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INVESTIGATING THE USE OF EFFICIENT LIGHTING STRATEGY IN MUSEUM ARCHITECTURE.

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Abstract
We need light to see the world around us. Light is a natural phenomenon vital to our very existence. The quality, quantity and intensity of light around us, greatly affects our visual appreciation of our surroundings. It is important for us to understand the relationship between light, colour, what we see and how we see it. The entirety of museum architecture, is designing a building that tells a 'story'; beginning from the concept and form of the building to materials and method of construction. These stories are mostly historical and visual in nature, which can be experienced through sighting of artefacts or virtual/guided tour. All these and more, are characterized by movement of people from space to space, of which requires efficient lighting of the spaces. To better address this issue, the authors have discussed both natural and artificial sources of light as a method of lighting museums. How these sources where best harnessed to ensure for efficient lighting in a museum, gives a good foundation to this research work. This research paper highlights the effects of light on 2-dimentional and 3-dmentional objects and the best type of lighting suitable. Furthermore, an investigation of behaviour of light on walls, ceilings and floors in relation to materials used, was also carried out.

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Keywords: *Museum Architecture, efficient lighting, Architecture design, Guggenheim Museum, Daylighting, Natural Lighting.*

1.0 Introduction
Amidst every other environmental conditions needed to be controlled such as: humidity, air temperature, atmospheric pollution, to completely accomplish comfort in museum, efficient lighting is unavoidably required to fulfil visual requirements of visitors and staff alike.
"Form only exists through light and our perception of the world around us is totally dependent on it" Claude Monet, (n.d).
Efficient lighting system is needed in a museum to prevent accidents and destruction of art works and historic artefacts on display as most of them, came in their native form and some irreplaceable or irreversible. Light is arguably one of the major causes of deterioration in museum collections, on the other hand, it is essential for vison and communication of information's; held within and around the objects in the museum's collection.
Several factors contribute to light damaging effects: the materials from which objects are made, the type and intensity of light they are exposed to and the duration of exposure. Especially sensitive to light are objects made of organic materials, documents and letters, photographs, works of art on paper, textiles, clothing and accessories. The result can be irreversible cumulative over the life of the objects. (Ajmat, et al., 2011).
The main goal of lighting in a museum is 'visibility' of the objects without affecting it's physical appearance or changing the way the objects are intended to be seen by visitor's.

1.1 Museum

Museum is a temple that connects art and knowledge to people. It can be defined as a semi-formal place of learning which collects, displays and interprets artefacts of some sort; for educational purposes and preservation of history.

In The Emergence of the modern Museums, (Siegel) defines a museum as a 'collection of repository of rare and curious things in nature and arts arranged for the purposes of study.' as cited in (Palak, 2013).

1.2 Light, Human Eye and Vision.

We can recognize light in nature through the sunlight, starlight and moonlight; which are the most important sources of light to life. Human activities and needs outside the original garden, has led to inventions of enclosed architecture rather than the open. The need for additional light, have made humans learn to create their own light as well. Understanding the fundamental difference between natural and man-made sources of light and know how it can be effectively applied in different architectural masterpiece like a museum, is the beginning of lighting.

Lighting, on the other hand, is the application of light to illuminate objects, surfaces, scenes, pictures and people and places. Since it is the application, it is both a science and an art. Science because it makes use of the science of light and employs methods and techniques developed through time. It is an art because the personal taste (preference) and artistic sense of the designer and owner greatly influence the manner by which lighting is applied.

Light is the portion of electromagnetic spectrum to which the eye responds. The visible energy is a small part of the total spectrum which ranges from cosmic rays with extremely short wavelength in hundred kilometres as shown in figure 1.1. The visible portion lies between 280 and 770 nanometres (a unit of wavelength equal to $1x10^{-9}$ meter or one billionth of a meter). The colour of light is determined by the wavelength. Visible energy with the shortest wavelengths (380 to 450) nm. Produce sensations of red. In between light blue (450 to 490) nm. Green (490 to 560) nm. Yellow (560 to 590) nm and orange (590 to 630) nm. (Department of Energy (DOE), 2007) '*The human eye can perceive the wavelength of light spectrum falling between 380nm-750nm*. Science struck, *(n.d).*

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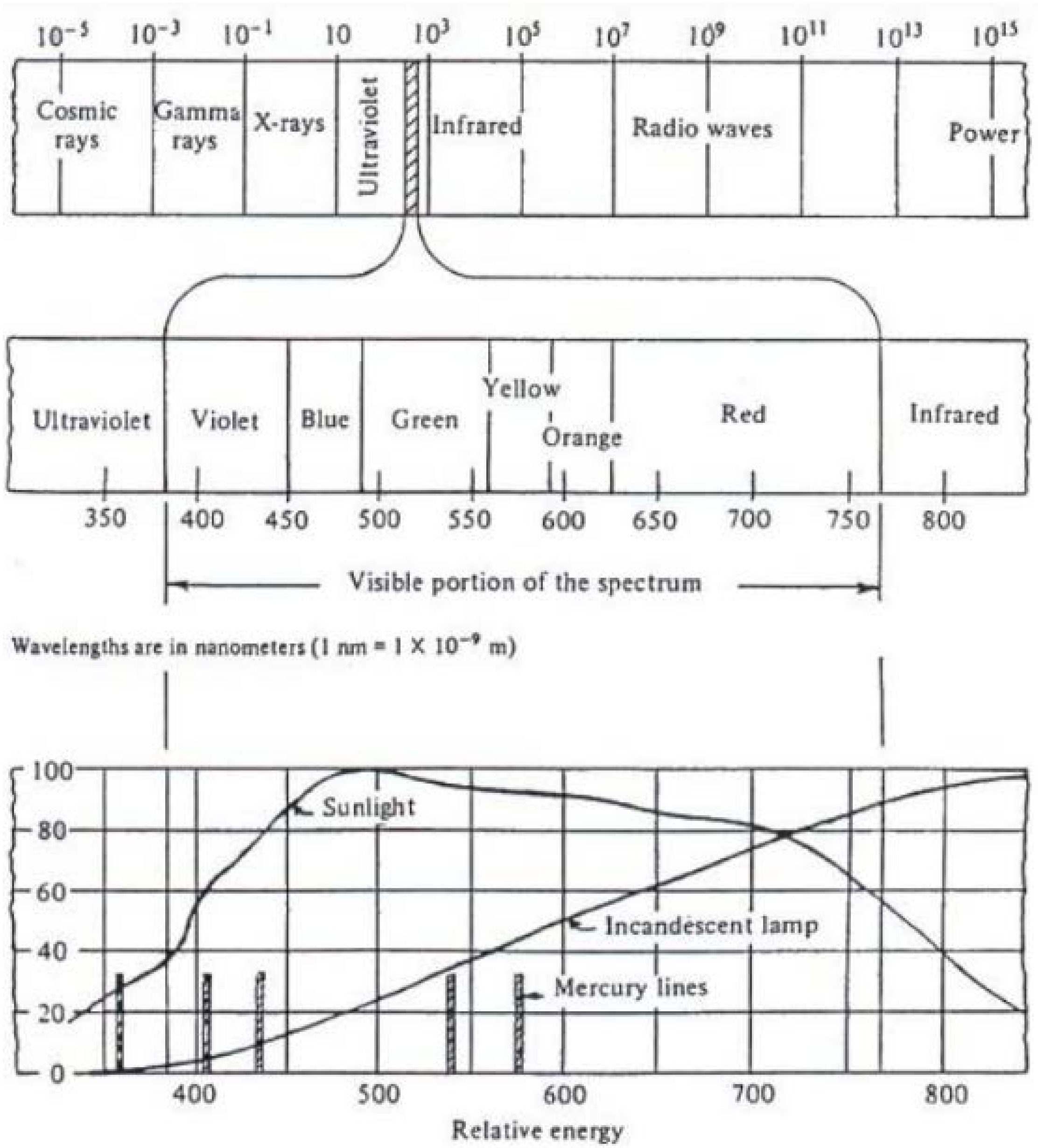

Figure 1.1 A sketch showing the region of visible light/portion of the light spectrum. (Department of Energy (DOE), 2007).

The human visual system responds to the very small part of the electromagnetic spectrum that leis between 380 and 760 nanometres. However, it does not respond uniformly. Given the same output of power at each wavelength, the visual system (eye) will sense the yellow-green region as the brightest and the red and blue region as the darkest. This is why the light source, which has most of its power in the yellow-green area, will have the highest visual efficiency, i.e., the highest lumens per watt. However, without a reasonable proportion of red or blue in its output, a light source will not be able to render colours satisfactorily. With most sources, the wider the range of wavelengths present, the lower the efficiency.

How to see depends on the wavelengths emitted by the light source, the wavelengths reflected by the objects, the surroundings in which we see the objects and the characteristics of the visual system. Exactly how the visual system (eyes) really sees colours is still only a theory. (Department of Energy (DOE), 2007).

Efficient lighting can improve employee working conditions. It is also possible to use lighting to reduce fatigue, encourage concentration or to improve awareness or decision-making. It can create an atmosphere of comfort, relaxation or trust or help people recover from illness or fatigue.

1.3 Definition of Terminologies

a) Luminous Flux (**ϕ**): this can be referred to be all the radiating power emitted by a light source and perceived by the eye. The unit of measurement is 'lumen (lm)'

b) Luminous Intensity (l). Light sources emits its luminous flux (**ϕ**) in different directions and at different intensities. The visible radiant intensity in a particular direction is call luminous intensity (**l**). The unit of measurement is the candela (**cd).**

c) Illuminance (**E**): Illuminance (**E**) is a measure of the amount of light falling on a surface. The distance of the light source from the area being illuminated influences it. An illuminance of 1lux occurs when a luminous flux of 1lumen is evenly distributed over an area of 1square meter. Unit of measurement is **lux** (**lx**). I.e. An average illumination of a surface is luminous flux per unit area. LUX=lumens/m^2.

d) Luminance (**L**): The luminance (l) is the brightness of an illuminated or luminous surface as perceived by the human eye. Luminance depends on the surface size seen and the light intensity, reflected by the surface towards the eye. Unit is **Candela/m^2 (cd/m^2)**

e) Luminous Efficacy (**η**): Luminous efficacy indicates the efficiency with which the electrical power consumed is converted into light. The unit of measurement is **lumens per watt** (**lm/w**).

f) Energy Efficiency: Energy efficiency is defined as optimisation of energy consumption, with no sacrifice in lighting quality. It is a combination of thoughtful design and selection of appropriate lamp, luminaire and control system selection, made in conjunction with informed choices of the illumination level required, integration and awareness of the environment or space which is being lit. (Arup, 2021).

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1.4 Aim of study

The aim of this study is to investigate the efficient use of natural and artificial lighting by both Architects and designers in museum interiors and how visible the objects can be without affecting its physical appearance or changing the way the objects are intended to be seen by visitors and staff alike.

1.5 Objectives

i. To identify the various sources of light and the application in museum architecture design.
ii. To investigate how these various sources of light are applied in exhibition spaces/gallery to ensure maximum visibility while ensuring preservation of all exhibits.

1.6 Research questions

i. What are the various sources of light and type of lighting fixture suitable for lighting in museums?
ii. How can good lighting application increase efficiency and visibility in museums while still not affecting the way visitors and staff will see the exhibits differently?

2.0 Lighting in museum

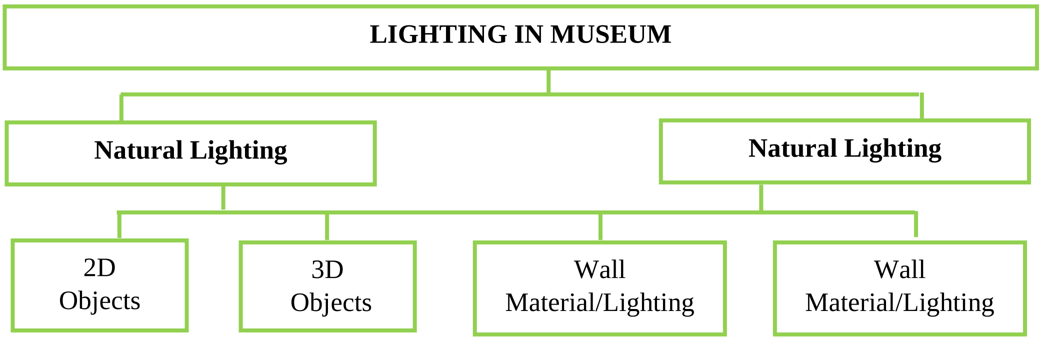

Figure 2.0 classification of lighting in Museum and art galleries.

Light is essential to vision, as the principal means of communicating the information held within and around the objects in the Museum's collection hitherto, light is arguably one of the greatest causes of deterioration in Museum collections of which, most of them are irreversible.
Lighting plays a vital role in guiding visitors through their museum or gallery experience; the moment a visitor sees the exterior façade, the journey has begun. From creating anticipation on arrival to communicating drama or contemplation within the exhibition space indeed, lighting has a key role to play:

- It can be used to alter the mood of the exhibition space
- It can be used to draw the eye to stunning artwork and sculptures
- The subtle play of light and dark can be used to guide the visitor's journey from entrance to exit. And much more.

Figure (1.1) above, reveals the light to which museum collections are exposed; made up of three parts: ultraviolet UV radiation at one end of the spectrum, visible light in the middle and infrared radiation at the other end. A common misconception is that: eliminating UV light solves the problem of deterioration but all lights where ever it falls on the spectrum, is energy; and it is energy that drives the chemical reactions that result in damage to objects from fading. High energy UV-light falls outside the range of human perception and so is not necessary for viewing a museum exhibit. At the other end of the spectrum, is infrared lights which produces 28 heat damage from infrared light. Museums environmental control involves air conditioning & (cooling or heating), presence of people and lighting, all these factors disturb the natural micro climate of the area and may have a negative impact on conservation of exhibited artefacts. Some studies carried out have been based on medium and long term monitoring in order to determine by simple indicators, the quality of the micro climate in relation to the requirements to eliminate risks of preservation. . (Palak, 2013)

Table 2.1 Recommended Lux level for various objects and artefacts in Museum and Art Galleries. As adapted from: (Sylvania, 2015).

Material/Exhibit	Sensitivity	Recommended Lux Level
Costumes and other textiles, fur and feathers, dyed leather, prints, drawings, watercolours, stamps, manuscripts, coloured, old photographs, miniatures, transparencies, and unprimed thinly coloured paintings on canvas.	HIGH	50 Lux
Oil and tempera paintings, lacquer ware, plastics, wood, furniture, horn, bone, ivory, undyed leather, minerals and modern black and white photographs.	MEDIUM	100Lux
Stone Ceramic, Glass and Metal	LOW	300Lux

2.1 Natural/Daylighting In Museum

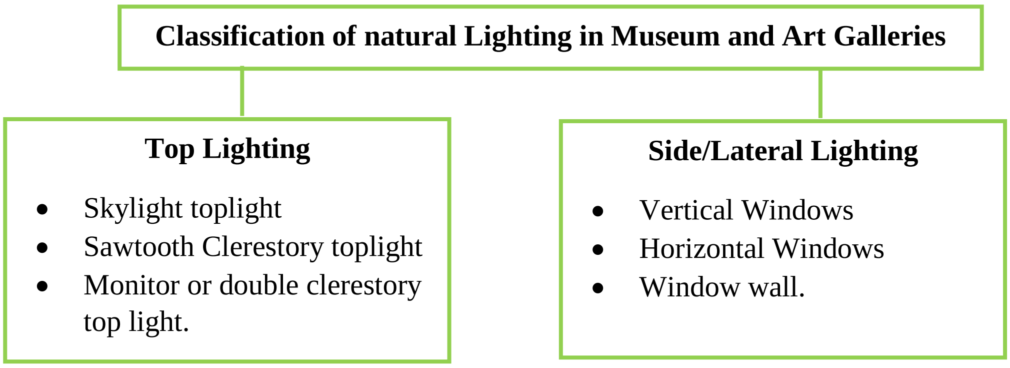

Figure 2.2 Classification of natural Lighting in Museum and Art Galleries.

Daylighting is an excellent light source for almost all interior spaces. For large spaces such as Museum and Art Galleries requiring a lot of Light; windows, skylight and other forms of fenestration are used to bring daylight into the interior of buildings. Daylight is highly desirable as a light source because people respond to it. The amount of available daylight varies according to time of the day, month of the year, weather, pollution, levels, surrounding landscape and so on.

The maximum amount of daylight is about 10,000 foot-candles on a sunny summer day. For energy efficiency in buildings, however only, only about 5% of the daylight or a peak of about 500foot-candles, should be allowed into a building; more will generate so much heat that energy will be wasted in air conditioning. (Department of Energy (DOE), 2007).

The color of daylight varies as well. The color temperature of the setting sun is as low as 2000K, and the normal sun and sky temperature at noon on a sunny day is between 5500K-6000K. The cold blue light from winter north sky is over 10,000K, the color quality is excellent however, and daylight has a relatively high ultraviolet (UV) light content, which has potential negative side effects such as cancer, sunburn and skin cancer. Extreme care must be exercised when using daylight in places such as museums and art Gallery where damage called ‘’Photodegradation’’ causes bleaching of pigments and paintings, and other harm to irreplaceable art and antiquities.

2.2 Artificial/Man-Made Lighting in Museum.

The role of artificial lighting in Museums and Art Galleries, cannot be underestimated; with it’s potential of scalability and flexibility, what designers could possibility achieve with it, is limitless and astonishing. Due to uncontrollable nature of heating effects from sunlight, the role of artificial lighting becomes even more interesting in Museums. The following are the controllable qualities of artificial lighting:

a) Availability;
b) Flexible angle positioning;
c) Intensity control;
d) Distribution control;
e) Colour choice;
f) Mobility.

Artificial lighting in Museum is typically in the two forms: directional lighting and diffuse lighting. A system such as wallwashers, may have a combination of these two forms of lighting which could be sometimes referred to diffuse/directional lighting.

- **Diffuse lighting:** Diffuse lighting illuminates room zones from a surface that radiates lights in all directions. The direction from which light comes cannot be clearly determined and it produces little to no shadows in Museums. This can be achieved by using reflected ceiling as shown in (fig 2.14) or cove luminaries (fig. 2.3 & 2.4).

Figure 2.3 Medieval Renaissance Galleries, London, UK. (Arup, 2021). Showing the use of cove luminaires to litup the entire exhibition space (Diffuse lighting).

Figure 2.4 The Waterhall, Birmingham Museum and Art Gallery, UK. (Arup, 2021). The entire ceiling furnished with cove celling to bring out the beauty of the exhibition room.

- **Directional Lighting:** Directional lighting is mostly by punctual light sources i.e. lamps that are small in relation to the lighting distance. Light falls directly onto the objects illuminated at an angle, creating a clearly defined shadow. This can be used in museums to enhance the visual impact of three-dimensional surface.

Figure 2.5 Application of directional lighting on 3d objects with clearly defined light and shadows. ‘’Ashmolean Museum, University of Oxford, UK. The world oldest public museum and one of Europe’s most popular cultural tourist destinations. Source: (Sylvania, 2015).

- **Room Lighting:** lighting for exhibition rooms in museums is made up of diffuse and directional light. The relative amounts and resulting mix of the two form of light, determines the harshness of the shadows cast by picture frames and the three dimensional impact of sculptures and spatial objects. The diffuse and directional light mix also defines the overall impression made by the room.

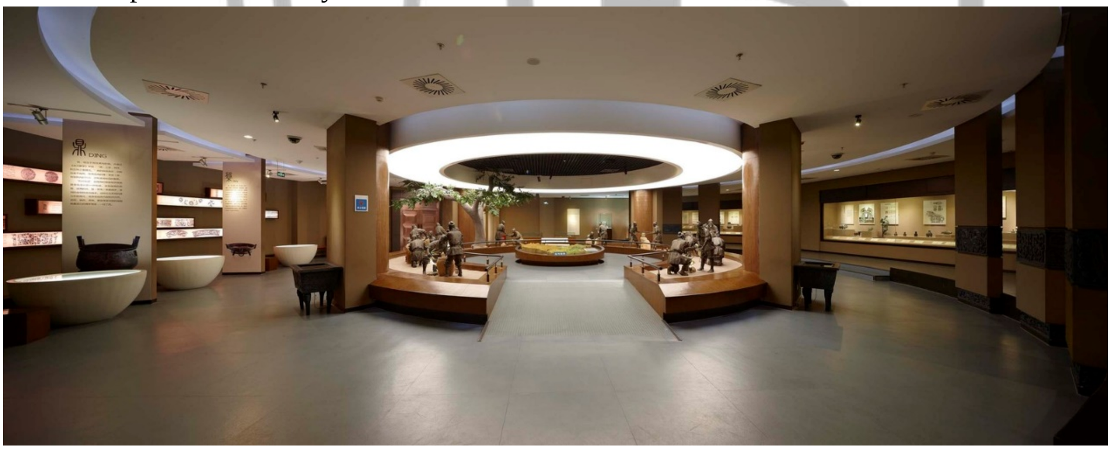

Figure 2.6 A smart combination of diffuse and directional lighting mix to create an impressive visual impact of the exhibition space. ‘Baoji Bronzeware Museum’. Image Source: (Chen) as cited in (Shuang, 2020).

- **Route Lighting:** In some exhibition rooms and galleries, visitors are free to move around in any direction, however, because of nature of exhibition space or for organizational reasons, they need to be directed. Luminaries which highlight circulation routes without interfering the display areas are named as route lights.

Figure 2.7 Showing use of routes lights on floor, wallwashers on walls, and directional spot lights on ceilings to create an impressive light and shadow in the interior space. . 'Baoji Bronzeware Museum'. Image Source: (Chen) as cited in (Shuang, 2020).

2.3 The Burke Museum

Location: Seattle, Washington, United States
Architects: Olson Kundig
Area: 110000 ft²
Year of completion: 2019.

The Burke Museum is the oldest public museum in Washington State with a collection of over 16 million artefacts and specimens, ranging from totem poles and gemstones to dinosaur fossils. Large areas of glazing maximize transparency and expose the interior experience to the street to connect the Burke to the campus, landscape and city.

Figure 2.8 Burke Museum Northern Façade showing solar exposure and transparency using Horizontal glazed windows and wall windows. Image Source: (Aaron, Mikel, & Olson) as cited in (Pintos, The Burke Museum, 2021)

The use of clear windows help to frame and exhibit objects for both internal and external views, while providing natural light and ventilation.

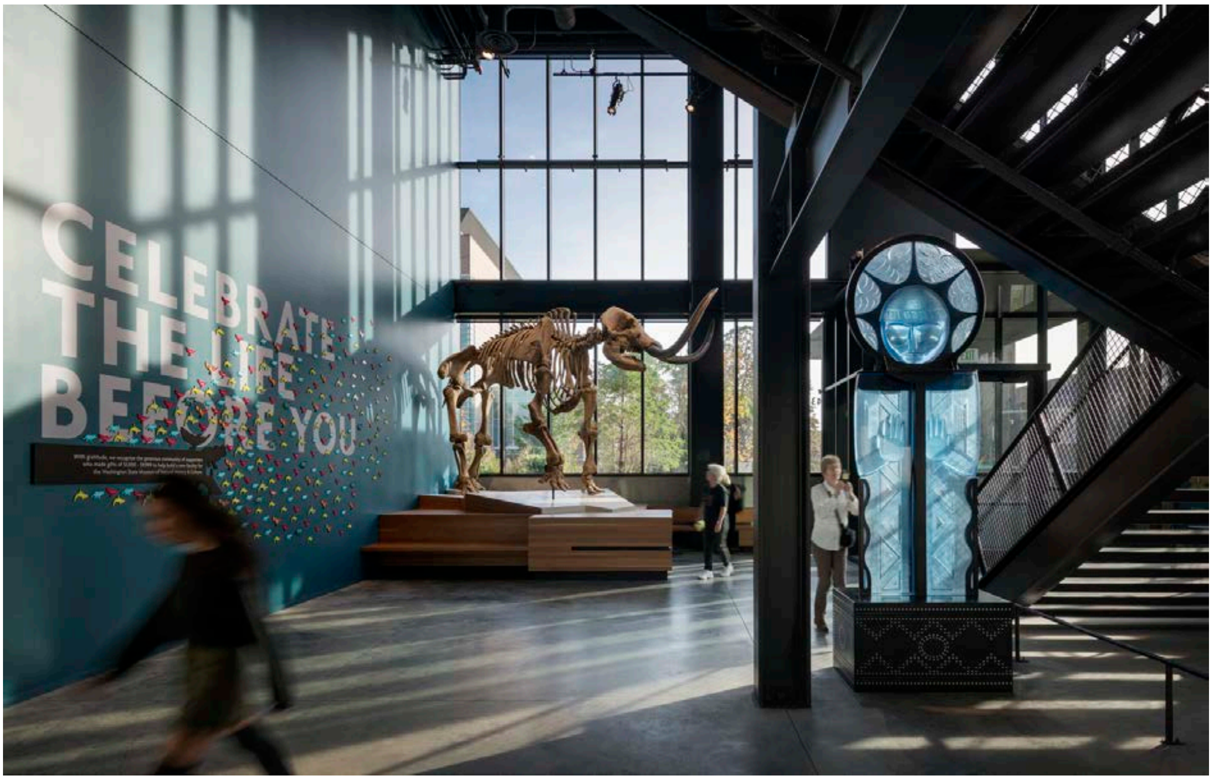

Figure 2.9 Effective use of clear windows to clearly show exhibition while also serving for ventilation. Image Source: (Aaron, Mikel, & Olson) as cited in (Pintos, The Burke Museum, 2021)

A large central atrium and "smart glass" skylight likewise foster a bright, daylit interior experience, without risking damage to sensitive artefacts. The project is LEED® Gold certified. The building's rational scheme holds the complexity of the Burke's activities and collections, both now and into the future.

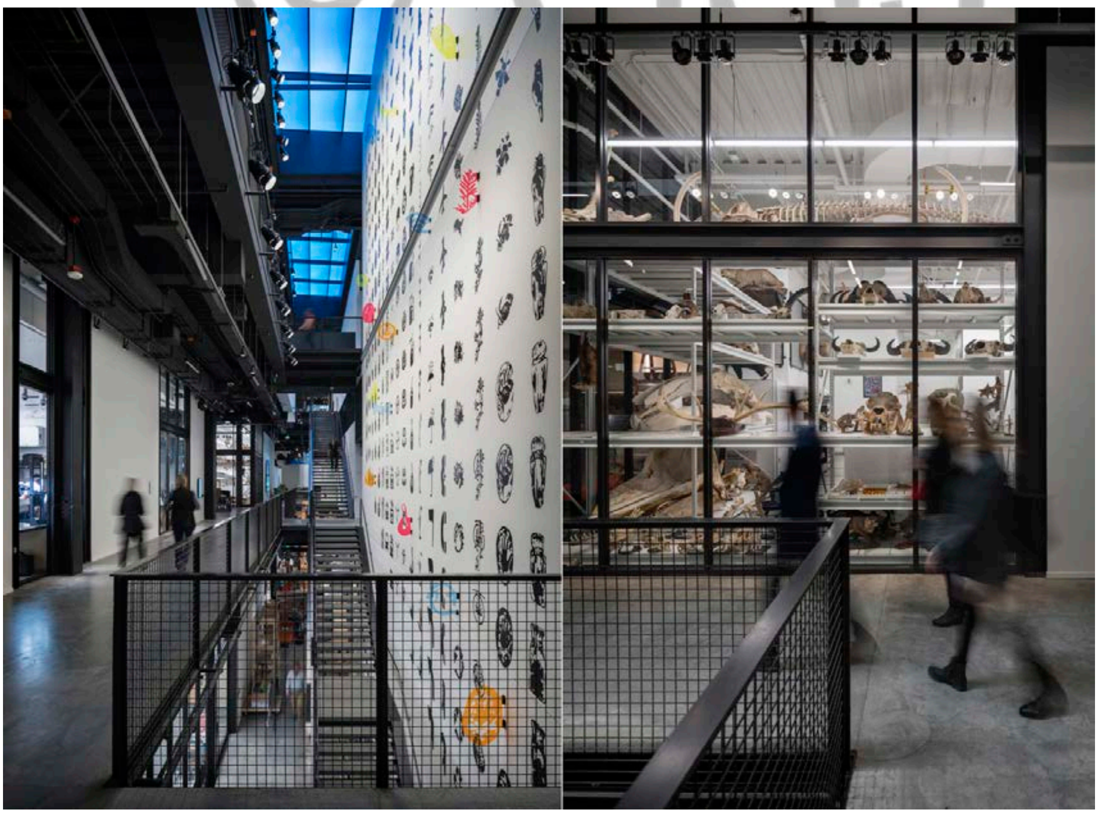

Figure 2.10 Smart use of treated reflected ceiling and spot light to give clear emphasis to images on walls. Image Source: (Aaron, Mikel, & Olson) as cited in (Pintos, The Burke Museum, 2021)

2.4 Baoji Bronzeware Museum

Architects: Architectural design-and research institute of Tianjin University
Address: Shigu Garden, Weibin District, Baoji City, Shaanxi Province, China
Area: 34100m2
Year of completion: 2009.

The form expressed high platform door and bronze thick soil. The use of full glazed flat roof skylight and glass walls in the open exhibition space, not only flooded the area with natural light but also allowed the visitors to feel the look of the beautiful high mountains and surrounding water bodies.

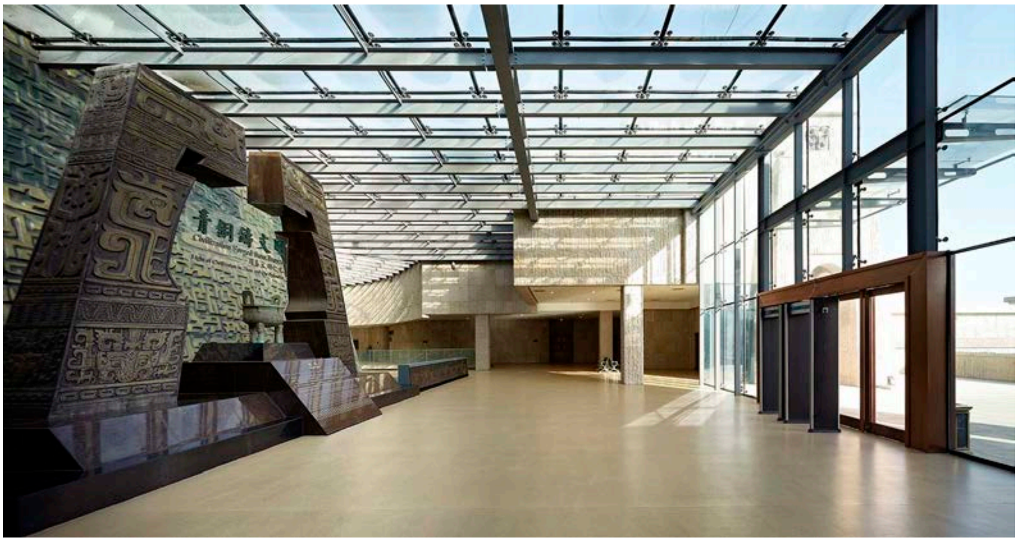

Figure 2.11 Combination of full glazed flat-roof skylight and glass Walls for natural/daylighting. . Image Source: (Chen) as cited in (Shuang, 2020).

The designer adopted a series of local characteristics and historical inheritance to express 'form, order and space in Architecture'

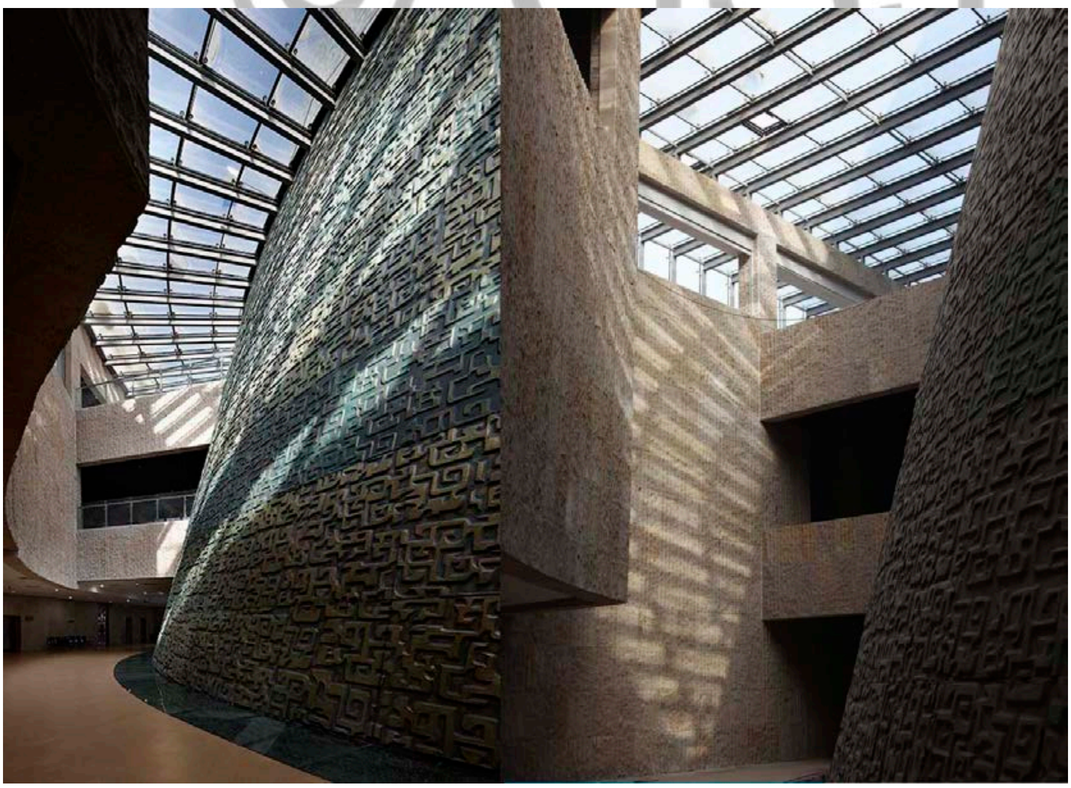

Figure 2.12 Corridors with clear efficient glazed skylight avoiding the need of Artificial lighting during the day. Image Source: (Chen) as cited in (Shuang, 2020).

2.5 Kunsthaus Zürich Museum Extension

Location: Heimplatz 1, 8001 Zürich, Switzerland
Architects: David Chipperfield Architects
Area: 23300 m²
Year of completion: 2020

The new Kunsthaus Zürich extension expands the existing Kunsthaus museum , situated between the Grossmünster church and the university. The Kunsthaus Zürich now represents the largest art museum in Switzerland, comprising four buildings from different eras – the Moser building (1910), the Pfister building (1958), the Müller building (1976), and now the Chipperfield extension (2020). The new freestanding building houses the collection of classic modernism , the Bührle collection , temporary exhibitions, and art from 1960 onwards. The urban concept for the extension envisaged the placement of a clear geometric volume on the northern edge of the square. The building form takes inspiration from the old cantonal school, built in 1842 to the north of the site, which defines the urban frame with its architectural clarity.

Figure 2.13 Excellent combination of Luminaires and daylighting full glazed wall to illuminate the hallway/exhibition space. Image source: (Noshe) as cited in (Pintos, Kunsthaus Zürich Museum Extension / David Chipperfield Architects, 2020)

Figure 2.14. Brilliant use of reflective ceilings as an artificial lighting strategy to litup exhibition space Image source: (Noshe) as cited in (Pintos, Kunsthaus Zürich Museum Extension / David Chipperfield Architects, 2020)

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The internal organisation is based on the concept of a 'house of rooms'. This idea finds its expression in the different designs of the rooms in terms of size, orientation, materiality, and lighting, giving each its own character and creating a diverse sequence of spaces. The varyingly dimensioned exhibition spaces are characterised by calm materiality and an abundance of daylight – side light on the first floor and skylight openings on the second floor – placing the immediate experience of art at the centre of the visitor experience.

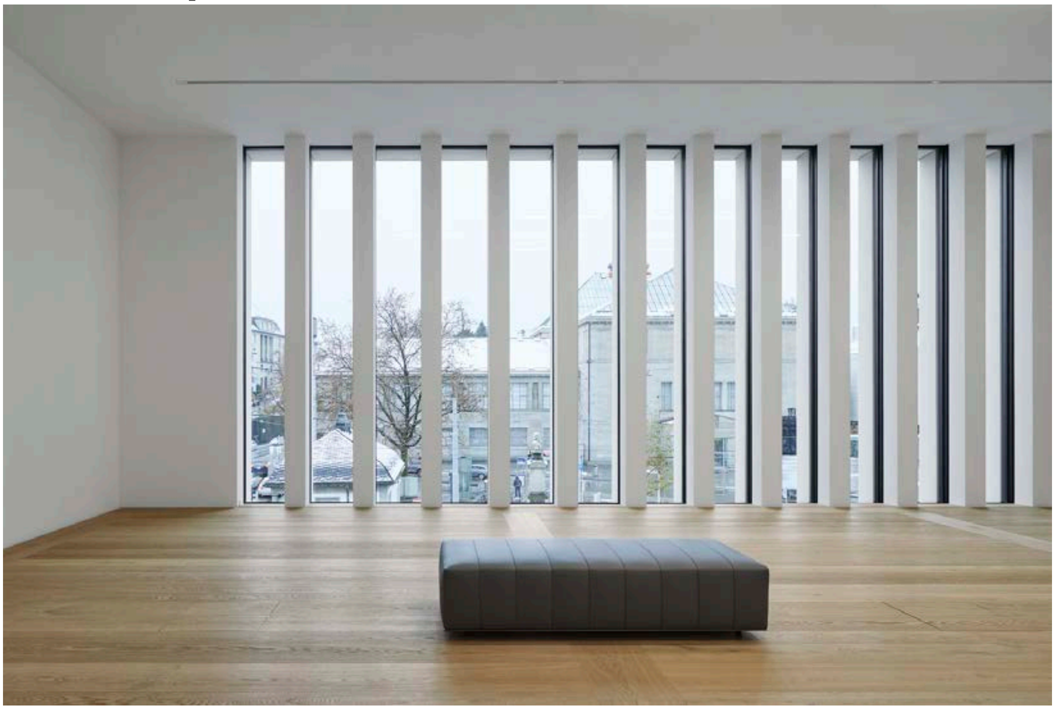

Figure 2.15 Use of South-facing Horizontal windows as an efficient daylighting strategy for exhibition. Image source: (Noshe) as cited in (Pintos, Kunsthaus Zürich Museum Extension / David Chipperfield Architects, 2020)

2.6 Royal Academy of Arts, London, UK.

The Royal Academy of Arts (RA) is one of the oldest arts institution in Britain. The acquisition of 6 Burlington Gardens enabled the RA to extend and expand its facilities to the north of Burlington House. The Laboratories Galleries are daylit through the original clerestory windows. The windows were re-glazed and a re-directing film applied to them. This system ensures that exhibits are uniformly illuminated with diffuse daylight. Circulation spaces are lit by custom luminaires which provide general lighting.

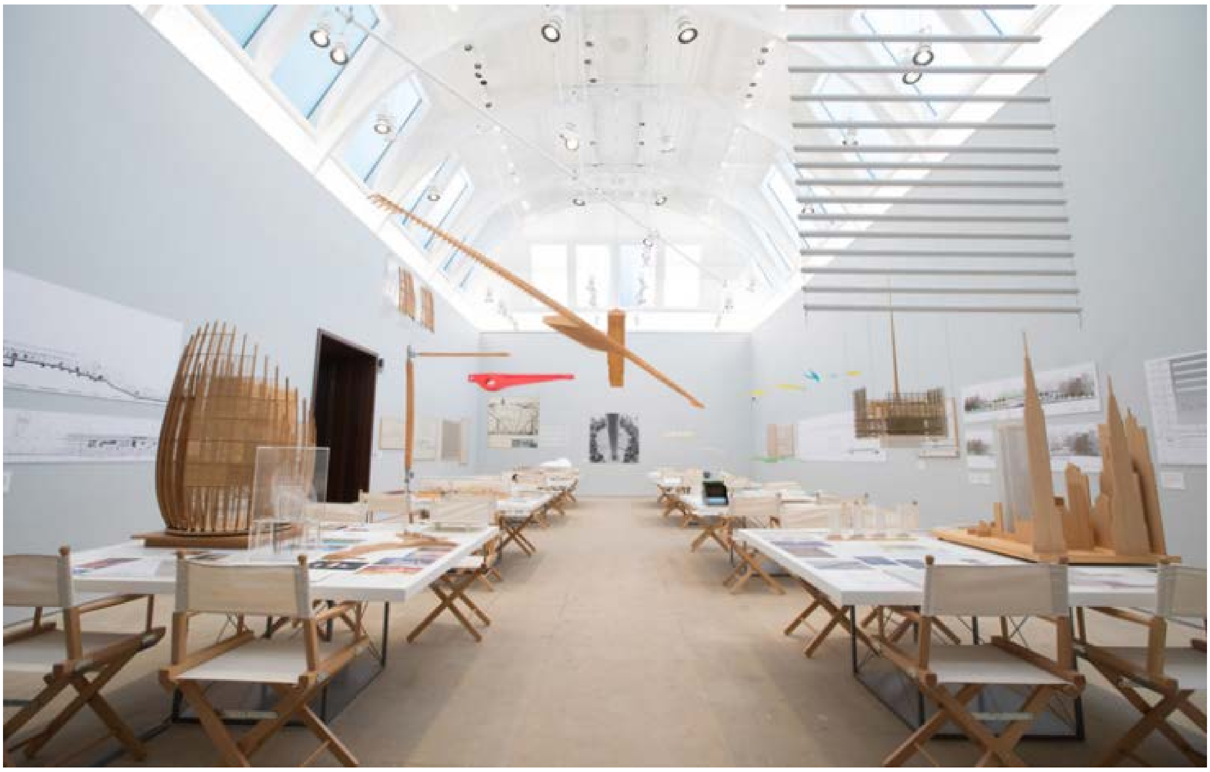

Figure 2.16 efficient use of double clerestory toplight as daylighting strategy in exhibition space. (Arup, 2021)

3.0 Control Systems

The control of daylight and electric lighting is fundamental to the success of any museum and gallery lighting installation. Control systems often need recommissioning to ensure energy and conservation objectives are being achieved. New light sources can also provide opportunities to simplify control systems and, where appropriate, to consider smart control systems that can respond to occupancy or user preference.

Reviewing the control of existing daylight systems or re-opening windows and skylights that have been obscured can lead to many benefits. The use of daylight within display spaces does however require careful consideration. When used successfully daylight can offset a considerable amount of electric lighting use. Daylight also has significant benefits for museum staff, where access to daylight and views can improve wellbeing and productivity. (Arup, 2021)

4.0 Recommendation

Museums and Galleries should be developed with lighting quality as a primary objective. This ensures that displays are experienced as the artist intended.

From an energy efficiency perspective, daylighting has a significant advantage over artificial lighting. At least 2.5 times as much air conditioning is needed to cool heating effects of the most efficient artificial light producing the same lighting level as daylight. Therefore, Architects should pay critical attention to the brief, putting into consideration the various kinds of art and antiquities to be displayed and creating a form and functional spaces that allows for the interior to be properly and efficiently litup; harnessing both natural and artificial lighting strategies where necessary.

5.0 Conclusion.

The introductory part of this research work exhaustively discuss what light and lighting in museum is. It also clearly states the aim and objectives of this research work. The second part, has given a clear answer to the research questions by revealing different methods of natural and artificial lighting strategies in museum through careful reviews of reports, case studies and existing publication on lighting in museums. It is important that any lighting system is fit for purpose: It should provide a quality and quantity of light that is appropriate for the environment in which it is being used; enable tasks to be performed efficiently and effectively; be perceived as comfortable and give people a high level of satisfaction. The aim is to achieve this whilst providing a good balance of cost and energy consumption through good design and optimum selection of products.

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