of which was explained before the directional spotlight. Another type was used for other halls, such as the bronze galleries, where the designer used Black Parscan with 15 W and Luminous Flux of 1650 lm. The Parscan has a CRI level of 92 with a Kelvin value of 3500 K. Another type of lighting that was used in the area that separates the galleries was the Pollux Spot Light, which was designed especially for the Louvre to enhance the passage area. This light had a wattage of 6 W and a lumen output of 825 lm. It had a CRI value of 92, with a 3500 K. The fourth type of lighting that was used is wall washed lighting with a 4000K color temperature to create a line of light that connects the spaces. Table 1 shows a comparison.

Table 6.1. materials used in Selected Zones *(Author)*

	Zone	Location	Flooring materials	Walls materials	Daylight	Artificial Light	Artifacts
Selected Zones	Gallery 1		Semi-Glossy Moscato Beige Marble Texture Flooring As seen below. 	Beige Paint on the ultra-high-performance concrete panels	Minimal focus on Daylight	Quintessence 87 round Directional Light: Wattage: 32 W Lumens: 3170 lm Color: 3000 K CRI: 97	Objects such as Vases, Mini Sculptures. Which would require 50 Lux for such sensitive objects. As mentioned before
	Gallery 7		Glossy porcelain flooring 	Matte White Paint on the ultra-high-performance panel's concrete panels	No use of Daylight	Quintessence 18 round Directional Light: Wattage: 32 W Lumens: 3170 lm Color: 3000 K CRI: 97	Objects such as big Globe, Mini written drafts Which would require 50 Lux for such sensitive objects. As mentioned before
Remaining Zones	Bronze Galleries		Glossy Black Marquina Marble 	Matte White Paint on the ultra-high-performance panel's concrete panels	Minimal focus on Daylight	Black Parscan: Wattage: 15 W Lumens: 1650 lm Color: 3500 K CRI: 92	Various Objects such as Paintings, Sculptures, vases would require various Lux values from 50 to 100 Lux

6.1.1 Field Visit Survey

During the visit that was made on the mentioned date, a survey was conducted, focusing mainly on the visitors that were leaving the museum. The survey target was to analyze the visitor perception of the lighting used in the Louvre Abu Dhabi. The analysis was mainly focused on asking questions related to the daylight and artificial light used in the space. This survey would help to understand the user's perception of the lighting and how much the lighting impacted their visit. Additionally, most of the questions that were asked were a mix between open-ended questions and multiple-choice questions. This would help not consume significant amounts of time for the targeted users or visitors. Survey and questionnaire answers and questions are demonstrated in Appendix 1.

A) ***Public Users***

This part of the survey focused on analyzing the data that was extracted from asking questions to users who generally use museums, not specific to Louvre Abu Dhabi visitors. This survey was conducted over a period from October 21st to December 12th, and it was conducted via the Qustionedpro Engine as mentioned in Chapter 3. The number of results that were received was around 100 users. Additionally, the results of the questionnaire (Appendix 1) are demonstrated in the table. As seen from Figure 6.3 to Figure 6.13, the responses that were received from the 25 users who participated in the survey were analyzed. As seen in the Figure 6.3, around 84% of the participants agreed that they visit museums once in a while, and 12% agreed that they never visit museums, while 4% suggested that they visit museums half of the time.

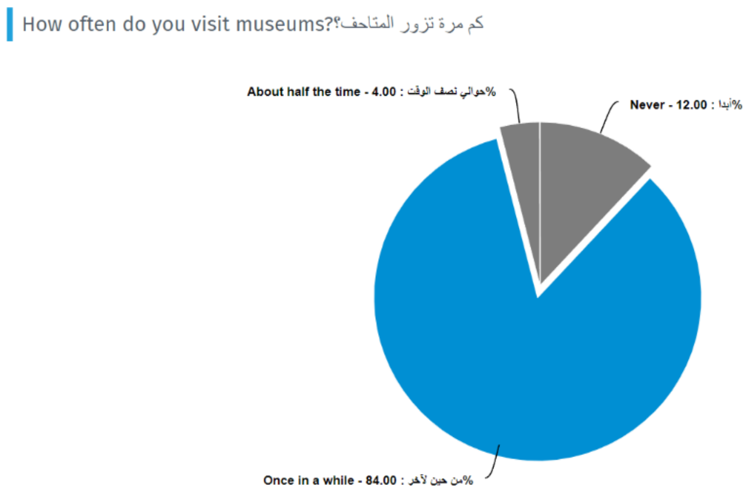


Fig 6.3. Total Visiting Time *(Author)*

Additionally, 36% of participants suggest that they most often visit museums to learn about different cultures, which suggests that people are aware of one of the main goals of museums, which was mentioned earlier in Chapter 1. While 30% focused on the Museum's design and used solutions that were interesting to observe. 14% of the participants agreed that they enjoy visiting museums to appreciate the artifacts that are on display. 12% of the participants want to visit the museum to get general information. While the lowest percentage of participants (8%) focused on education during their visit as seen in Figure 6.4.

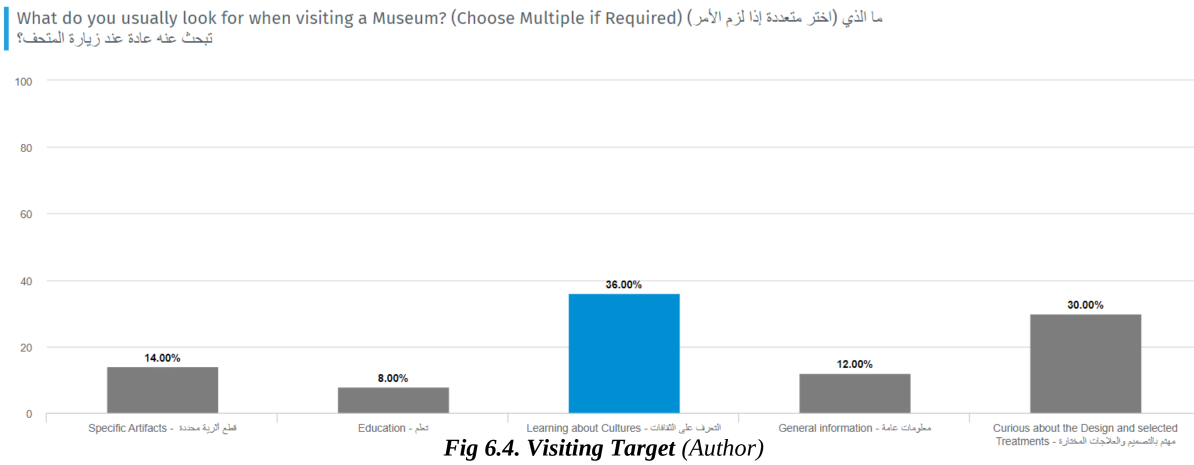


Fig 6.4. ***Visiting Target*** *(Author)*

Furthermore, 28.57% of the applicants suggested that museums crowded with artifacts and objects are their least favorite thing in museums. This gives a perspective on the role of the interior designer in the museum space. Additionally, participants agreed that ventilation and artifact arrangements are similar in importance when it comes to the participant's least favorite thing in museums, with 25.71%. Also, participants agreed that they usually do not hate the lighting that is used in museums, with only 14.29% of the participants agreeing that lighting is the worst thing in museums. This illustrates that museums are usually well designed from a lighting perspective, because, as mentioned before, lighting has a huge impact specifically on museums, and in order to have a successful museum design, it's important to have a wide analysis of lighting. Moreover, participants agreed that museums are usually well organized from a movement perspective, as 5.71% only agreed that museums usually don't have a good movement design as seen in Figure 6.5.

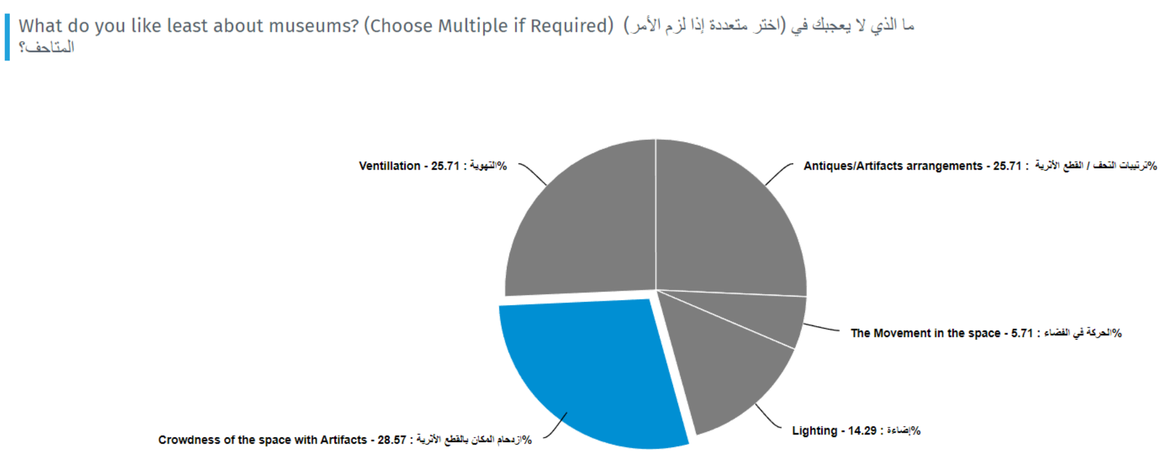


Fig 6.5. ***Museum worst Design feature*** *(Author)*

Moving along, generally, the number of visitors that visit the museum has a huge impact on the lighting from a distribution aspect. Therefore, participants were asked to determine whether they preferred to visit the museum alone or with a group. 76% agreed that they prefer to visit museums with others, while the remaining participants 24% said they prefer to visit museums alone as seen in Figure 6.6.

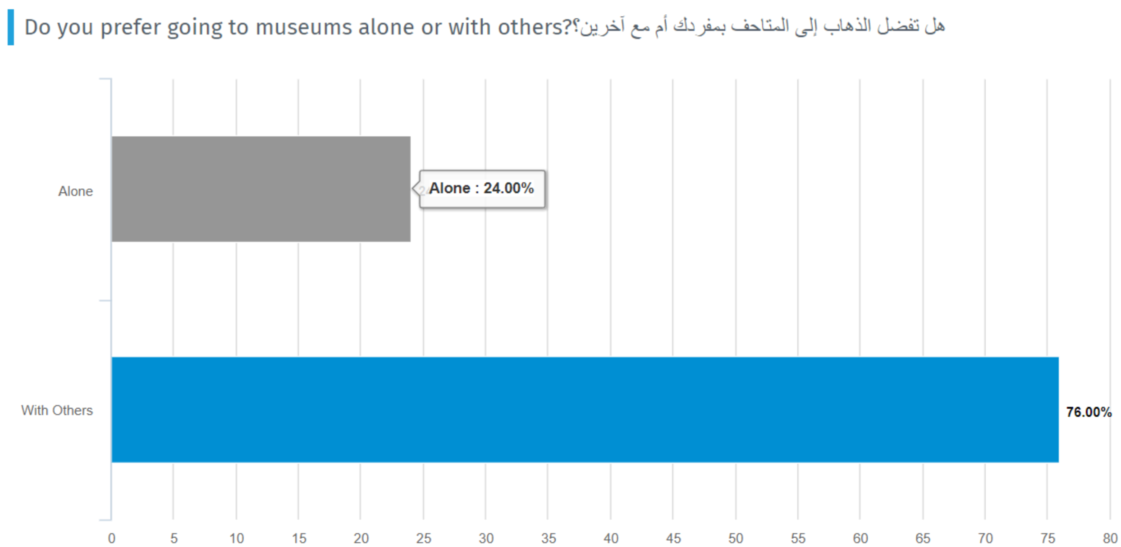


Fig 6.6. Visiting Conditions of the Museum *(Author)*

Moreover, the participants were asked to evaluate the importance of lighting in the museum with a yes or no question. As 84.4% answered "Yes" to the importance of lighting to museum design, this illustrates that lighting has a huge impact on museums as perceived from the viewer's perspective, as the importance of lighting is transferred in the effectiveness of it as seen in Figure 6.7.

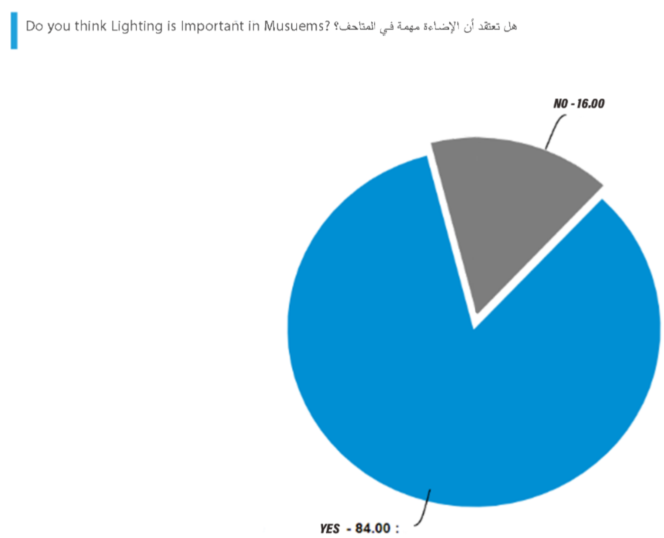


Fig 6.7. Lighting Importance *(Author)*

Participants suggested that the length of time spent in museums range from 30 minutes to 4 hours. Majority, with 66.67%, suggested that they stay in the museum for 30 minutes to an hour. While 33.33% suggested that they stay in museums for 2 hours to 4 hours. This is important in order to assume the opening hours of the museum, which will, on the other hand, have an impact on the energy consumption and lighting lifetime as seen in Figure 6.8.

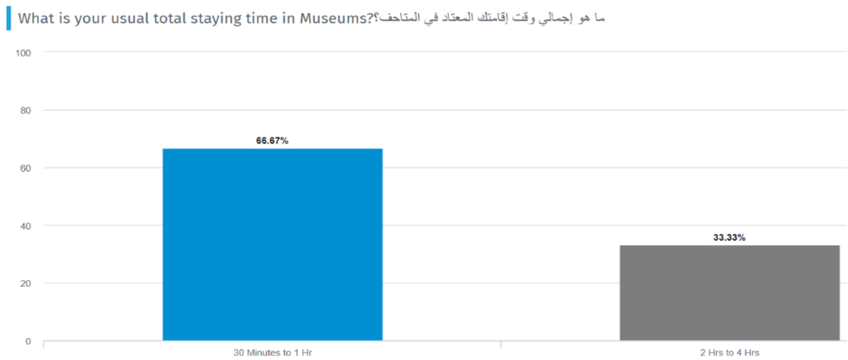


Fig 6.8. Museum Visit Period *(Author)*

Also, the participants were asked to evaluate whether they preferred natural or artificial lighting. The results were close, with 54.17% suggesting that they prefer museums with artificial lighting, while 45.83% suggested they prefer museums with natural lighting. This demonstrates that the use of artificial lighting is recognized due to its effectiveness in museums as seen in Figure 6.9.

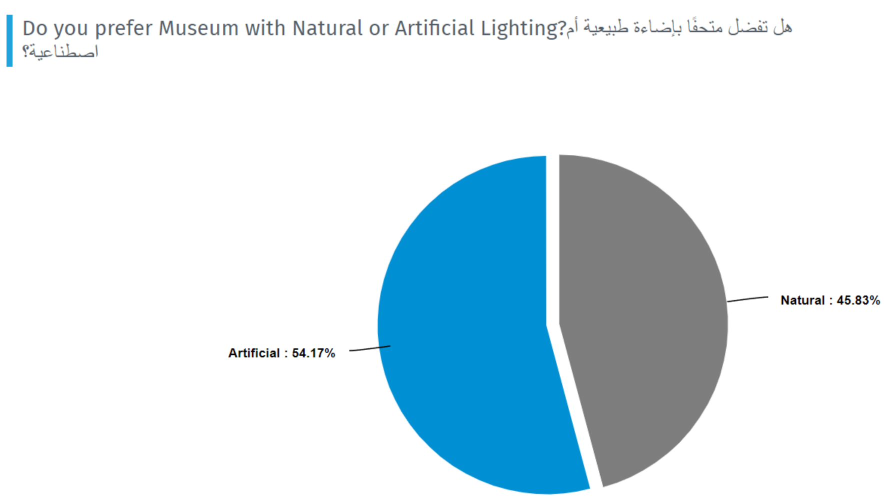


Fig 6.9. Natural or Artificial lighting *(Author)*

Additionally, it was shown that around 91.67% of the participants recognized the importance of lighting in the museum experience, while 8.33% only suggested that lighting was not important in the museum experience as seen in Figure 6.10.

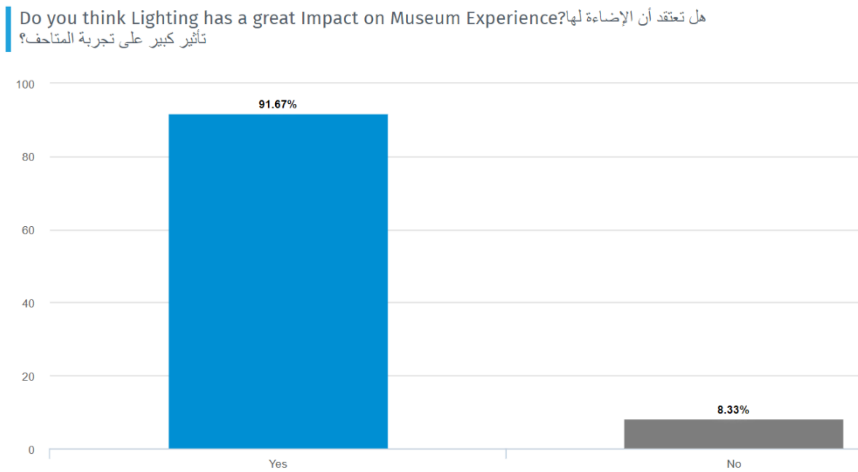


Fig 6.10. Lighting Impact on museum Experience *(Author)*

Similarly, 28.57% of the participants suggest that usually lighting requires improvements in museums. This illustrates that the focus in museums is mostly dedicated to lighting. While 21.43% suggested that the artifacts' arrangement usually requires improvements in museum design, whereas 19.64% suggests that the movement in museums frequently requires development. 17.86% recommended that materials selection usually requires improvement in museums. Lastly, 12.50% suggested that furniture selection required improvement. This shows the least important furniture in the space because, as mentioned before, usually museum design focuses on minimalism with the least furniture as seen in Figure 6.11.

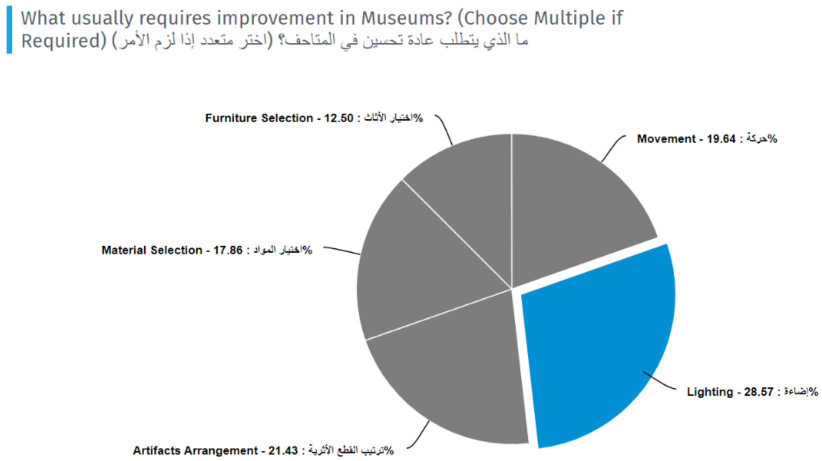


Fig 6.11. Lighting Impact on museum Experience (*Author)*

Additionally, the participants were asked to evaluate and rate specific aspects based on lighting on a scale from 5 to 10. The first aspect is the role of lighting in space enhancement, where participants rated it at 4.32/5. The second aspect is the artifact quality, where participants rated it at 4.46/5. This confirms the point that was discussed earlier in the impact of lighting on the artifacts and the requirements sometimes for a microclimate to protect the artifacts. The third aspect is the improvement of the experience, as participants gave it a rate of 4.12/5. The fourth aspect is the role of lighting in energy saving. The participants gave it a rate of 3.83/5, which is the least rated aspect. This suggests that lighting does not contribute to energy saving, which was confirmed earlier, that around 20% of energy in developed countries is consumed by lighting. Unless, of course, lighting treatment and solutions are included; in that case, lighting will aid in energy conservation as seen in Figure 6.12.

Please rate the below based on Lighting::يرجى تقييم ما يلي بناء على الإضاءة

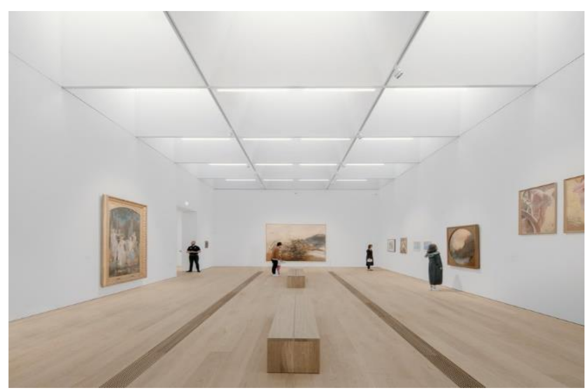
Question	Count	Score
Space Enhancement - تحسين المكان	94	4.32
Artifacts/Showcases Quality - جودة المعروضات	94	4.46
Experience Improvement - تحسين التجربة	94	4.12
Energy Efficiency and Power Saving Role - دور توفير الطاقة وكفاءة الطاقة	94	3.83
Quality of the Space - جودة المكان	94	4.46
Average		4.24

Fig 6.12. Rating lighting impact on different aspects *(Author)*

Additionally, participants were asked to choose between to different types of lighting systems used in museums ambient and task lighting which is shown in below images

Where 52% demonstrated that they prefer the use of Ambient Lighting, while the other 48% suggested the use of Task light as seen in Figure 6.13. These results are quite close which shows that the use of both types of lighting is preferred as also demonstrated in Chapter 2.

Task *(Author)*



Ambient *Author)*

Answer	Count	Percent
Ambient Lighting	85	52%
Task Lighting	85	48%
Total	85	100%

Fig 6.13. Preferred Type of lighting *(Author)*

Lastly, the last question that was asked was an open-end question, where the author asked the participants about enhancing their museum experience. Here are some of the answers.

- By having various Interactive activities.
- Good Natural lighting that is not disturbing the harmony of the space.
- Adding more colors to the space in relation to the concept.
- By having more emotionally driven lighting with some background music and artificial lighting and technology about explaining things in the museum.
- By focusing on lighting.
- More interactive tools and activities.
- Making the experience unforgettable.

Moreover, this point was done in a sample study of 25 participants results might change based on the number of participants. Furthermore, the below table 6.2 shows a summary of all the public surveying results.

Table 6.2. Public Users Survey Summary Results *(Author)*

	Survey main Points	Result Conclusion
1	**Number of Visits**	**People Visit Museum not often**
2	**Staying time in Museums**	**Users Visiting time is usually 30 minutes to 1 Hr**
3	**Preferred Lighting Type**	**People prefer the use of Artificial Lighting**
4	**Lighting impact on Museums**	**People significantly agree with the effect of lighting on Museums**
5	**Rating Lighting based on different Parameters**	**Users agree that Lighting enhances the space, Lighting improve the user's experience, affects the quality of the space, and impact the quality of the Artifacts**
6	**Enhancing the Museum Experience**	**By improving the Lighting quality and adding more interactive artifacts.**

B) Louvre Abu Dhabi Visitors

Moving along, this portion of the survey will focus on analyzing some of the Louvre Abu Dhabi aspects based on the visitor's point of view and perspective. This survey was conducted on a period of 3 days where a survey was distributed on Louvre Abu Dhabi visitors. A total of 39 participants took part o the survey. The survey started by asking the visitors about the visiting quantity or how many times did they visit the Louvre Abu Dhabi. The results concluded that around 41.03% of the participants have visited the Louvre Abu Dhabi around 4 times, which is a huge number of visits which illustrates that the Louvre Abu Dhabi is attracting visitors to come more than once. While 35.90% of the participants demonstrated that they visited the Louvre one time. 15.36% demonstrated that they have visited the Louvre Abu Dhabi 2 times. While 5.13% have visited the Louvre 3 times. And 2.56% of the participants have visited the Louvre more than 4 times. This concludes that around 38.46% have visited the Louvre more than 3 times which is the higher majority of the participants which demonstrates that the Louvre Abu Dhabi was successful in attracting the visitors which will on the other hand mean that the space was well designed and studied as illustrated in Figure 6.14.

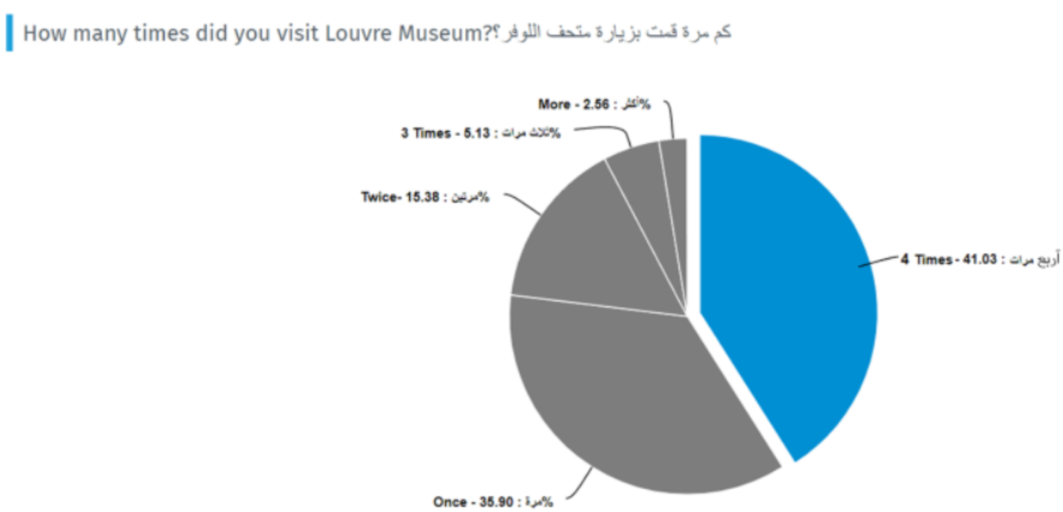


Fig 6.14. Times the Louvre Abu Dhabi was visited *(Author)*

Additionally, the participants usually focus on learning about new cultures when visiting Louvre Museums with 37.66% of the participants agreeing to that. While 23.38% suggested that they are attracted to the Design and Treatments of the Museum. 16.88% focused on the Artifacts and types of Artifacts that are showcased. Participants that visited for Education had a percentage of 11.69%, while 10.39% enjoy Louvre for general information as seen in Figure 6.15. This demonstrates that the Design and Treatments in Louvre Museum are successful as it attracts visitors.

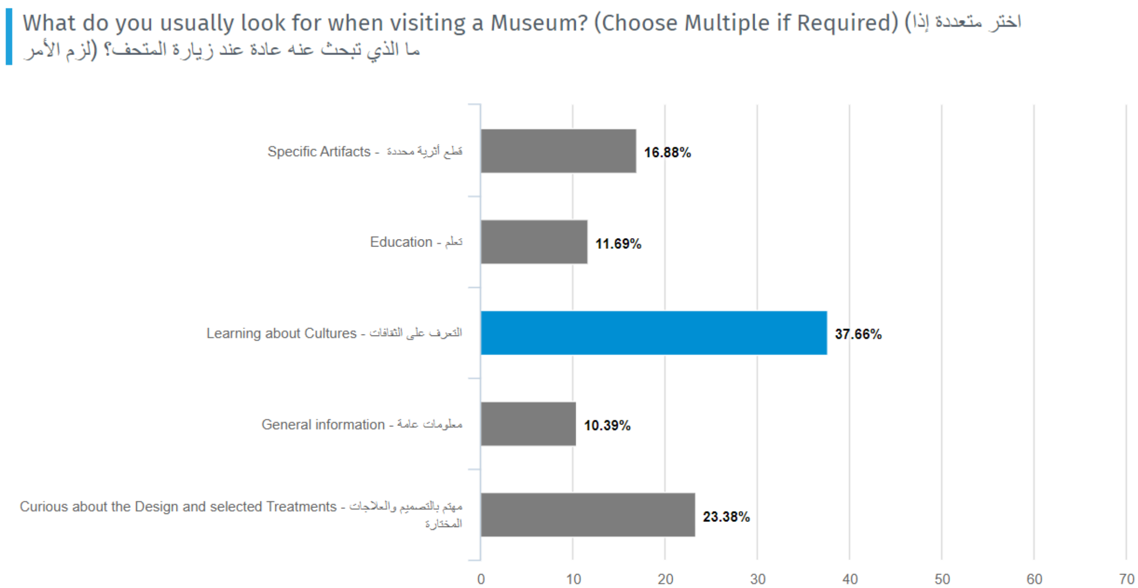


Fig 6.15. Louvre Museum Attractions *(Author)*

The visitors were asked about the staying time in Louvre Museum, 43.56% suggested that they usually stay in Louvre Museum for 2 hours. 25.64% of the participant proposed that they prefer to stay in Louvre Museum for 1 Hour. While 17.95% suggested that the duration of their visit to the Louvre Museum is around 3 hours. 10.26% indicated that their duration of visit time in the Louvre Museum is 4 hours or more. While the least duration period that the visitor stay at Louvre is for 30 minutes. This demonstrates that people prefer to stay in Louvre for a long period of time which also indicates the success of the Museum from a Design perspective as shown in Figure 6.16.

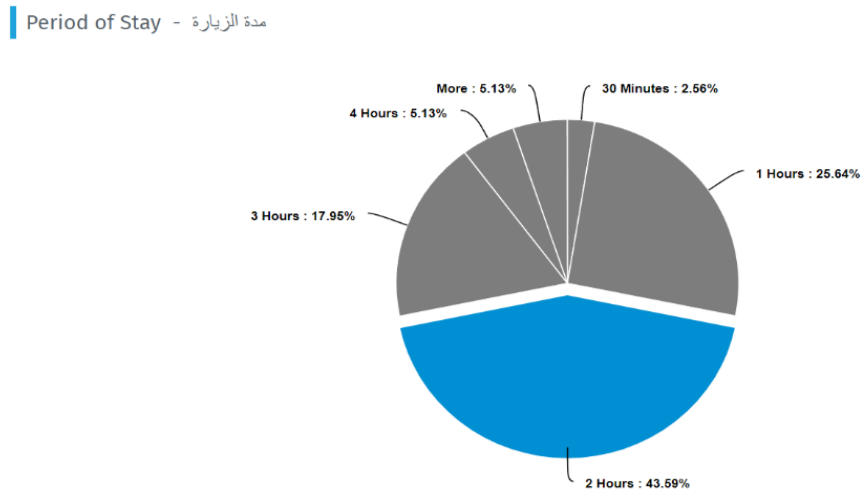


Fig 6.16. Louvre Museum Staying period of Time *(Author)*

Additionally, 51.28% of the Louvre visitors indicated that they did not stop for any reason while having their tour or visit. While 48.72% demonstrated that they did stop for specific reasons. Some of the reasons are mentioned below:

Taking Pictures.

Reading the Artifact Caption.

An unusual thing that caught the viewer's eye.

The results for this question indicate that the circulation and organizing of the Louvre are well designed as 51.28% of the participants demonstrated that they did not stop for any reason during their tour. This will result in a smooth pathway and smooth movement in the space as demonstrated in Figure 6.17.

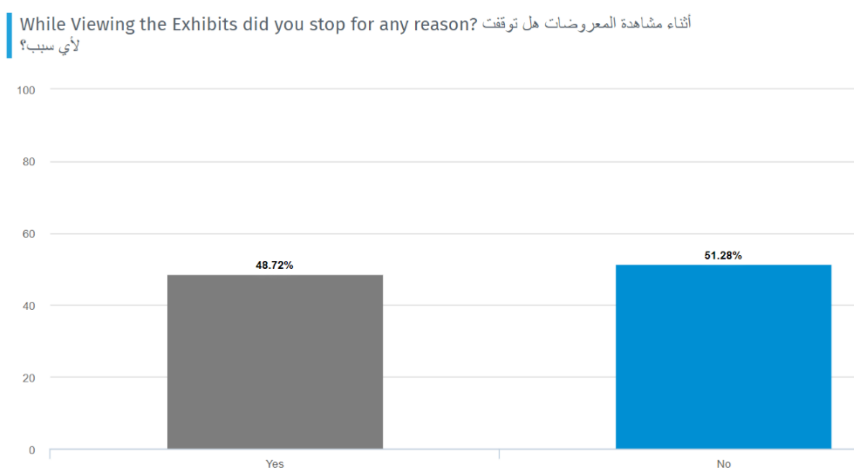


Fig 6.17. Louvre Museum stopping reasons *(Author)*

An open-end question was asked to the participant which focused on the exhibiting method in Louvre Museum. The results are demonstrated below:

- It is good and the artifacts are not crowded.
- It is clean. Straight forward. But I recommend the text of the artifacts to be much bigger and higher up at eye level.
- The architecture is more interesting than the actual exhibits.
- Perfect method of exhibiting the Artifacts.
- Very Interesting Technique of displaying.
- A good method of showcasing the different eras.

Another important aspect of the Design is the movement in the space, especially in Museums. Therefore, a question was asked to the participants that focused on Movement in the Louvre Museum. 45.45% demonstrated that they are satisfied with the movement in the Louvre Museum, and 42.42% illustrated that they are Very Satisfied with the Louvre Movement. While 9.09% demonstrated that they are Neutral about the movement in the space. With only 3.03% resulted with being Unsatisfied about the Movement in the space as seen in Figure 6.18.

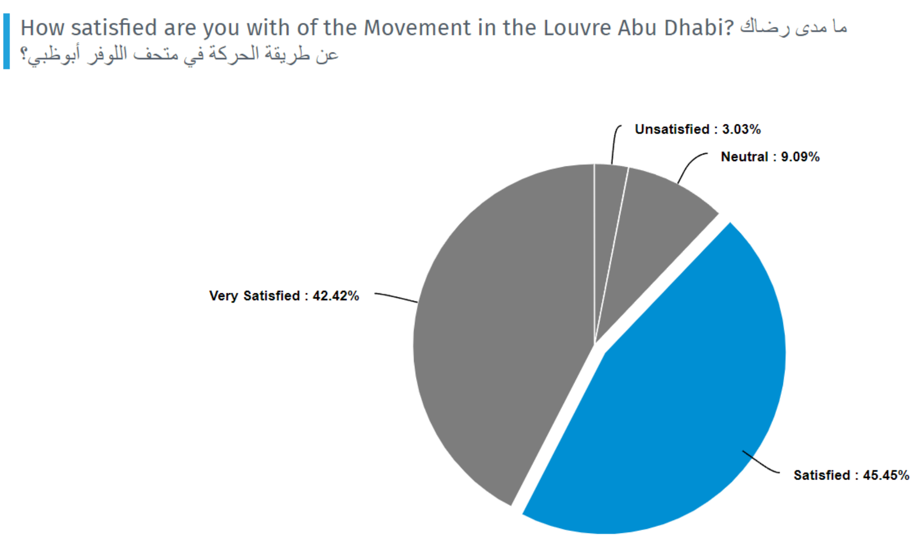


Fig 6.18. Louvre Museum Movement *(Author)*

Furthermore, Lighting has a huge part in the Louvre Museum Design therefore the participants were asked to relate the Lighting used in Louvre Museum with different aspects and rate them from 5. The first aspect was the Lighting impact on the space enhancement where participants gave it a rate of 4.25/5. The second aspect of Lighting impact on the quality of Artifacts in the Louvre the participants gave it a rating of 4.16/5. The third aspect is the Lighting effect on space improvement in the Museum experience where people gave it a rate of 4.41/5. The fourth and most important aspect is the effect of lighting on Energy consumption, the participants have rated this point 4.38/5 which shows the awareness of people about the role and of Lighting on Energy consumption. The fifth and last point is the quality of space and how lighting affects it, participants rated this point 4.34/5 as illustrated in Figure 6.19.

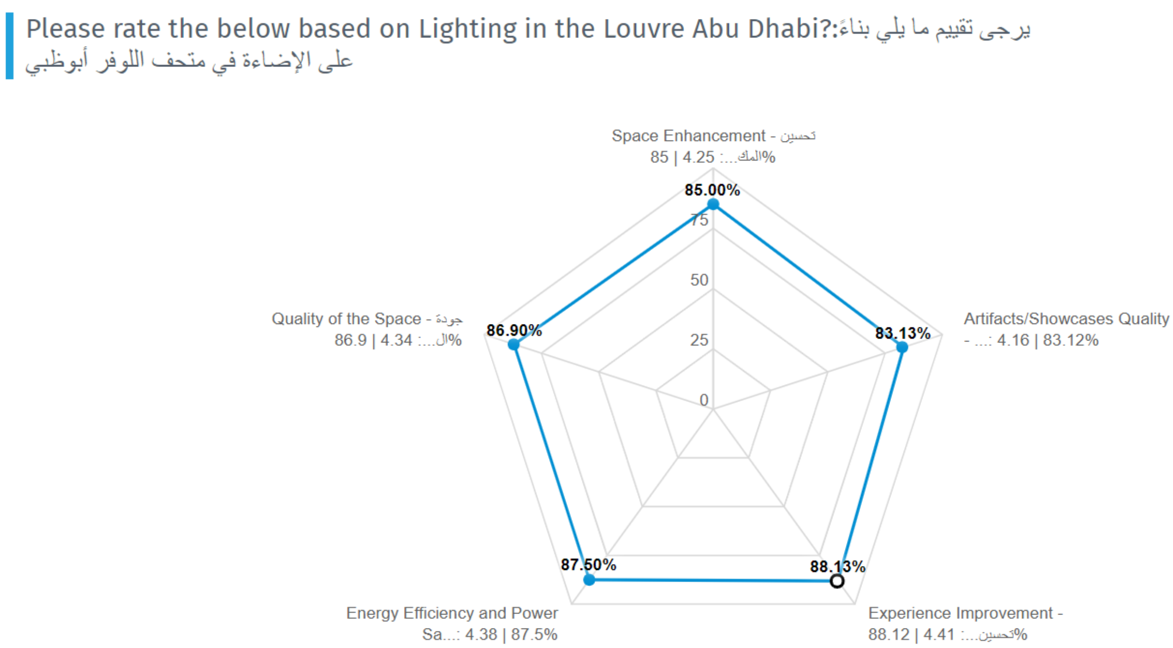


Fig 6.19. Lighting impact on different aspects in Louvre Museum (Author)

Moreover, participants were asked about the satisfaction rate they have for the lighting in the Louvre Museum. Where 53.12% were Very Satisfied with the Lighting in the Louvre Museum, while 43.75% were Satisfied with the Lighting and its impact on the Museum experience. 3.12% was Neutral about the Light in Louvre Museum. Important point is that 0% of the participants were not satisfied with the Lighting used in the Museum as shown in Figure 6.20.

Answer	Count	Percent
Very Unsatisfied	0	0%
Unsatisfied	0	0%
Neutral	1	3.12%
Satisfied	14	43.75%
Very Satisfied	17	53.12%

Fig 6.20. Lighting Satisfaction rate in louvre Abu Dhabi *(Author)*

As mentioned before the focus on using Natural lighting is a huge target in Louvre Abu Dhabi, therefore Participants were asked to evaluate the use of Natural lighting in Louvre Abu Dhabi. Where 65.62% indicated that Natural Lighting was efficiently used in the space. While 18.75% indicated that Natural Lighting was extensively used in the space which indicates that participants suggested that the amount of Natural light that the space receives could be enhanced. 9.38% suggested that the Natural light used in Louvre Museum needs to be improved. And 6.25% indicated that the natural light is used to its minimal and can be used more. As illustrated in chart below Figure 6.21.

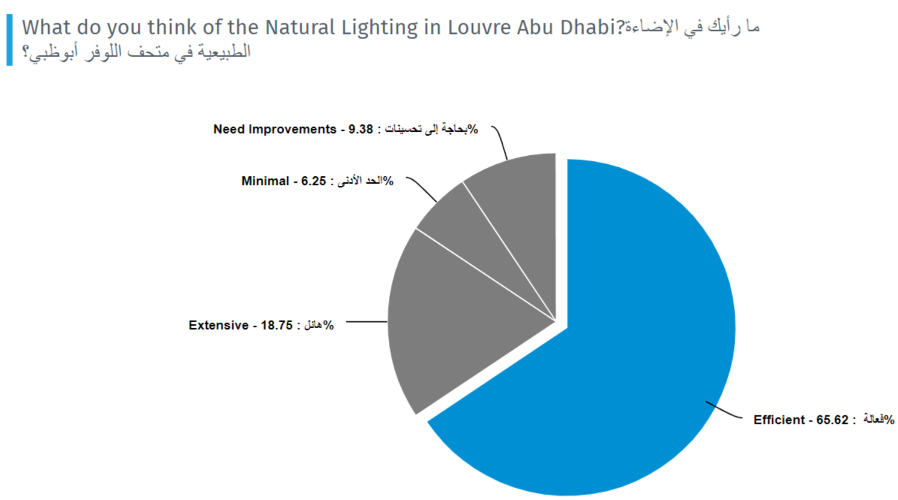
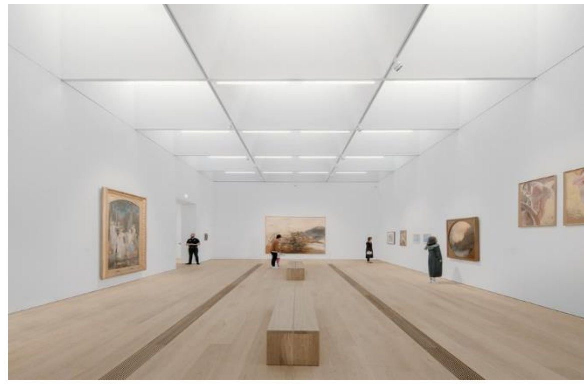


Fig 6.21. Natural Lighting in Louvre Abu Dhabi *(Author)*

It's important to understand the type of Lighting used based on the User's perception and understanding. Therefore, participants were asked to choose between 2 images that greatly describe the Lighting used in Louvre Abu Dhabi which are illustrated below. The below images describe the main types of Lighting that are used in the Louvre Museum which are Ambient and Task lighting.

Task *(Author)*



Ambient *(Author)*

Participants demonstrated that Louvre Museum focused on using Ambient Lighting with 68.57% indicated to that. While 31.43% of the participants indicated that Task lighting was the main type of lighting used in the Museum. Which is illustrated in Figure 6.22.

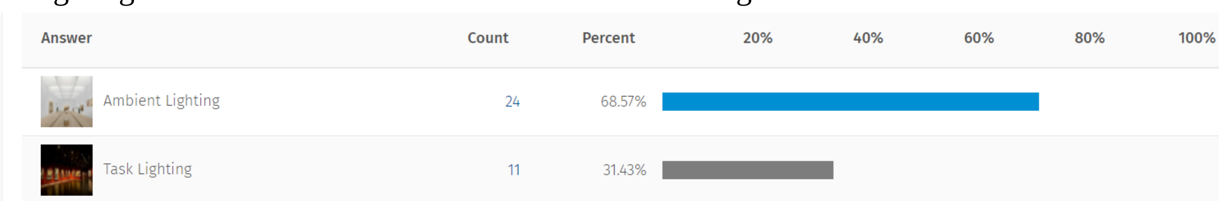


Fig 6.22. Type of lighting used in Louvre Abu Dhabi *(Author)*

Lastly, the participants were asked an open-end question to add their perception of how would the experience in Louvre Abu Dhabi be enhanced. The answers are demonstrated below:

- Adding more Interactive Activities.
- Adding more acoustical solutions and acoustical background.
- Presenting more temporary Exhibitions.
- Adding more open circulation.

The Summary for the Louvre Abu Dhabi users survey is illustrated in the below Table 6.3.

Table 6.3. Louvre Abu Dhabi Visitors Survey Summary Results *(Author)*

	Survey main Points	Result Conclusion
1	Number of Visits	Most of the people visited Louvre Abu Dhabi more than 3 times.
2	Museum Visit reason	People when visiting Louvre Abu Dhabi targets to Learn more a cultures and to know more about the Design of the space.
3	Period of Visit	The participant indicated that they usually stay in Louvre Abu Dhabi for 2 hours or more.
4	Stopping during the tour and visit.	50% of the participants suggested that they did not stop for any reason during their visit and tour. While the other 50% indicated that they did stop for different reasons during their tour.
5	The satisfaction rate of visitors of the Louvre Museum Movement.	Participants indicated that they are highly Satisfied with the movement in Louvre Abu Dhabi.
6	The satisfaction rate of visitors with the Louvre Museum Lighting system.	Participants were very satisfied with the Lighting system used in Louvre Abu Dhabi.
7	Natural Lighting used in Louvre Abu Dhabi	Visitors indicated that the Natural Lighting used in Louvre Museum is Efficient but somewhat extensive.

6.2 Stage 2 Proposed Enhancement

The second stage of assessing the difficulties is to evaluate the lighting system of the space using the mentioned tool in Chapter 3 in order to analyze all of the different factors that affect the natural and artificial lighting. This stage mainly is divided into multiple phases:

6.2.1 Simulation Results

Phase 1 is to start by modeling the Louvre Museum using Sketchup. In order to have an accurate result, the different rooms of the museum were represented as blocks, as seen in Figure 6.23. Adding the skylight opening was essential to get an accurate reading of the Daylight Factor and the daylight impact in the interior space.

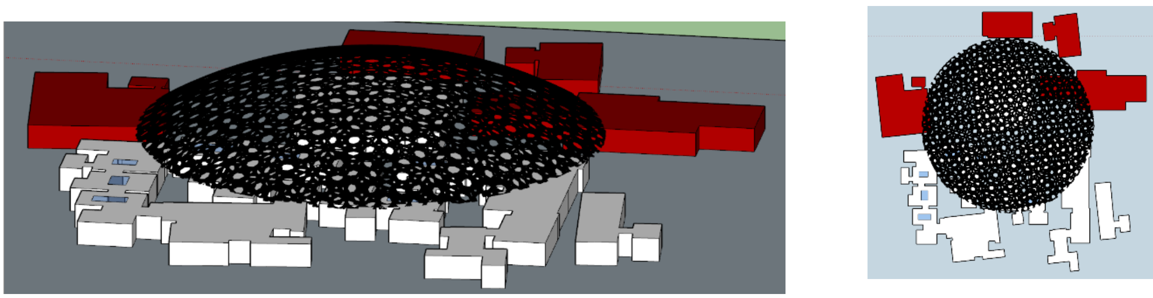


Fig 6.23. Sketchup Modeling *(Author)*

Phase 2 is the transformation of the modeled project to the simulation program explained in Chapter 3. After transforming the model to IESVE simulation program, some changes were made to the model to get an accurate result. Adding glazing openings and doors in the IESVE was necessary to get a precise outcome as well as seen in Figure 6.24.

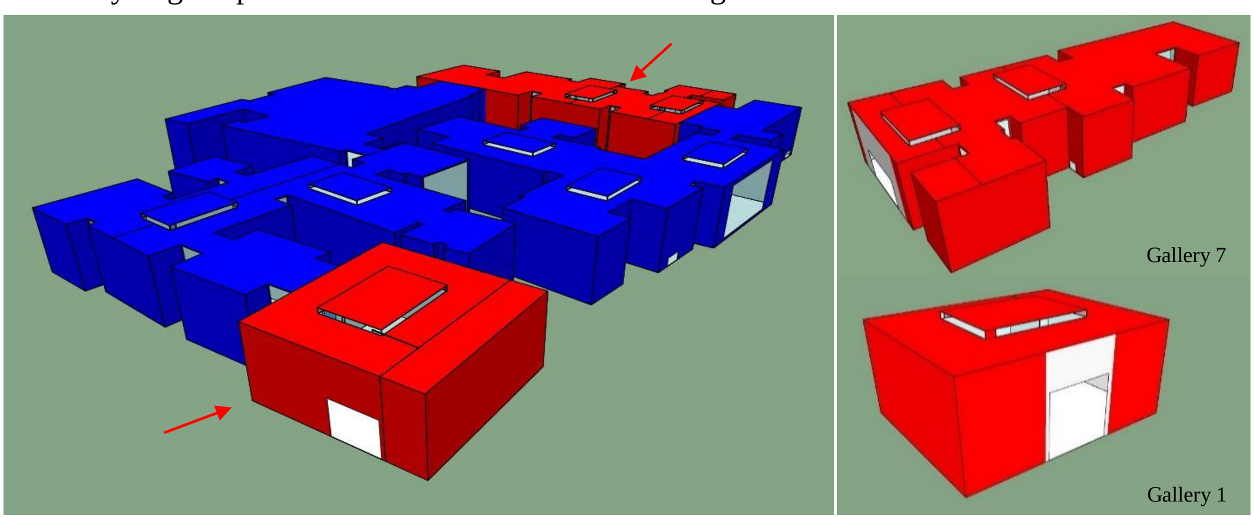


Fig6.24. IESVE Model *(Author)*

After that, the first part of the simulation was the definition of the project location using the latitude and longitude of Abu Dhabi. The second part is to define the working days and hours of the museum in order to get an accurate reading of the energy consumption of the space. As mentioned earlier, the museums is open from Tuesday till Sunday from 10:00 am to 06:30 pm and is closed on Mondays (*Plan Your Visit | Louvre Abu Dhabi* n.d.). The third part was the definition of the main materials used in the museum, which are divided into exterior and interior as demonstrated before. The materials that are used in the project as illustrated below in Table 6.4. The analysis of the material will focus on the finish, thermal conductivity, and density.

Table 6.4. Louvre Museum materials *(Author)*

	Material	Finish	Specififciations
Exterior Walls	Fiber Concrete ultra-high-performance panels	light Gray fiber Cement	U Value: 0.0238 W/ m²K Thickness: 200 mm
Interior Walls	Gypsum Board	Paint	U Value: 1.7326 W/ m²K Thickness: 75 mm
Flooring	Marble/Stones	Black Marquina, Black Saint Laurent, Red Levanto	U Value: 1.5369 W/ m²K Thickness: 190 mm
Ceiling	Gypsum Board/Glass Ceiling	White Paint/Clear & Frosted Glass	U Value: 1.0866 W/ m²K Thickness: 280 mm
Openings	Clear Glass	Double Glazed VLT: 60%	U Value: 1.6 W/ m²K Thickness: 24 mm

The analysis of the daylight of the space will mainly focus on studying the zones in two different conditions: the space without the Dome, and the space with the Dome. This will help to define the impact of the dome on the spaces and the artifacts. Moving along, the next phase will be the study of the artificial light in the space. This analysis will be done by dividing the study into two cases, the base case which demonstrates the existing light and its impact on the energy consumption and the user experience, while the design case will focus on the suggested solutions and its impact on energy consumption and users. Additionally, to get an accurate result the museum was studied in two different seasons and times. Findings resulted that the months where the Dry-Bulb temperature reached its maximum and its minimum are demonstrated in the below Table 6.5 these results were extracted from IESVE the simulation tool explained in Chapter 3.

Table 6.5. Max and Min vale of Dr-Bulb temperature in Louvre Abu Dhabi location *(Author)*

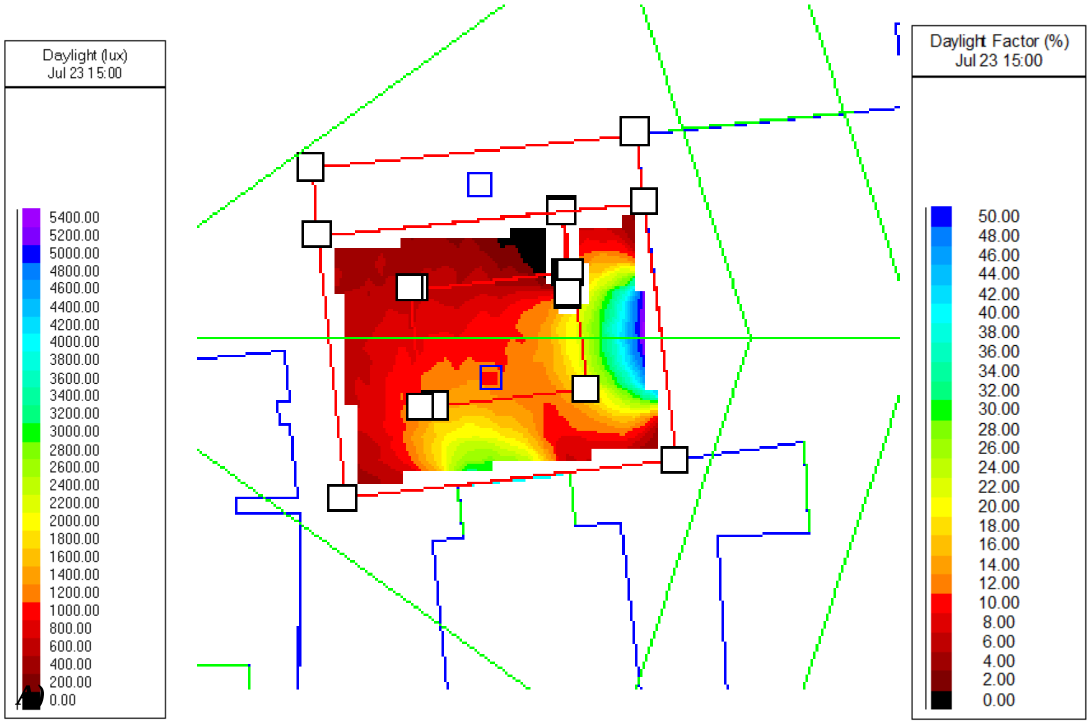
Name	Location	Type	Min Val	Min Time	Max Val	Max Time	Mean
Dry-Bulb Temperature	Abu Dhabi	Temperature°C	5.00	08:00 02/Feb	47.00	15:00 23/Jul	27.14

A) <u>Base Case</u>

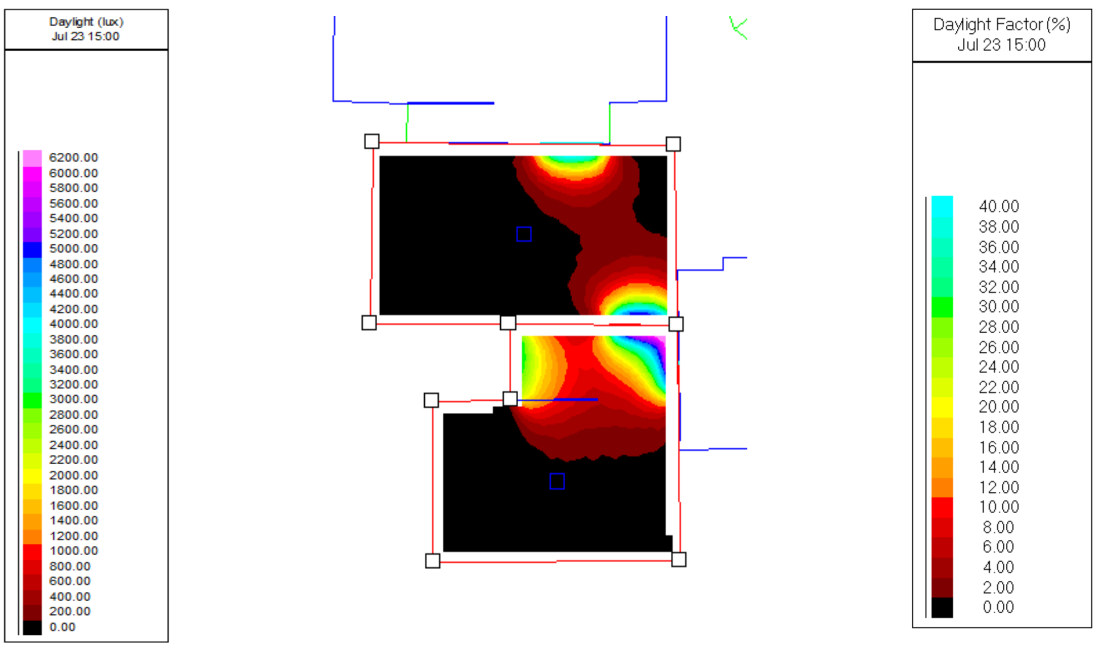
This section will focus on analyzing the museum based on the available specifications. Having a dome that covers Gallery 1 and doesn't cover Gallery 7, the skylight in Gallery 1 is being used to allow natural light to penetrate the space while the skylight in Gallery 7 is completely blocked to limit the amount of natural light that the space receives. The simulation was done in two different seasons and times as mentioned before.

- *<u>Lighting</u>*

Starting with the hot weather, which is as mentioned before was the 23rd of July at around 03:00 pm. As seen in Figure 6.25, the amount of natural light that Gallery 1 receives is noticeably much more when compared to Gallery 7 due to the absence of skylight and openings there. Additionally, the average DF that Gallery 1 receives is around 13.5% with an average of 823.3 lux while the average DF in Gallery 7 is 3.9% with an illuminance value of 593.89 lux. This clearly demonstrates that Gallery 1 receives more daylight when compared to Gallery 7 due to the absence of the skylight and openings in the space as seen in Figure 6.25. This illustrates the efficiency of the designed dome because as mentioned before that Gallery 7 is not located under the dome and still it is receiving less daylight when compared to the zone located underneath the dome, Gallery 1. This demonstrates the efficiency of the designed dome. See Table 6.6 for a comparison between both Galleries focusing on daylight.



A)



B)

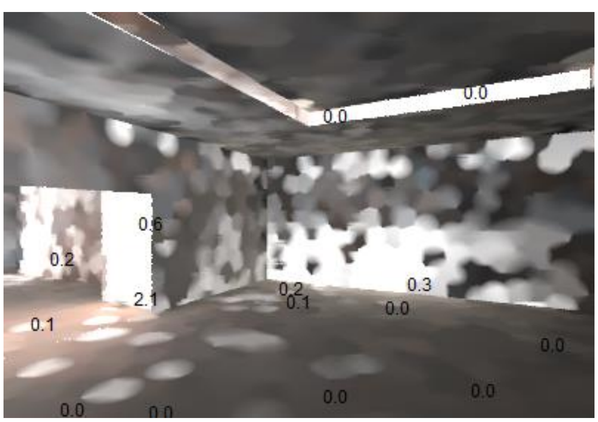
Fig 6.25. A) Gallery 1 Daylight Factor and Daylight Illuminance *(Author)*

B) Gallery 7 Daylight Factor and Daylight Illuminance *(Author)*

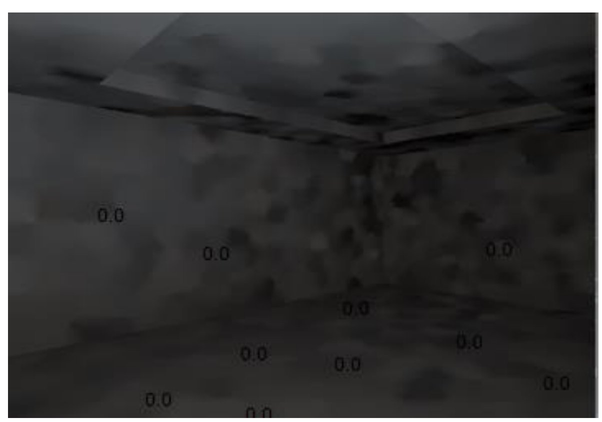
Table 6.6. Gallery 1 and Gallery 7 comparison from Daylight perspective on the 23^rd^ of July at 03:00 pm *(Author)*

Surface	Quantity	Values			Uniformity (Min.Ave.)	Diversity (Min.Ave.)
		Min.	Ave.	Max.		
Gallery 1						
Working Plane 1 Reflectance=0% Transmittance=100% Area= 1090.779 sq. m	Daylight Factor	0.0 %	13.5 %	50.9 %	0.00	0.00
	Daylight Illuminance	1.45 lux	823.25 lux	3099.78 lux	0.00	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00
Gallery 7						
Working plane 1 Reflectance=0% Transmittance=100% Area=510.835m²	Daylight Factor	0.0%	3.9 %	41.0 %	0.00	0.00
	Daylight Illuminance	0.79 lux	593.89 lux	6296.77 lux	0.00	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00

In addition to that as demonstrated in Figure 6.26 below that the amount of Daylight that Gallery 7 receives would require enhancement as it seems dark. While when compared to Gallery 1 which receives an efficient amount of Daylight



Gallery 1



Gallery 7

Fig 6.26. Daylight Factor impact on the Interior Space *(Author)*

The next section will analyze the daylight in the second selected time and season, which is the 2nd of February at 08:00 am. What was noticed during the simulation is that the amount of daylight has greatly been influenced by the change of the season; this is of course due to the huge difference in heat and sun movement. Moreover, Gallery 1 has demonstrated a huge decrease in the amount of daylight that penetrates the space as seen in Figure 6.27, with an average DF of 13.5% and illuminance average of 206.66 lux. While Gallery 7 demonstrated an average DF of 2.9% with a lumens average of 110.31 lux. This demonstrates a huge reduction in the daylight illuminance between the two seasons and periods of the day, which was predicted. But the DF is closely similar between the two seasons as seen in Table 6.7 which demonstrates a comparison between both galleries.

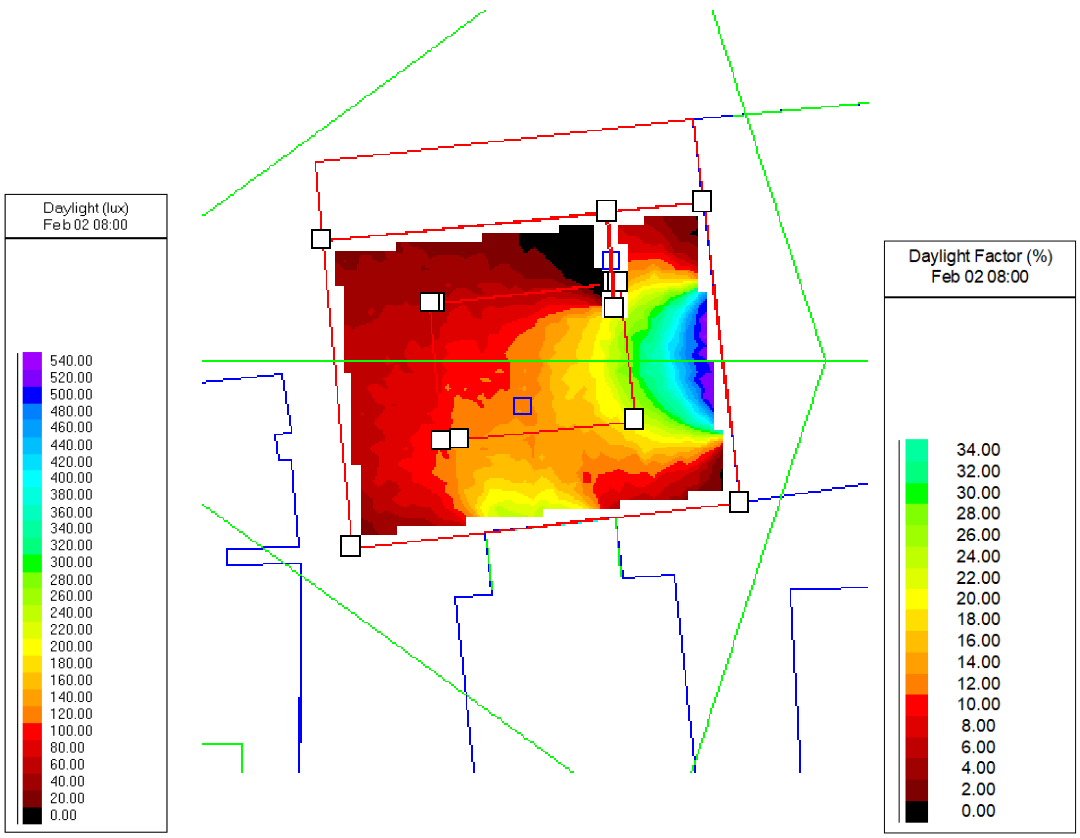


Fig 6.27. A) Gallery 1 Daylight Factor and Daylight Illuminance *(Author)*

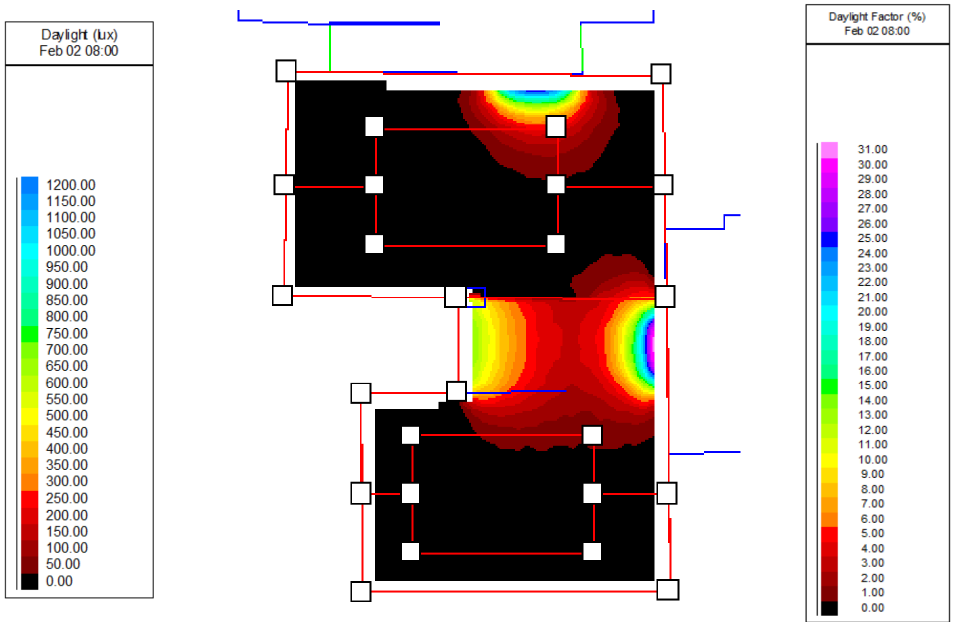
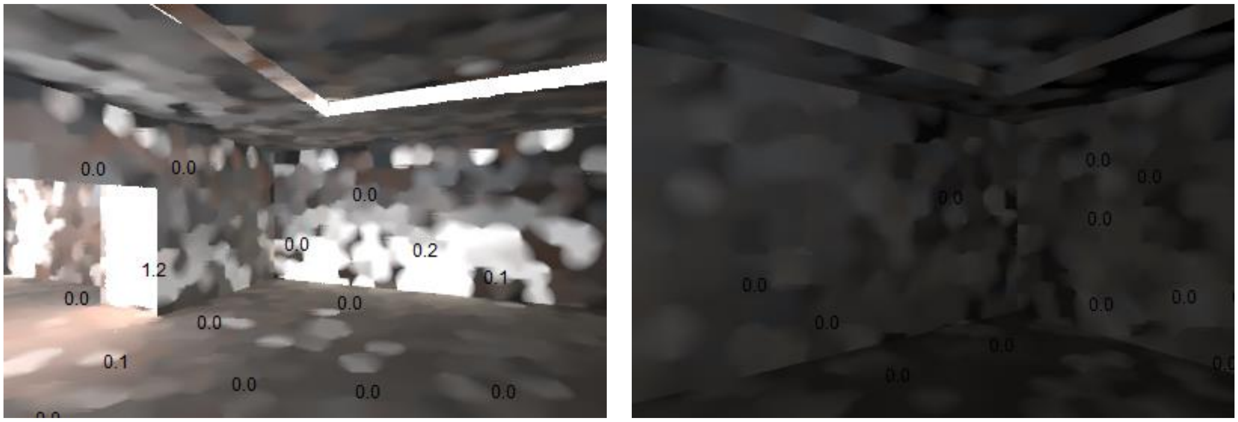


Fig 6.27 B) Gallery 7 Daylight Factor and Daylight Illuminance *(Author)*

Table 6.7. Gallery 1 and Gallery 7 comparison from Daylight perspective on the 2nd of February at 08:00 am *(Author)*

Surface	Quantity	Values			Uniformity (Min.Ave.)	Diversity (Min.Ave.)
		Min.	Ave.	Max.		
Gallery 1						
Working Plane 1 **Reflectance=0%** **Transmittance=100%** **Area= 1090.779 sq. m**	Daylight Factor	0.0 %	8.9 %	35.8 %	0.00	0.00
	Daylight Illuminance	0.09 lux	135.92 lux	546.16 lux	0.00	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00
Gallery 7						
Working plane 1 **Reflectance=0%** **Transmittance=100%** **Area=510.835m²**	Daylight Factor	0.0%	1.7 %	31.3 %	0.00	0.00
	Daylight Illuminance	0.12 lux	66.13 lux	1207.51 lux	0.00	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00

Additionally, Figure 6.28 below demonstrates that the amount of daylight that Gallery 7 receives would require enhancement as it seems dark while when compared to Gallery 1 which receives an efficient amount of daylight.



Gallery 1 ***Gallery 1***

Fig 6.28. Daylight Factor impact on the Interior Space *(Author)*

Therefore, what’s concluded from this phase is that the techniques for the natural light especially for Gallery 1 translate the sophistication of the design of the dome as it doesn’t completely impact the amount of daylight that the space receives but reduces it based on the requirements. That being said, the average Lux value that artifacts such as the objects that are exhibited in Gallery 1 and 7 is around 50 lux per hour as mentioned before. This means that the amount of daylight that penetrates the space might affect the exhibited objects but as the objects are exhibited in a micro-climate this will reduce the harmful impacts of the daylight illuminance greatly. In addition to that as seen in Figure what was noticed in Gallery 7 that the amount of daylight that the space receive could be enhanced in order to improve the psychological impact of the natural light which was mentioned before in Chapter 2.

Energy Consumption

This section will focus on energy consumption based on artificial lighting. This analysis was conducted after the analysis that was done during the visit, which demonstrated the number and type of Luminaires used in the space. Additionally, based on the simulation as illustrated in the Figure 6.29, in Gallery 1 the months with the most lighting energy consumption are January, July, October and December with 6.135 MBtu, and the month with the least lighting energy consumption was February with 5.454 MBtu as seen in the Figure 6.30 below.

	Total lights energy (MBtu)
Date	gallery 1 consumption14.aps
Jan 01-31	6.135
Feb 01-28	5.454
Mar 01-31	5.908
Apr 01-30	5.908
May 01-31	5.908
Jun 01-30	5.908
Jul 01-31	6.135
Aug 01-31	5.908
Sep 01-30	5.908
Oct 01-31	6.135
Nov 01-30	5.681
Dec 01-31	6.135
Summed total	71.124

Fig 6.29. Gallery 1 energy consumption *(Author)*

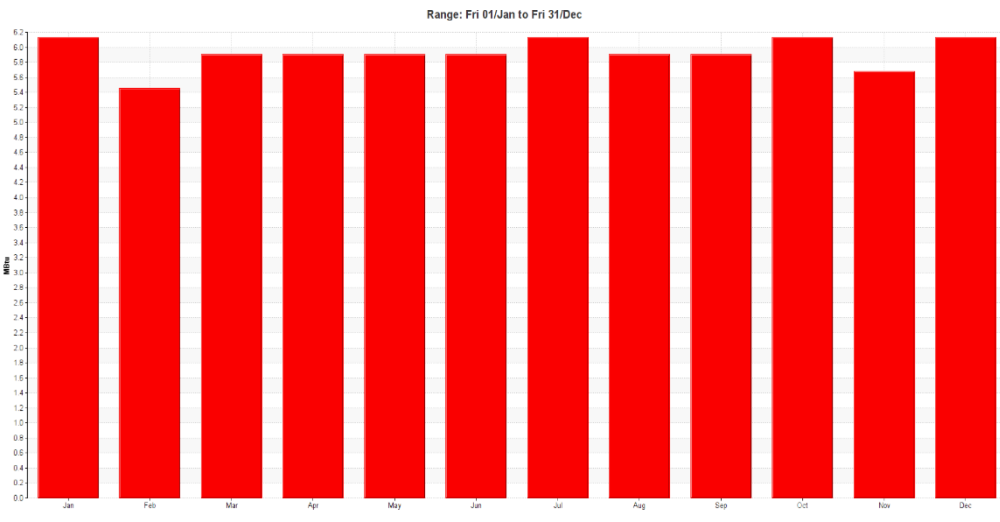


Fig 6.30. Gallery 1 lighting Energy Consumption along the year

Furthermore, the consumption in Gallery 7 is clearly much less due to the amount and number of spotlights used in both spaces. As mentioned before Gallery 1 has a total of 87 spotlights while Gallery 7 has a total of 25 spotlights. Therefore, the consumption in Gallery 7 reached its peak in January, July, October and December with 2.123 MBtu as seen in Figures 6.31 and 6.32.

	Total lights energy (MBtu)
Date	gallery7 2.aps
Jan 01-31	2.123
Feb 01-28	1.887
Mar 01-31	2.044
Apr 01-30	2.044
May 01-31	2.044
Jun 01-30	2.044
Jul 01-31	2.123
Aug 01-31	2.044
Sep 01-30	2.044
Oct 01-31	2.123
Nov 01-30	1.965
Dec 01-31	2.123
Summed total	24.607

Fig 6.31. Gallery 7 energy consumption *(Author)*

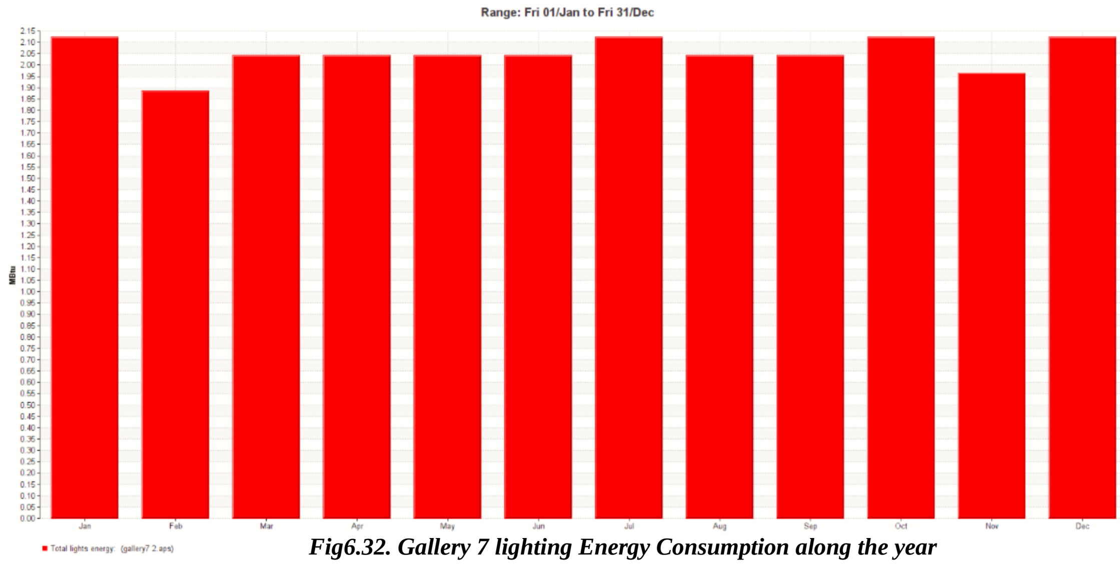


Fig6.32. Gallery 7 lighting Energy Consumption along the year

B) <u>Proposed Case</u>

This portion of the study will focus on analyzing different enhancement methods and possibilities that might enhance the lighting artificial and natural in both galleries, focusing on Gallery 7 as it receives the minimal amount of daylight, while in Gallery 1 the proposed case will focus on artificial light as the space receives a sufficient amount of natural light. As mentioned before, Gallery 7 has two openings and one skylight but all of these openings are closed and sealed in order to limit the amount of daylight that penetrates the space due to the absence of the dome. A simulation was done evaluating the amount of daylight that the space would receive if all of these openings were unsealed. The results were as follows. Gallery 7 is mainly divided into two parts as seen in Figure 6.33. The first part has a skylight that is sealed as seen in the Figure while the other part has no skylight but has openings that are also sealed using window shutters as seen in Figure 6.34.

Fig 6.33. Gallery 7 Parts

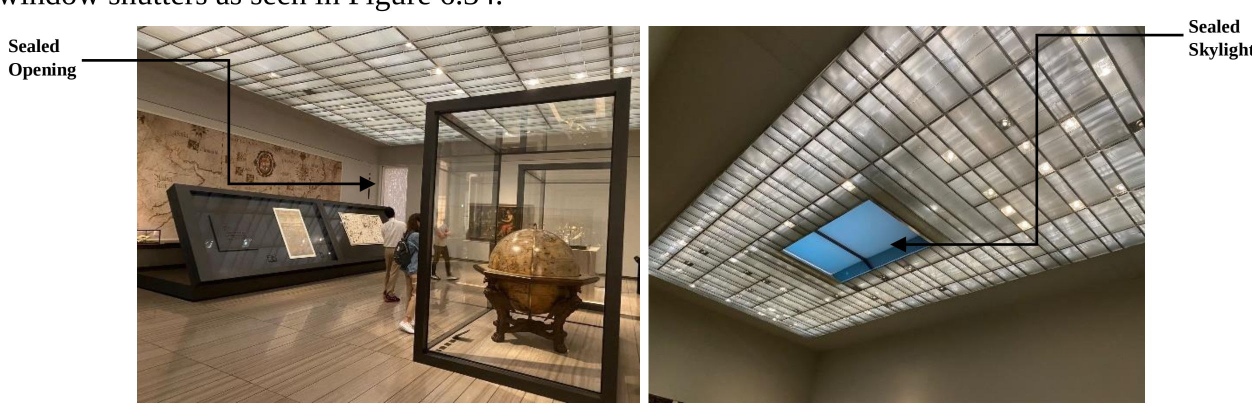
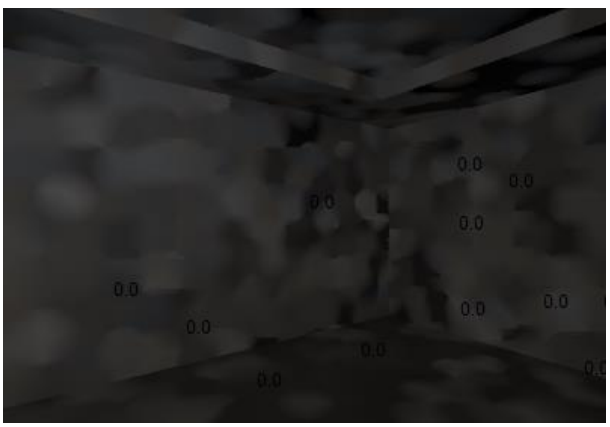


Fig 6.34. Gallery 7 Openings

The target of this proposed case is to study the analysis of opening the sealed skylight and adding some sort of moving louvers in the opening in part two of Gallery 7. This would control the amount of natural light that penetrates the space based on the requirements and target. What was noticed during the visit is that the target of this gallery is to showcase the artifacts in a slightly dark environment, therefore, some type of opening solutions would be recommended in the next phase of the analysis of the proposed case in order to control the amount of natural light while allowing an efficient amount to penetrate the space. The first part of this proposed case is to analyze the existing openings both the skylight and the window opening and their impact on the amount of light that the space receives. It was observed that the amount of light that penetrates the space through the skylight and the apertures would somewhat improve the amount of light that the space receives. As seen in Table 6.8 the average amount of DF that the spaces receive after opening the apertures is 2.9% and the average illuminance is 112.79 lux which demonstrates the improvement in the daylight when compared to the base case as seen in the Figure 6.35. However, some sort of treatments and solutions would be required in order to help improve the amount of light more efficiently.



Gallery 7 before

Gallery 7 after

Fig 6.35. Daylight in Gallery 7 before and after *(Author)*

Table 6.8. Comparison before and

Gallery 7		
	Before	After
Daylight Factor Average	1.7 %	2.9 %
Daylight Illumination Average	66.13 lux	112.79 lux

Additionally, the amount of natural light that the selected zone receives is efficient but could be enhanced by analyzing different procedures. This part of the stage will analyze the implementation of one of the procedures that are widely used and were discussed in Chapter 4 in one of the case studies. Louvers are well known for helping to limit the amount of natural light that a space receives. This analysis will focus on discussing the impact of louvers on the selected galleries. The first step was to determine the louver size that fits the size of the opening and space. In addition to that, louvers are mainly divided into three types: stationary or fixed; adjustable or movable; and combination, which is a mix of both. In this analysis, the use of movable louvers would better fit the requirements of the project because, as mentioned before, the selected gallery sometimes requires the visitor to experience a dimming environment, which would require limiting the amount of natural light that penetrates the space. Therefore, based on the requirements of the task, the louvers could alternate to allow or block additional light. An important aspect of the louvers is the assigning of the angles that the movable louvers would alternate along. This was done using the equation explained in Chapter 4, which focused on finding the ideal angle based on the size of the opening and size of the louver. The distance between the louvers to be used on each of the openings is found by dividing the height of the opening at 650 cm (h) by the total number of panels 20 (n). The distance between each panel is based on the selected material, which is similar to the material used in the dome design, stainless steel, which is 38 cm. The ideal angle that would completely block the direct sun, which is always harmful to artifacts in museums, is found using the below equation.

$$\beta_{max} = \alpha - \cos^{-1}(s\cos(\alpha)/w)$$

$$\beta_{max} = 0 - \cos^{-1}(33\cos(0)/38)$$

$$\beta_{max} = 30^{\circ}$$

The louvers will mainly have 3 conditions fully open, fully closed and opened at the studied degree 30° as seen in Figure 6.36. After the defining all of these parameters the next step was implementation, as seen in the Figure, applying the designed louvers in both opening to evaluate the effectiveness of this suggestion.

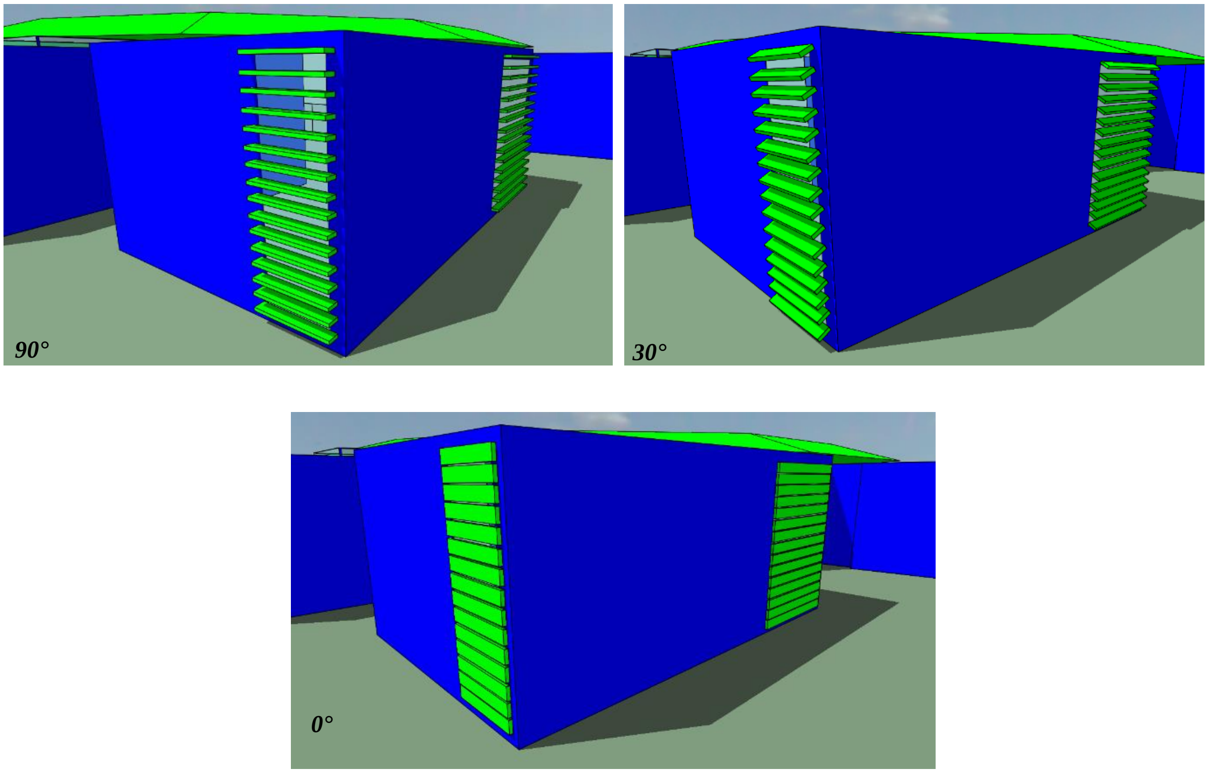


Fig 6.36. Louver Design in Gallery 7 openings

Next, I will analyze the suggested system to evaluate its impact on the amount of natural light that penetrates the space. The first part analyzed the interior space while the louvers at 0°, which resulted in slight enhancement as there is 2 cm distance between the louvers which allowed some of the sunlight to penetrate as seen in Figure 6.37.

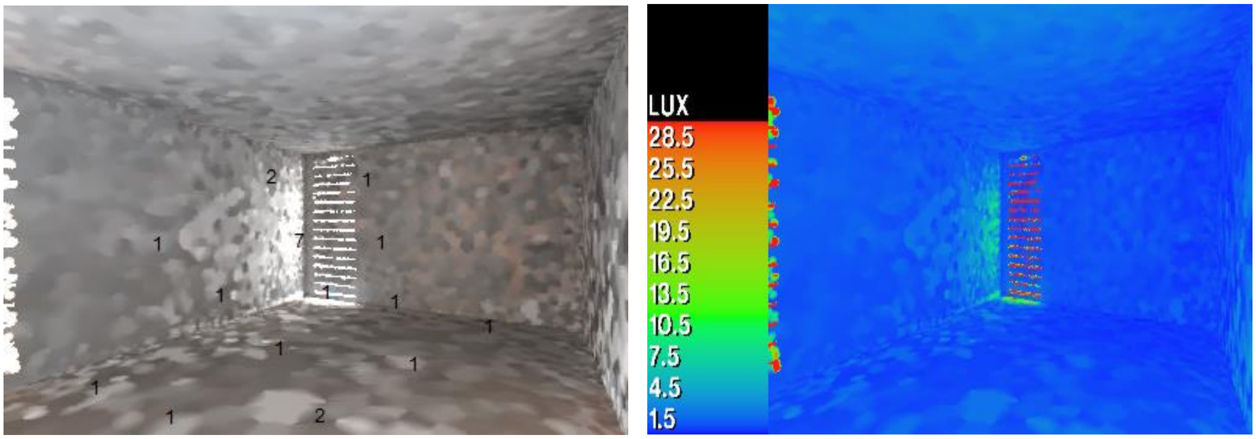


Fig 6.37. Louver impact at 0° *(Author)*

The second simulation was done using the 90° louver, which resulted in a huge amount of daylight penetrating the space, where it reached near the opening of 467 lux, which is a great amount of sunlight which might harm the artifacts and objects as seen in the Figure 6.38.

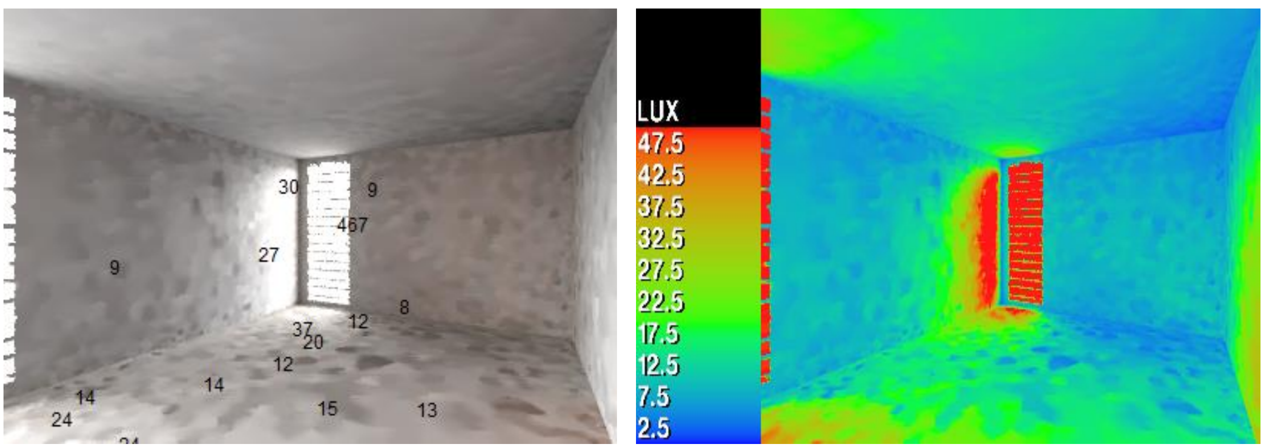


Fig 6.38. Louver impact at 90° *(Author)*

The third aspect is using the 30°, which resulted in a moderate amount of natural light as seen in Figure 6.39 with a maximum value of 50 lux beside the openings when compared to the previous suggestion with 467 lux. This demonstrates the effectiveness of the 30° louvre, but the space would also require adding artificial lighting in order to improve its movement and visibility. That being said, the effect of the louver is affected by the time and season throughout the year. That is why the suggested enhancement was a movable louver that would be adjusted based on the date and time.

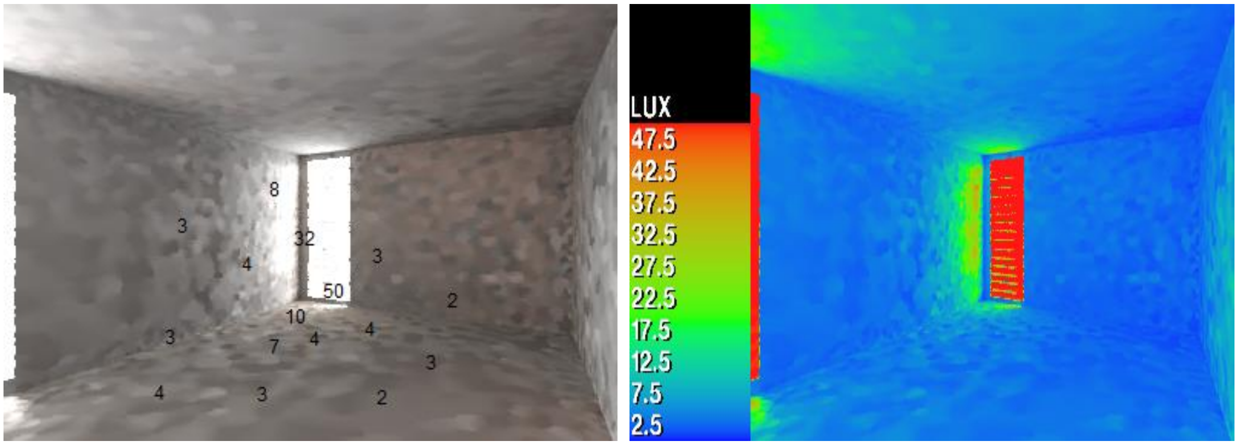


Fig 6.39. Louver impact at 30° *(Author)*

6.3 Stage 3 Comparison

This stage will focus on comparing between the two results extracted from the previous stages in order to get an accurate understanding of the lighting used in Gallery 1 and Gallery 7. This analysis will focus on the natural light in Gallery 7 and artificial light in Gallery 1, the reason being that the natural light in Gallery 7 could be enhanced while the artificial light in Gallery 1 could be more efficient from an energy perspective.

6.3.1 Natural Lighting

The way the designer employed natural light in the Louvre Abu Dhabi is significantly efficient, especially in Gallery 1, however the amount of daylight that Gallery 7 receives could be enhanced. The reason for this deficiency is due to the openings that are completely sealed. Furthermore, the results of the study on the amount of daylight that Gallery 7 obtains is demonstrated in Table 6.9 below where a comparison was done to demonstrate the difference in DF value and daylight illuminance. Proposed Case Gallery 7 has an average of 104.62 lux for daylight illuminance and a DF average of 2.7%. In the table below, a comparison was done which illustrates that the difference between both cases is minor but this minimal effect is due to the angle of the louver as the efficiency of louver improves based on the angle of the sun. In the selected time and date which is 2nd of February at 08:00 am the sun is close to the east and the location of Gallery 7 is facing west. Another simulation was done on the same date but at 03:00 pm to determine the effectiveness of the louver system in different angles results are illustrated in Figures 6.40.

*Table 6.9. **Louver impact at 30°*** *(Author)*

Surface	Quantity	Values			Uniformity (Min.Ave.)	Diversity (Min.Ave.)
		Min.	Ave.	Max.		
Base Case 2nd of Feb 08:00 am 30°						
Working Plane 1 **Reflectance=0%** **Transmittance=100%** **Area= 1090.779 sq. m**	Daylight Factor	0.0%	2.9 %	31.3 %	0.00	0.00
	Daylight Illuminance	0.12 lux	112.79 lux	1207.51 lux	0.00	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00
Proposed Case 2nd of Feb 08:00 am 30°						
Working plane 1 **Reflectance=0%** **Transmittance=100%** **Area=510.835m²**	Daylight Factor	0.0%	2.7 %	33.5 %	0.00	0.00
	Daylight Illuminance	0.12 lux	104.62 lux	1292.28 lux	0.00	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00

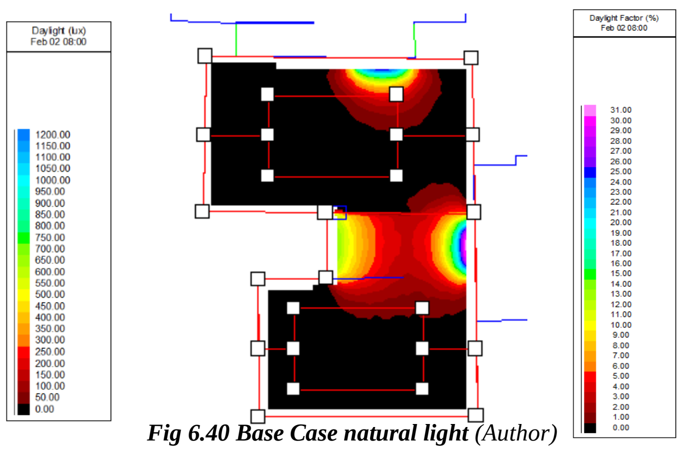


Fig 6.40 Base Case natural light *(Author)*

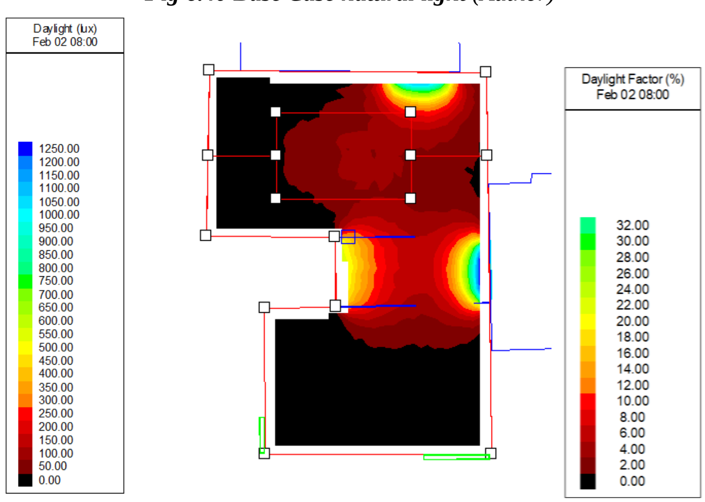


Fig 6.40 Proposed Case natural light *(Author)*

Table 6.10. Different louver angles light impact *(Author)*

Surface	Quantity	Values			Uniformity (Min.Ave.)	Diversity (Min.Ave.)
		Min.	Ave.	Max.		
Proposed Case 2nd of Feb 03:00 pm 0°						
Working Plane 1 Reflectance=0% Transmittance=100% Area= 1090.779 sq. m	Daylight Factor	0.0%	1.7 %	31.3 %	0.00	0.00
	Daylight Illuminance	0.12 lux	66.13 lux	1207.51 lux	0.00	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00
Proposed Case 2nd of Feb 03:00 pm 30°						
Working plane 1 Reflectance=0% Transmittance=100% Area=510.835m²	Daylight Factor	0.0%	2.7 %	33.5 %	0.00	0.00
	Daylight Illuminance	1.28 lux	298.53 lux	3687.69 lux	0.00	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00
Proposed Case 2nd of Feb 03:00 pm 90°						
Working plane 1 Reflectance=0% Transmittance=100% Area=510.835m²	Daylight Factor	0.0 %	2.8 %	33.8 %	0.01	0.00
	Daylight Illuminance	2.95 lux	313.29 lux	3715.28 lux	0.01	0.00
	Sky View	1.00	1.00	1.00	1.00	1.00

6.3.2 Energy Consumption

As discussed previously, the energy consumption that is incurred by lighting could be enhanced by reducing the number of spotlights used in the space. The reason for that is the energy consumption of the space and also to reduce the amount of light that is directed at the exhibited objects. As mentioned before, sensitive objects like the ones that are exhibited in Gallery 1 and 7 would require around 50 lux per hour. Based on the analysis, it was concluded that Gallery 1 produces around 10 lux per luminaire. As mentioned before, Gallery 1 has a total of 87 luminaires, which is equal to 870 lux for all luminaires while Gallery 7, with the same luminaire type and specifications as mentioned before, produces a total of 250 lux for all luminaires. Therefore, it would be beneficial for the exhibited item to be exposed to a lower number of lux values. However, as mentioned, most of the items in Galleries 1 and 7 are exhibited in micro-climates that help limit such outcomes, also the direction of the fixture will highly have an impact on this outcome. In addition to that, an analysis was done to evaluate the amount of light that the artificial light produces in both galleries, and as seen in the Figure, the amount of light is somewhat high. This also resulted in high glare values, as seen in the Figure 6.41.

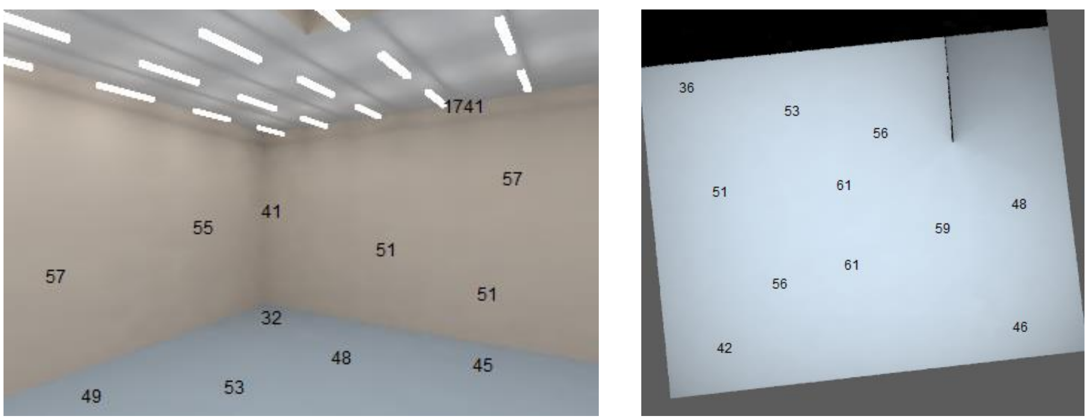


Fig 6.41. Base Case Luminaires *(Author)*

Therefore, the suggestion of reducing the wattage and lumens factor of the used LED light in order to decrease the amount of light that is formed would also decrease the energy consumption of lighting. What was noticed during the simulation was that new suggested lighting enhanced the lighting in the space by reducing the consumption of electricity, as seen in the Figure, while still having enough lighting for the space function. The Figure 6.42 and Figures 6.43 demonstrate a comparison between Base Case lighting and Proposed Case lighting. In January, the lighting electricity reached a maximum of 6.135 MBtu in the Base Case, while it reached 4.649 in the Proposed Case, resulting in a 24.22% reduction in electricity.

	Lights electricity (MBtu)	Lights electricity (MBtu)
Date	Proposed Case .aps	Base Case .aps
Jan 01-31	4.649	6.135
Feb 01-28	4.133	5.454
Mar 01-31	4.477	5.908
Apr 01-30	4.477	5.908
May 01-31	4.477	5.908
Jun 01-30	4.477	5.908
Jul 01-31	4.649	6.135
Aug 01-31	4.477	5.908
Sep 01-30	4.477	5.908
Oct 01-31	4.649	6.135
Nov 01-30	4.305	5.681
Dec 01-31	4.649	6.135
Summed total	53.899	71.124

Fig. 6.42 Base Case and Proposed Case light electricity consumption

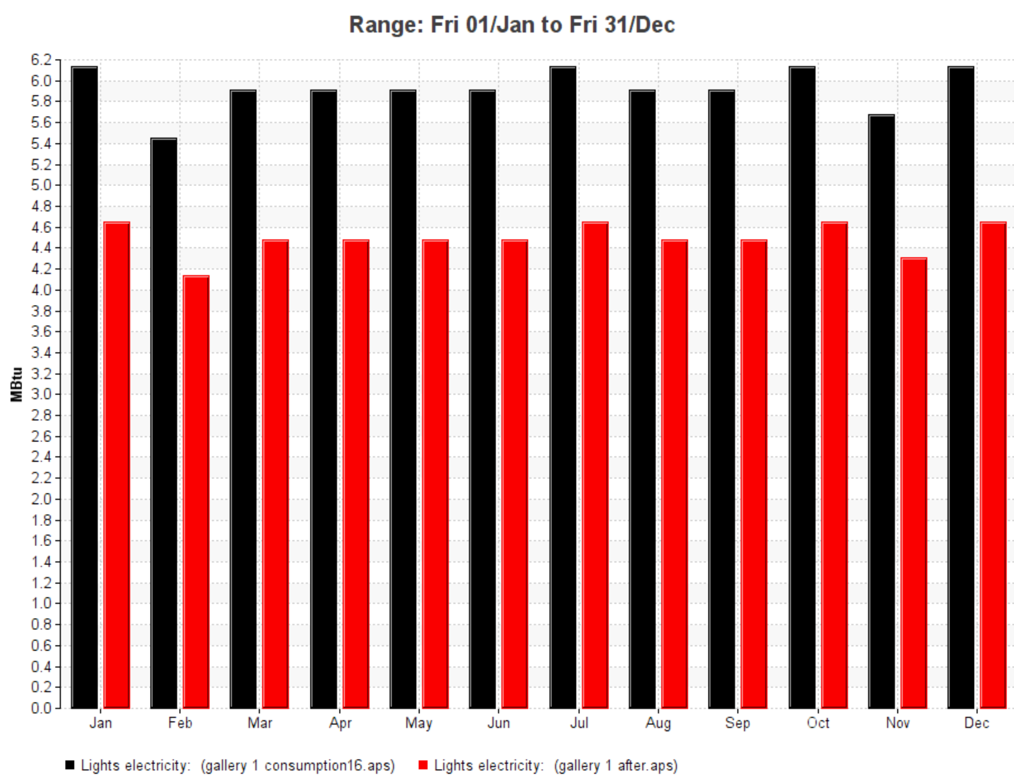


Fig 6.43. Base Case and Proposed Case light electricity consumption

6.4 Result Brief Overview

This portion of the paper is the main and core of the research as it concludes all of what was discussed in previous chapters as results and implementation. It focused on analyzing data that was assembled during multiple visits to the selected case study and through the literature review, This analysis of the data suggested some enhancement possibilities that were discussed and analyzed through different stages of this chapter to come up with some results that would try to enhance the experience of the users in the museum. Additionally, this portion mainly was divided into three main stages: (1) Data assembly which was done through the site visit and with the help of the literature review; (2) Proposed enhancement which will focus on suggesting enhancement procedures and techniques; and (3) which is the last stage of Chapter 6 which will include a small comparison between both cases before and after applying some of the enhancement techniques.

CHAPTER 7

Conclusion

7

C H A P T E R   V I

7. Conclusion

The importance of Museums in impacting the environment from all its different fields and categories where it started as a history preservation and ended up something much more. This study focused on the analysis of a selected case study located in U.A.E, Louvre Abu Dhabi is counted as one of the most important Museums in U.A.E due to multiple factors that was mentioned before.

Moreover, this study focused on analyzing different indoor environment quality aspects but mainly focusing on lighting due to its high impact on the museum environment and experience. The target of the study is to enhance the Indoor Quality through lighting 2 factors Natural and Artificial

The study focused on analyzing these aspects following specific Methodologies mainly focused on using a combined method of Screening, observations and analysis of data. In addition to that evaluating the current situation of the actual museum is relatively important to help with the suggested enhancement procedure. This was done by conducting multiple site visits which resulted with the survey answers which is part of the qualitative analysis and these results was later on experimented using different programs to find specific statistical outcomes which is part of the quantitative analysis.

Mainly the analysis of the Louvre Abu Dhabi focused on using 2 main cases as to compare between them to define whether the enhancement is effective or not. The Base Case reflects all the specifications and qualities of the existing lighting system used in the Museum. While the Proposed Case include some minor changes to the lighting and openings in the Galleries and they are as follows:

1- Opening the existing aperture in Gallery 7 in order to allow more daylight to the space.
2- Adding movable louvers to the openings in Gallery 7 to control the amount of light that penetrates the space. The louvers angle was found using the equation specified in the case study analyzed in Chapter 4.
3- Decreasing the number of luminaries specified in Gallery 1 to fit the requirements.

These minor changes resulted in some slight enhancement in the lighting of the space, for instance the amount of daylight illuminance average that Gallery 7 receives has changed from 66.13 lux to 112.79 lux without louvers but after implementing the louvers an average of 104.62 lux which demonstrates a small reduction in the average daylight illuminance in every case. Also, in Gallery 7 the consumption of energy has slightly changed, the annual lighting electricity consumption in the Base Case the is 71.124 MBtu while in the Proposed Case the annual consumption is 53.899 MBtu which shows 24.22% decrease in the lighting consumption.

Overall, through the research in can be concluded that the Louvre Abu Dhabi is considering all the aspects and regulations for international museums ICOM and adding the suggested enhancement and optimization factors would help develop and improve the quality and experience of the museum. Additionally, this type of museum would spread the awareness and understanding of and environment friendly museum from a lighting perspective.

7.1 Research Limitation

As mentioned before the major challenges that were encountered through the research process, was mainly the timeframe of the research the reason for that is because any Indoor Quality analysis would require testing and analyzing on different period of times and on a long period and due to the submission date and period this was not possible. Also defining the ultimate lighting specifications used in Abu Dhabi was a challenge due to the limited number of research related to lighting in museums. In addition to that the surveying method sometimes results in some quality and quantity issues, for instance having small number of participants or having low quality of answers. This was faced in this paper the quality of the answer was not efficient enough.

7.2 Research Recommendations

A future study analyzing the same case study would focus on the analysis of other indoor quality features such as Relative Humidity, Temperature, Heat gain and heat loss etc. in addition to that analyzing different case studies in the region to have a comparison of the results with the research outcomes. Also, a study that focuses on analyzing Louvre Abu Dhabi from a visitor perspective and focus on the psychological impact of Museums on the visitor.

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Appendix A

<u>Public Users</u>

Q1

How often do you visit museums?

كم مرة تزور المتاحف؟

Never - أبدا

Once in a while - من حين لآخر

About half the time - حوالي نصف الوقت

Most of the time - معظم الوقت

Always - دائما

Q2

How often do you visit museums?

كم مرة تزور المتاحف؟

Never - أبدا

Once in a while - من حين لآخر

About half the time - حوالي نصف الوقت

Most of the time - معظم الوقت

Always - دائما

Q2

How often do you visit museums?

كم مرة تزور المتاحف؟

Never - أبدا

Once in a while - من حين لآخر

About half the time - حوالي نصف الوقت

Most of the time - معظم الوقت

Always - دائما

Q3

How often do you visit museums?

كم مرة تزور المتاحف؟

Never - أبدا

Once in a while - من حين لآخر

About half the time - حوالي نصف الوقت

Most of the time - معظم الوقت

Always - دائما

Q4

What do you usually look for when visiting a Museum? (Choose Multiple if Required)
(اختر متعددة إذا لزم الأمر) ما الذي تبحث عنه عادة عند زيارة المتحف؟

Specific Artifacts - قطع أثرية محددة

Education - تعلم

Learning about Cultures - التعرف على الثقافات

General information - معلومات عامة

Curious about the Design and selected Treatments - مهتم بالتصميم والعلاجات المختارة

Q5

What do you like least about museums? (Choose Multiple if Required)

(اختر متعددة إذا لزم الأمر) ما الذي لا يعجبك في المتاحف؟

Antiques/Artifacts arrangements - ترتيبات التحف / القطع الأثرية

The Movement in the space - الحركة في الفضاء

Lighting - إضاءة

Crowdness of the space with Artifacts - ازدحام المكان بالقطع الأثرية

Ventillation - التهوية

Q6

Do you prefer going to museums alone or with others?
هل تفضل الذهاب إلى المتاحف بمفردك أم مع آخرين؟

Alone

With Others

Q7

Do you prefer museums with interactive exhibits or those you just look at?
هل تفضل المتاحف ذات المعروضات التفاعلية أم تلك التي تشاهدها فقط ؟

Interactive

Not Interactive

Q8

What is your usual total staying time in Museums?
ما هو إجمالي وقت إقامتك المعتاد في المتاحف؟

30 Minutes to 1 Hr

2 Hrs to 4 Hrs

4 Hrs and More

Q9

Do you prefer Museum with Natural or Artificial Lighting?
هل تفضل متحفًا بإضاءة طبيعية أم اصطناعية؟

Natural

Artificial

Q10

Do you think Lighting has a great Impact on Museum Experience?

هل تعتقد أن الإضاءة لها تأثير كبير على تجربة المتاحف؟

Yes

No

Q11

What usually requires improvement in Museums? (Choose Multiple if Required)
(اختر متعدد إذا لزم الأمر) ما الذي يتطلب عادة تحسين في المتاحف؟

Movement - حركة

Lighting - إضاءة

Artifacts Arrangement - ترتيب القطع الأثرية

Material Selection - اختيار المواد

Furniture Selection - اختيار الأثاث

Q12

Do you prefer a Museum Dedicated to 1 Civilization or More? and define the reason in the next quesiton? هل تفضل متحفًا مخصصًا لحضارة واحدة أم أكثر؟ حدد السبب في السؤال التالي؟

1 Civilization - حضارة واحدة

More than 1 Civilization - اكثر من حضارة

Q13

Please define the Reason for that?

الرجاء تحديد سبب ذلك؟

Multiple Row Answer text

Q14

Please rate the below based on Lighting:

يرجى تقييم ما يلي بناءً على الإضاءة:

Space Enhancement - تحسين المكان

Artifacts/Showcases Quality - جودة المعروضات

Experience Improvement - تحسين التجربة

Energy Efficiency and Power Saving Role - دور توفير الطاقة وكفاءة الطاقة

Quality of the Space - جودة المكان

Q15

Please choose 1 of the below images that best describes the type of Lighting you prefer in the Museum Space
يرجى اختيار إحدى الصور أدناه التي تصف على أفضل وجه نوع الإضاءة التي تفضلها في مساحة المتحف

Ambient Lighting

Task Lighting

Q16

How can your Museum Experience be enhanced?
كيف يمكن تحسين تجربتك في المتحف؟

Open-end question

Appendix B

Visitors Survey

Q1

How many times did you visit Louvre Museum?

كم مرة قمت بزيارة متحف اللوفر؟

Never - أبدا

Once - مرة

Twice- مرتين

3 Times - ثلاث مرات

More - أكثر

Q2

What do you usually look for when visiting a Museum? (Choose Multiple if Required)

(اختر متعددة إذا لزم الأمر) ما الذي تبحث عنه عادة عند زيارة المتحف؟

Specific Artifacts - قطع أثرية محددة

Education - تعلم

Learning about Cultures - التعرف على الثقافات

General information - معلومات عامة

Curious about the Design and selected Treatments - مهتم بالتصميم والعلاجات المختارة

Q3

What do you like least about museums? (Choose Multiple if Required)

(اختر متعددة إذا لزم الأمر) ما الذي لا يعجبك في المتاحف؟

Antiques/Artifacts arrangements - ترتيبات التحف / القطع الأثرية

The Movement in the space - الحركة في الفضاء

Lighting - إضاءة

Crowdness of the space with Artifacts - ازدحام المكان بالقطع الأثرية

Ventillation - التهوية

Q4

Do you prefer going to museums alone or with others?
هل تفضل الذهاب إلى المتاحف بمفردك أم مع آخرين؟

Alone

With Others

Q5

Do you prefer museums with interactive exhibits or those you just look at?
هل تفضل المتاحف ذات المعروضات التفاعلية أم تلك التي تشاهدها فقط ؟

Interactive

Not Interactive

Q6

What is your usual total staying time in Museums?
ما هو إجمالي وقت إقامتك المعتاد في المتاحف؟

Left Anchor

Right Anchor

	30 Minutes	1 Hours	2 Hours	3 Hours	4 Hours	More
Period of Stay - مدة الزيارة	○	○	○	○	○	○

Q7

While Viewing the Exhibits did you stop for any reason?

أثناء مشاهدة المعروضات هل توقفت لأي سبب؟

Yes

No

Q8

If you Answered the previous question with Yes, Please define the reason for stopping.

إذا أجبت على السؤال السابق بنعم ، يرجى تحديد سبب التوقف.

If you Answered with No, Please Answer with None.
إذا أجبت بـ "لا" ، يرجى الإجابة بلا.

Multiple Row Answer text

Q9

What do you think of the Method of Exhibiting the Work in the Louvre Abu Dhabi?
ما رأيك في طريقة عرض العمل في متحف اللوفر أبوظبي؟

Multiple Row Answer text

Q10

How satisfied are you with of the Movement in the Louvre Abu Dhabi?
ما مدى رضاك عن طريقة الحركة في متحف اللوفر أبوظبي؟

Very Unsatisfied

Unsatisfied

Neutral

Satisfied

Very Satisfied

Add Question

Page Break Separator

Q11

Do you prefer a Museum Dedicated to 1 Civilization or More? and define the reason in the next question?
هل تفضل متحفًا مخصصًا لحضارة واحدة أم أكثر؟ حدد السبب في السؤال التالي؟

1 Civilization - حضارة واحدة

More than 1 Civilization - اكثر من حضارة

Q12

Please define the Reason for that?

الرجاء تحديد سبب ذلك؟

Multiple Row Answer text

A

Q13

Please rate the below based on Lighting in the Louvre Abu Dhabi?

يرجى تقييم ما يلي بناءً على الإضاءة في متحف اللوفر أبوظبي:

Space Enhancement - تحسين المكان

Artifacts/Showcases Quality - جودة المعروضات

Experience Improvement - تحسين التجربة

Energy Efficiency and Power Saving Role - دور توفير الطاقة وكفاءة الطاقة

Quality of the Space - جودة المكان

Q14

How satisfied are you with the illumination/Lighting of the Louvre Abu Dhabi?

ما مدى رضاك عن إنارة متحف اللوفر أبوظبي؟

Very Unsatisfied

Unsatisfied

Neutral

Satisfied

Very Satisfied

Add Question

Page Break Separator

Q15

What do you think of the Natural Lighting in Louvre Abu Dhabi?

ما رأيك في الإضاءة الطبيعية في متحف اللوفر أبوظبي؟

Efficient - فعالة

Extensive - هائل

Minimal - الحد الأدنى

Need Improvements - بحاجة إلى تحسينات

Q16

Please choose 1 of the below images that best describes the type of Lighting in Louvre Abu Dhabi?
الرجاء اختيار إحدى الصور أدناه التي تصف أفضل نوع إضاءة في متحف اللوفر أبوظبي؟

Ambient Lighting

Q17

How can your Museum Experience in Louvre Abu Dhabi be enhanced?
كيف يمكن تحسين تجربتك في متحف اللوفر أبوظبي؟

Multiple Row Answer text