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Title: Bringing the Dynamic Qualities of Natural Light into Thorvaldsen's Museum Front Hall

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Abstract:

Thorvaldsen's Museum front hall works as a threshold between two realms – the outside streetscape and the inside of the museum, where Bertel Thorvaldsen's work is housed. The current arrival to the museum foyer is supported by a static lighting system that doesn't complement the dynamic qualities of daylight. The daylighting museum opened doors in 1848, where no artificial lighting was present, and therefore, this project will focus on applying a double dynamic lighting strategy to increase visitors' spatial experience and improve visitors' first impressions of the space. Dynamically illuminating this space's first impressions is the core of this project, where the grandeur of Thorvaldsen's work is to be seen under focused light and a changing ceiling light, for the most favourable perception of form. Ambient diffuse lighting and directional lighting tailored to the daylight inflow from side windows will be combined in a proposed lighting design that looks to achieve an optimal balance between the two and light modelling qualities that support the sculptural work representative of this solemn space. The double dynamic lighting concept for office environments will be translated to this specific cultural context that is the recently re-opened entrance hall of Thorvaldsen's Museum, for a better understanding of how to apply task and background dynamic lighting strategies for a differently tailored space.

Keywords: Thorvaldsen's Museum • double dynamic lighting • spatial experience • first impressions • ambient diffuse lighting • directional lighting • entrance hall

Content

Introduction 3

Background and vision 4

Thorvaldsen's historical significance 4

Design vision – potentials, problems and initial research question 5

Literature review 6

Analysis 10

The Space 10

The Lighting 16

The Daylight 20

Survey 20

Sunpath 21

Design intentions – within three criteria 23

Design proposal 24

Design evaluation 29

Findings and limitations 36

Future work 37

Conclusion 37

References 39

Introduction

This research project aims to design lighting that supports the overall experience of visitors by proposing an alternative design that seeks to heighten visitors' curiosity into taking their journey throughout the entrance hall of Thorvaldsen's Museum. It focusses on an entrance approach as it stems from the belief that the beginning is as important as the process, meaning that the first impressions towards a space are as relevant as the consecutive ideas one elaborates throughout the process of navigating a public building past the entrance hall. Drawing focus to the foyer motivates the guest to explore beyond that. Moreover, the first impressions of this space will influence the rest of their multi-sensory journey.

Thorvaldsen's front hall has recently been re-opened to the public and thereby my focus on enhancing the experience of the space and the sculptures. Besides marking a starting point in the museum tour, it also brings some social events to light. Therefore, it's of most importance to consider the space beyond its transitionary and preparation purposes, as it also represents a hub for creativity and gathering. As a symbol of Danish culture, and of neoclassical art, Thorvaldsen's Museum is of my choice to focus on, as a multi-sensory spatial experience that starts from the stranger in the street wanting to go into the solemn front hall.

The museum is designed as a daylight museum; therefore, the aim is to investigate how to complement the dynamic qualities of daylight, with a double dynamic lighting approach, to better serve the purpose of this space and bring it to life. By bringing in the skylight, night sky and flow of light into the room the arrival to the foyer will be felt differently and the aim is to give the visitors an immersive experience, more attuned to the outside world. Either to contemplate the sculptures or gather for coffee, or both, Thorvaldsen's Museum Front Hall is a place of stillness and appreciation, where the tone for the rest of the cultural journey will be set.

Background and vision

Thorvaldsen's historical significance

One of the most characteristic buildings in Copenhagen, houses the remains of Bertel Thorvaldsen himself, Thorvaldsen's own sculptures, models and drawings, and his extensive collections of paintings and antique objects. Opened in 1848 as Denmark's first public museum building, with grand architectural features to complement the neo-classical statues of mystical and historical figures.

Designed by Michael Gottlieb Bindesbøll, the building was constructed from 1838 to 1848 following contributions from the royal family, the municipality and a public collection of funds. Its architecture reflects the neoclassical style, marked by its monumentality, proportion, colours, texture, classical and decorative motifs.

In an era where absolutism was coming to an end and "Art was being propelled into the public arena as part of the democratic enlightenment of the common man."[1], Thorvaldsen's Museum was a reference to the democracy of antiquity and draws away from the idea that art was aimed at and for noble people – "The publicly owned museum represented a break with the former artistic monopoly of the monarchy and nobility." (Lange 2002). Moreover, "In *Die vier Elemente der Baukunst* from 1851 Semper says that polychromy is the obvious expression of the spirit of Greek democracy. Thus the powerful colours in Denmark's first public museum building also have symbolic meaning.", also marks the democratic symbolism behind Thorvaldsen's Museum and how it has remained a colourful statement in the Copenhagen townscape, standing out from the colourless buildings in its surroundings. (Lange 2002).

"The compilation of historical and mythical references was intended to give the visitors the stimulation they needed, increase their psychological growth and strengthen their national and personal ego. For that purpose the legibility of the building was essential. It was a museum for and by the people and the exterior decoration was, according to the architect, 'an invitation to the man in the street and the vestibule a gateway to enjoyment'."[2]. This citation marks well the intention behind the neoclassical-style building with its own unique flair and roman baroque, Etruscan and Egyptian influences, that unites architecture, sculpture and painting for those in seek of enlightenment.

With a layout centred around a courtyard, reminiscent of roman villas, the museum is a building like no other with vibrant colours and a frieze – Sonne's Frieze – depicting Thorvaldsen's triumphant homecoming to Copenhagen in 1838 on the north side and dockworkers transporting his artworks on the east and south sided facades.

From carriage depot to art museum, Thorvaldsen's Museum is a democratic, artistic manifesto where Greek harmony, Roman grandeur, Baroque exuberance, Egyptian-inspired interiors and Etruscan vibrancy collide, joined together as a whole and total artwork – "Bindesbøll had created a *Gesamtkunstwerk"* (Lange 2002). It's an eclectic mix of antiquity with democratic symbolism, marked by ornamentation and strong, refined earthy colours – ochres, reds, deep browns *caput mortuum*, blue, greens and black as a background colour and for window bevels. These *caput mortuum* and ochre tones, used in roman frescoes and Pompeian walls, and even in renaissance paintings, also evoke ancient Etruscan and Egyptian art.

Design vision – potentials, problems and initial research question

The west facing public hall has big potentials in improving daylight intake and visitors flux if the main five doors were to be open at all opening times. However, because they're closed, the entry door is lateral and slightly hidden, therefore altering the magnitude of the entrance experience. However, the need to go around the building to enter the museum front hall provides a certain suspense to the overall experience and postpones the act of entering, which leads to people wondering and creating scenarios of what they're about to see.

The space appears dark on overcast days and there's a big contrast of what it feels to be inside it when it's overcast than when there's direct sunlight. Whilst the direct sunlight barely permits it to contemplate the statues due to glary sunrays, the ambient skylight is insufficient and weakly complemented by artificial lighting.

Given that the museum was built for daylighting, its lighting design should complement its changeability. Moreover, the current lighting fails to light the ceiling and therefore bring a proper ambient light into the room during and after opening hours.

Furthermore, my vision is evident in my initial research question – imagine if I could light this public space in a way that would make visitors have the urge to continue their journey when inside the front hall but also support Thorvaldsen's work and the activities unfolding there after opening hours. In light to this, a lighting design concept is here investigated with the aim of complementing daylight with artificial lighting and use it as a basis for a dynamic lighting strategy, where both ambient and directional lighting are present as a double layered lighting proposal.

Literature review

A literature review was conducted regarding daylighting uses through time, Thorvaldsen's Museum historic background, its architecture, use of colours and light, investigations of museum foyers and double dynamic lighting as a design strategy to enhance users' spatial experience. These key ideas are important to the task at hand of proposing a more responsive design to daylighting changeability for the museum foyer as a transitionary and gathering space. An understanding of how daylighting was approached before artificial lighting, the importance of foyers and dynamic lighting strategies, as well as Thorvaldsen's Museum history and architecture, are of importance for the scope of this project.

Moore (1985)[3] explores the historical use of daylighting in architecture and its evolution through various periods, from pre-industrial times to the post-modern era. It examines how different cultures, and architectural movements have utilized and perceived daylight, influenced by climate, technology, and cultural values. Daylight was admitted in past architecture where it was wanted, and openings were given special prominence within the structure. Ancient Egyptians minimised openings due to intense sunlight. In ancient Greece, temples and monuments were designed to be viewed from the outside and not to be inhabited and "the extensive use of columns on the exterior (as well as the interior) created colonnades and porticoes for protection from the warm summer sun and sudden winter showers." Greek temples also featured coffered ceilings above the colonnades, where abundant reflected light was needed to reveal these forms. They were usually east oriented to illuminate the sculpture at sunrise through doorways. It was once believed that large roof openings were essential to provide additional direct sunlight for the statues, however recent findings suggest that door openings were the sole source of interior illumination. "Because of the relatively small opening spans, this illumination was characterized by narrow shafts of direct sunlight at low sun angles (morning) and more diffuse sky light and reflected ground light during the remainder of the day". Courtyards to the south were also used for increased sunlight and winter solar penetration. In contrast to the Greek small openings and use of colonnades for protection from the sun, in ancient Rome, "The development of the round arch, barrel vault, and dome allowed masonry materials (inherently weak in bending) to be used in compression for large spans. In addition to allowing larger uncolumned interiors, this created the potential for large wall openings that could admit great sheets of light". Romans developed the use of glazing materials and other strategies for daylight illumination given the many monumental public buildings built.

Lange (2002) examines three core elements of Thorvaldsen's Museum, its architecture, colours and light. It analyses the building's innovative layout, including its central courtyard and natural light optimization, highlights the bold use of polychromy, challenging the monochromatic norms of Neoclassicism and approaches the use of

focused light and projector-like light. The interplay of light and colour transforms the museum into a living space. It reflects Denmark's golden age values, bridging art, architecture and national identity. It explains the entrance to the museum and how the side entrance became the main entrance, because the entrance through the five portals became somehow impractical and were only opened on festive occasions. Moreover, how the asymmetry of the slanted five portals with Etruscan influences give dynamism to the building façade. Focused light was a preference referred to in this book and given to the rooms by Bindesbøll as it was the light known from ateliers, to emphasise that Thorvaldsen's art was not an open-air sculpture, but rather to be viewed under concentrated light that gives the sculptures shadowing and a precise impression of form. "*The light is about as high and wide as in his large studio*", and the projector-like light was also referred to as the general type of lighting for artists' studios, including Thorvaldsen's own atelier at the Academy of Fine Arts at Charlottenborg Palace. The building is referred to as being a light fixture itself and the afternoon light is said to be the best, where "Light streams into the rooms like a 'fabric' and the floor mosaics gleam in the sunbeams.". "Bindesbøll made it a rule that the heads of statues would receive the most light.". Moreover, in the entrance hall "Square window holes were cut in the vaulting to illuminate the Alexander frieze".

Jørgensen (1984) discusses the establishment and design of Thorvaldsen's Museum in Copenhagen, emphasizing its role as a national cultural monument during a period of crisis – "Denmark needed a symbol, a cultural monument to strength the national awareness, and the building of museums was then, as it is today, the contemporary means to achieve this end.". Furthermore, it is said that "In Rome Thorvaldsen stated that in his view sculpture in a museum should be seen under the same lighting as that in the artist's studio. Side-lighting for reliefs, and a high and broad source providing light from one direction only for statues since more than one source of light prevents the most favourable perception of form.". The vestibule is described as "a portico for pleasure and ease for the visitors, decorated with Thorvaldsen's sculptures." Bindesbøll aimed for a museum that prioritized the display of art over grand architecture, reflecting Thorvaldsen's vision of simplicity – "four walls and a good light." Despite all challenges, the museum became a symbol of national pride, promoting art, education and accessibility, with Thorvaldsen's collection of 356 items at his death.

Laursen, D. et al. (2016)[4] investigates museum foyers as transformative communication spaces, identifying four key functions: arrival, orientation, service, and preparation during entry, and preparation, service, evaluation, and departure upon exit. It describes foyers as dynamic environments that shape visitors' experiences rather than just mere physical entities and advocate for a nuanced approach to museum communication, highlighting the need for museums to enhance visitor engagement through effective foyer design and service strategies. Qualitative studies of varies foyers existent in two

art museums, two cultural history museums and a science centre, all of which are in Denmark, were conducted, to which the authors revealed foyers to facilitate visitor transformation from non-visitors to visitors and back.

Youssef (2020)[5] explores the role of artificial lighting in emphasizing entrances to buildings, highlighting their importance regarding users' experience and architectural design. Defined as a threshold between two realms – "the first is an outdoor exposed to climatic change, hazards, and environmental factors, while the second is controlled, monitored, and determined to certain functions." – entrances shape first impressions of visitors when faced with the interior space of a building past the first realm and influence how one perceives the building's functions and aesthetics. It uses scientific methodology to evaluate entrance approaches, including identifying effective lighting techniques for entrances, its geometrical types – frontal, oblique and spiral – and design elements – materials, colours, style, entrance form, dimensions and location, structural elements and ornaments –, that serve to emphasize and contribute to the overall identity of the building.

Hansen, E. K., & Mathiasen, N. (2019)[6] investigate the integration of daylight dynamics – specifically the ratios of direct warm sunlight and diffuse cold skylight – into dynamic lighting design for open office environments. The direct warm sunlight and the diffuse cold skylight are the two daylight components regarding naturally changing sky conditions and the two variables when designing dynamic lighting to supplement daylight in the interior space. Double dynamic lighting has its primary focus on the distribution of light, with its variations in light intensity and correlated colour temperature.

People desire variation in light as they are predisposed daily by the natural dynamics of daylight. Similar parameters ought to be considered for dynamics in electrical lighting for lighting design strategies. How can people's needs be met for variation and light modelling qualities? Daylight is not a constant flow of light, but rather dynamic, varying with time and place. Changeability is crucial and our senses respond to change, not to unvarying conditions. So, a continual variation of brightness in a room is stimulating and desirable.

The light modelling concept refers to the balance between diffuse and direct light and its impact on visual perception. It determines the capability of the eye to detect objects in a space and discriminate contours, shapes and details. This concept is imperative for creating visually stimulating environments, as it affects how shadows and textures are perceived, enhancing the three dimensionality and overall appearance of objects.

The study reveals that human preference for light variation is often overlooked in standard lighting practices, which typically focus on uniformity. Through literature reviews and experiments involving four CIE sky types, the authors establish that a

balanced combination of direct and diffuse light enhances visual comfort and well-being. Findings suggest that optimal light modelling occurs with direct lighting ratios ranging from 13% to 52% – "The qualitative balanced light modelling has direct lighting in a range of 13-52%." –, achievable in standard office environments by adding a relatively small amount of direct light with the same directionality as daylight from a window (flow of light) – "(…) a light source creating a direct light with the same directionality as the daylight from the window and thereby supporting the flow of light as well as creating a more distinct light modelling and shadow pattern.". "Frandsen suggests that the diffuse light is combined with directional light where the angle of the directionality of the beam of light is between 11.5° - 40°.". The core hypothesis is that different combinations of diffuse and direct light can define much of the natural variation and light modelling qualities of daylight.

The study refers to how cloud coverage can affect the character of the light, that can differ dramatically from a clear blue sky, causing shard-edged shadows, to an overcast sky, causing diffuse and soft shadows. The directional and diffuse light condition of the CIE8 sky type was referred to be the closest to the best light modelling of an object, characterized by a clear directionality of light, a clear shadow pattern, without overexposure of light. It is also stated that even with the absence of direct sunlight in the space, the interior daylight illumination presents a distinct directionality, therefore being concluded that the diffuse daylight also produces a flow of light, related to the position of the window opening. The directionality of the light within CIE8 sky type is 13% and CIE13 sky type is 52%, therefore the mentioned earlier direct light in a range of 13% to 52% to be the optimal to create a well-perceived light modelling. With a standard diffuse ceiling lighting by adding at least 13% or more direct light on the work plane, the light modelling qualities can be achieved in office environments.

Hansen, E. K., Bjørner, T., Xylakis, E., & Pajuste, M. (2022)[7] investigate the effects of a double dynamic lighting system in an office setting, integrating electrical lighting that responds to daylight variations. The core idea is to test the interplay between dynamic daylight and electric lighting to inform design strategies. The double dynamic lighting design uses task lighting that complements daylight inflow, varying direct/diffuse lighting, and colour temperature responding to sky conditions.

Tridonic, Fagerhult, iGuzzini, Zumtobel, & Aalborg University Copenhagen. (2020)[8] present a novel approach to office lighting that mimics natural light variations. The Double Dynamic Lighting (DDL) concept seeks to improve office environments by integrating qualities of natural light through advanced, responsive lighting technology. This approach moves beyond static illuminance requirements by actively considering sky-type and daylight inflow, creating a dynamic office lighting experience. The core inspiration comes from direct warm sunlight and diffuse cool skylight, combining directional task lighting and diffuse ambient lighting to mimic natural luminous

variations. Initial studies investigated how direct and diffuse lighting components enhance visual qualities like flow of light, light modelling effect, and personalized light zones. Subsequent experiments defined the ratio of direct to diffuse lighting and correlated colour temperatures (CCT) that contribute to a favourable work atmosphere under different sky conditions. A field experiment was conducted over four months in a real office environment, comparing seven different light settings to static lighting. The study used live sky-scanner data and illuminance sensors to adjust lighting settings based on sky conditions and illuminance levels. Participants described the DDL concept as having a naturalness similar to daylight. “Direct light source with (warm) 3000 K, referring to the warm sunlight as a standard.” and “Diffuse light source, representing the ambient lighting with different colour temperatures; for overcast, (neutral) 4-5000 K, and for clear sky (cooler) 5-6000 K, to contribute to perceived atmosphere.” are specified in this paper.

Analysis

The Space

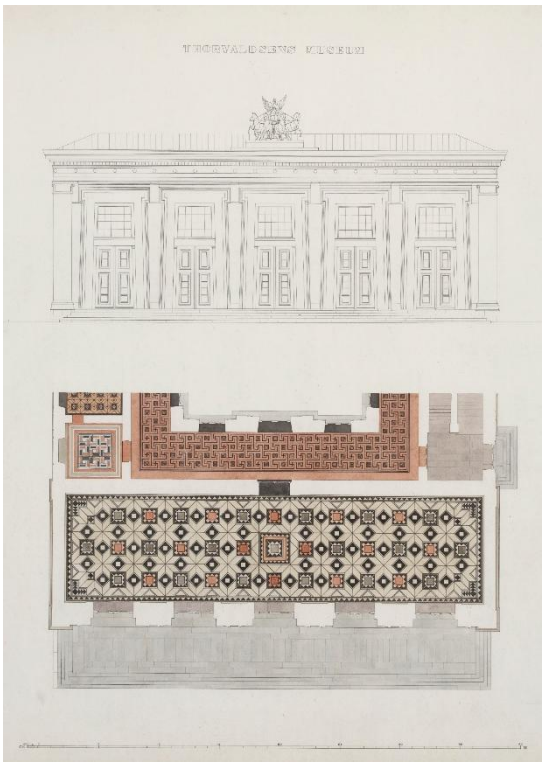

Figure 1 Top view and façade front view

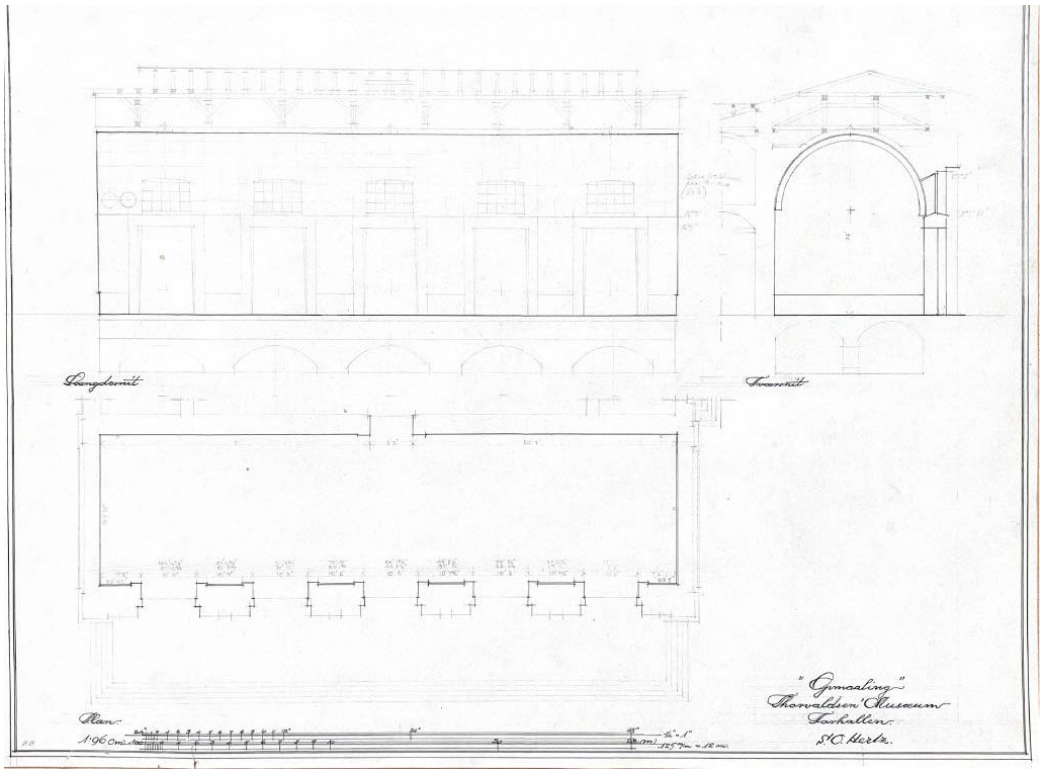

Figure 2 Front, top and side views

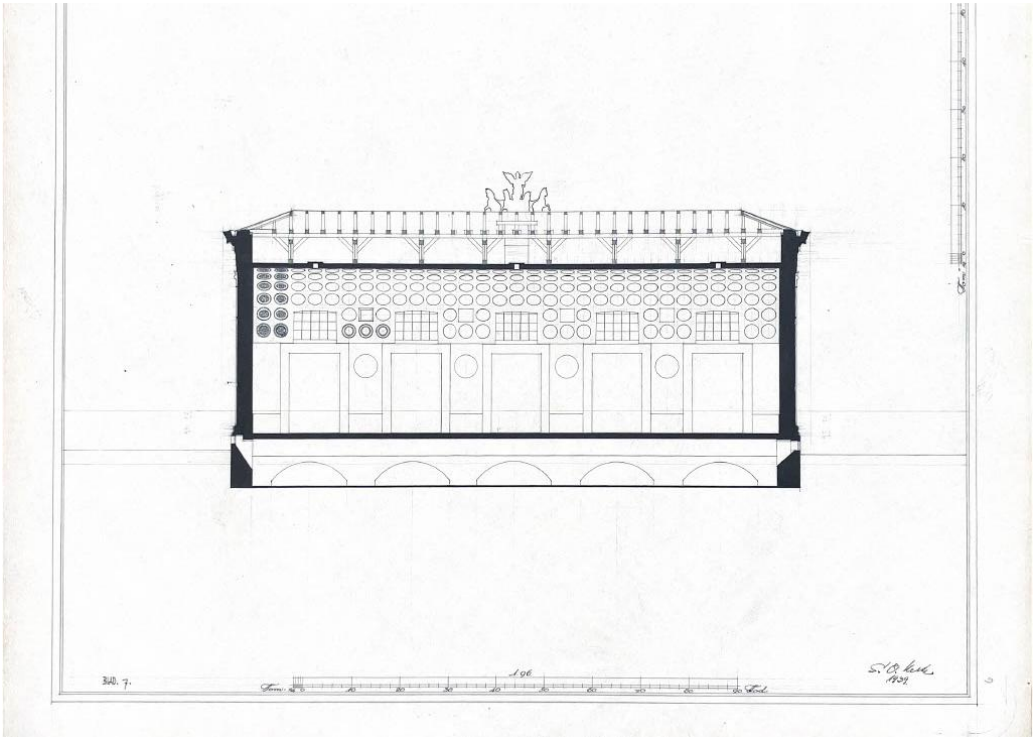

Figure 3 Front Hall section

Figures 1, 2 and 3 show plan views and section of the front hall at different scales. Measurements are indicated and were imperative to model the space on Dialux evo.

These drawings were obtained through *Det KGL. Bibliotek* platform and at Søborg Study Room.

Entrance hall, foyer, vestibule, portico, lobby, concourse are all words of identical meaning. They all describe an entrance to a public building and carry therefore the same purpose. A threshold between the outdoor environment and the indoor environment, a passageway that welcomes visitors to explore the inside of an architectural building and determines the tone of its first generated impressions.

An entrance hall is a transformative space where a non-visitor becomes a visitor as soon as it enters and marks the beginning of its journey throughout a built environment. Its responsibility to set the tone and prepare the guest for the consecutive journey is dependent on a foyer's atmosphere, and such will influence the visitor's approach towards an architectural space.

A solemn and dignified atmosphere like the one in Thorvaldsen's front hall will compel a guest to act respectfully when visiting the museum. The front hall acts as a bridge between the busy streets and the solemn contemplation of artworks, and is, therefore, responsible for setting the right mood for someone who just entered the space, yet to be explored further into the inside. Furthermore, it represents a starting point that provides orientation regarding on what's yet to unfold.

These so called first impressions in the context of a space stem from our immediate sensorial responses, formed rapidly and influenced by architectural elements like lighting, colours, textures, sounds, scents and the overall perceived ambiance. These subconscious reactions influence how we emotionally and behaviourally engage with a space and are therefore very impactful to a visitor spatial experience.

Illuminating first impressions suggests the illumination of the space that is pivotal to users' first sensorial experiences – a foyer – where first ideas of a building will be mentally and emotionally noted and taken into the rest of the spatial journey as a first generated thought, yet to be elaborated. Experiences in the illumination phenomenon described by Böhme, in which "spatial/light effects and the way in which objects are illuminated combine to create a specific atmosphere during the sensual, bodily experiencing of space", illustrate the role of illumination in giving shape and nuance to a built environment. In light to that, the way an environment and its objects are shaped and seen in light will influence how they're lived by its visitors, therefore dictating their impressions of the space and consequently how they engage with it.

The arrival into a space encompasses various elements, including the transformative experience, the impact of light, and the multisensory interactions that shape perception. Entering a space, such as a museum foyer, initiates a transformation from non-visitor to visitor. The architecture and atmosphere of the space, whether solemn or

inviting, influence the visitor's initial impression and behaviour. Visitors often pause to observe their surroundings and orient themselves within their social group.

Light plays a crucial role in shaping the spatial experience. "Light-cleared space" (Böhme 2014) allows for visual investigation and creates a sense of security. Artificial lighting further emphasizes the entrance, influencing a visitor's perception and anticipation of the interior. The strategic use of light can direct attention, enhance architectural features, and evoke specific emotions.

The act of entering a space involves more than just visual perception, meaning it is a multisensory experience that engages the body and influences our understanding of the environment. Approaching and confronting a building and the act of entering contribute to the overall architectural experience. The interplay of senses, such as sight, touch, and sound, enriches our perception and reveals the invisible dimensions of the space.

The space at hand, portrayed in figures 4 to 9, is marked by the wide domed and ornamented ceiling, Alexander Frieze, red, blue and amber-like hues, mosaicked floor, gathering spaces, Thorvaldsen's sculptures, vaulted windows, glass doors and soft daylight complemented by the warm-coloured lighting. Its purpose of acting as a bridge where the outside and inside meet, by welcoming visitors and setting the tone for their journey into the private building has space for improvement, following the identified problems and potentials in the design vision chapter. The entrance route is visible in figure 10 and portrays the current entrance through the south facing side of the building. According to Youssef (2020) paper, the entrance geometrical type in question could be classified as oblique or spiral depending on where the yet non-visitor comes from. However, if the entrance were to be through the front hall, its geometrical type would be frontal and the experience of arrival contrastingly different.

Figure 4 Front Hall

Figure 5 Front Hall

Figure 6 Front Hall

Figure 7 Front Hall

Figure 8 Front Hall

Figure 9 Front Hall

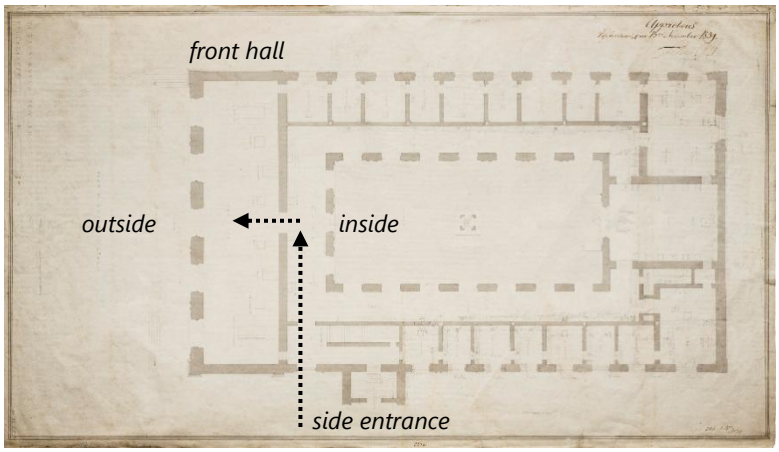

Figure 10 plan view and entrance route

Furthermore, the current colour temperature of the existent projectors is too warm compared to the light coming from the side windows on overcast days. This creates a big contrast on the sculptures, where one side is naturally and softly lit, and the highlighted patterns are soft and white coloured, and the other side is artificially lit with too warm correlated colour temperature providing the yellowish highlighted patterns. The contrast is unnatural and should be neutralised, as it is evident in figures 11 to 15.

Figure 11 Sculpture artificially lit

Figure 12 Sculpture artificially lit

Figure 13 Sculpture naturally lit

Figure 14 Sculpture naturally lit

Figure 15 Sculptures with yellowish tones

The Lighting

Lighting at Thorvaldsen's Museum Entrance Hall is provided by projectors on a black track system, as shown in figures 16 to 21, from ERCO manufacturer. Projectors pointed at the sculptures and reliefs highlight them in a warm coloured light. Additionally, there are also in-track spotlights on each of the five portals centred in the middle of each door, turned off during open hours, at least during the summer schedule.

All projectors, except for the ones signalling the doors, are lit up during opening doors, serving as accent lighting for the sculptures and reliefs. Therefore, one can state that lighting is not doing much in terms of uniformity in the room, but rather just providing accent on artwork. After opening hours, only half the projectors are turned on. Some have honeycomb, and some don't, causing a slight glare. It's a static lighting system that doesn't complement the space and daylight entering the room.

Analysis to measure the existent artificial lighting was conducted, by measuring the average illuminance in the room on an overcast day, on the 23rd of April 2025, at midday. "When measuring the average illuminance over an area, such as a horizontal working plane, mark out a regular grid and measure the illuminance at the required height at the centre of each grid cell. Then calculate the arithmetic mean of these."[9]. A calibrated lux metre was utilised to measure illuminance at each point in the room, 75 centimetres distance from the floor. The mosaicked floor was used as a reference for each grid cell, five steps distance from each point. The mean illuminance value obtained was approximately 147 lux, noting that the lights were turned on when illuminance values were measured. Figure 22 shows the values obtained and the corresponding mean illuminance value (146.55), which is slightly low given the time of day and year.

Artificial light only on moderately sensitive materials can go up to 200 lux, as described in table 1, by Tregenza, P., & Loe, D. (2014), which will be taken into consideration in my lighting design proposal.

Furthermore, wall reflectance at a point was calculated with both incident light and reflected light values measured, as shown in figure 23. The dark red wall shows an expected low reflectance value of 4% at a point in space, on the entrance hall background wall. The formula used was that of the reflected light value divided by the incident light value, multiplied by 100% to give out the value in percentage. A calibrated lux metre was used to conduct the analysis, approximately 75 centimetres above the ground. Incident light was measured by positioning the lux metre close to the wall and facing forward. Reflected light was measured by positioning the lux metre facing backward, with the light diffusor facing the wall.

The low reflectance value suggests that lighting the wall can be visually risky as to how marked it might look, due to possible harsh scalloping. Moreover, contrast issues are to

be taken into consideration, given that the adjacent sculptures have a higher reflectance and when lit, can provoke unnaturally shadowed or flat walls.

The existent lighting design system lacks the dynamic qualities of natural daylight, which changes in intensity, colour temperature, and direction throughout the day. This leads to the environmental space at hand feeling artificial and sterile.

After an interview conducted with the worker in charge of dealing with the lighting, some information was gathered. Firstly, as it was mentioned previously, half the fixtures providing illumination to the artwork stay on during dark hours, so that passers-by can have a look at what's inside the front hall. The exact specifications of these ERCO in-track spotlights are unknown to him. However, the product at hand is the *Parscan* spotlight with a 149 millimetres diameter from ERCO, as shown in figure 24. All fixtures in the room always maintain the same position and are scheduled to stay on from 5am to 11pm daily. There are no fixtures lighting up the ceiling and therefore, no diffuse lighting is present in the room to complement the directional lighting, and ultimately the dynamic daylight. Lastly, the wired switchable system has a centralized timer (Paladin) for scheduling, combined with a retrofit wireless control solution, most likely a Casambi Bluetooth-based system, that isn't and never was in use.

The Paladin timer represented in figure 25 is used for basic scheduling, turning lights on/off at the set times. The system is 15 to 20 years old, and the timer is the primary control, with the possibility for a wireless app as an optional add-on for remote adjustments, which as known is not in use.

Figure 16 Lighting fixtures

Figure 17 Lighting fixtures

Figure 18 Lighting fixtures

Figure 19 Lighting fixtures

Figure 20 Door lighting fixture

Figure 21 Relief and artwork lighting

			87		74	50				190	186	150	86		70		117	141		31	32		33	1247
			190	166	195	92			121	156	160	123	200	177	122		176	130	132	65	33	38	38	2314
			233	286	190	129	134	174	185	195	125	144	193	185	178	144	188	174	116	113	48	39	36	35	3244
			235	230		123	90	116	153	205	170	78	130	195	150	184	119			165	62				2405
166	175	67	110		192	175	61	90	184	271	120	87	75	166	267	118	104	102	157	199	120	58	47	55	3166
			72	129	190	195	178	161	65	343	155	195	111	153	422	138	200	80	106	340	169	130	34	42	3608
32	62	405	58	43	39	128	490	85	48	40	424	449	412	49	52	190	490	126	50	60	380	235	78	108	4533
																									146.55

Figure 22 Mean illuminance

5
125
4%

Figure 23 Reflectance at a point (%)

Table 13.1
Recommended illuminance and light exposure values

Type of exhibit	Maximum illuminance, lux	Maximum annual light exposure[1], lux-hours	Other considerations
Objects insensitive to light, e.g. metal, stone, glass and enamel	None	None	Beware of heating, visual adaptation and glare
Objects moderately sensitive to light, e.g. oil and tempera painting, fresco, lacquer and wood	200	600,000	Ultra-violet radiation control
Objects highly sensitive to light, e.g. textiles, water colours, tapestries, prints, manuscripts and natural history exhibits	50	150,000	Ultra-violet radiation control

1 Based on an exposure time of 3,000 hours per annum.
This requires the gallery to be in darkness outside gallery opening hours.

Table 1 Recommended illuminance and light exposure values, Tregenza, P., & Loe, D. (2014)

Figure 24 Parscan Spotlight

Figure 25 Paladin timer

The Daylight

For means of calculating the daylight in the entrance hall, the daylight factor was conducted. Noting that, "A daylight factor is the ratio of the amount of light in a room to the illuminance on the ground outside under a CIE Overcast Sky. (…) The daylight factor is defined more precisely in this way*: D* = $\frac{Ei}{Edh}$ x 100% where *E*i is the illuminance on a surface in the room, and *E*dh the simultaneous illuminance from the whole sky (the illuminance on an unobstructed horizontal surface outside)." (Tregenza, P., & Loe, D. 2014). The results, as shown in figure 26, show insufficient daylight intake and therefore, the room is mainly poorly lit, with moderately lit spots in the room where ≥2% values are observed. The daylight factor analysis was conducted on the 4th of March 2025 at 1pm, under an overcast sky. Posteriorly, the mean illuminance calculated was of 80 lux, which confirms that daylight alone is insufficient on overcast days.

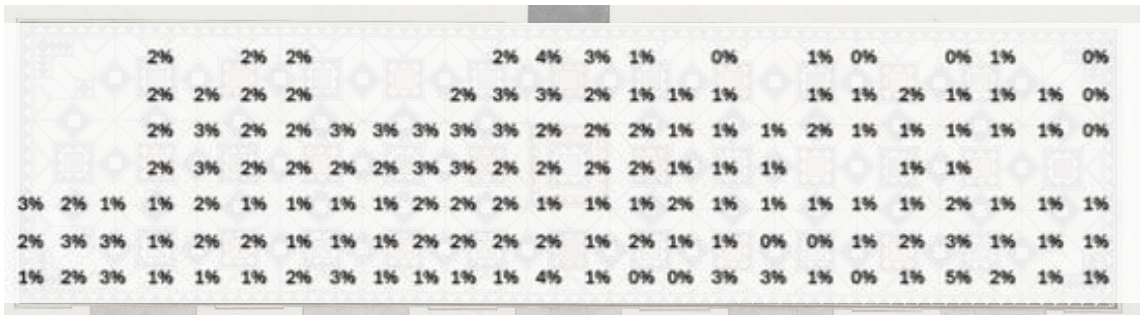

Figure 26 Daylight factor (%)

Survey

Figure 27 shows a survey that was conducted to the director of the museum, to have an overview of the purpose behind Thorvaldsen's Front Hall.

The purpose and need of this public space is therefore to “show the ‘grandeur’ of Thorvaldsen’s work, his inspiration from ancient Greece and Rome, and to make a reference to his workshop in Rome.”, and activities unfolding there after opening hours englobe talks, concerts, exhibition openings, sound baths and different creative workshops, which is when the space has use after its closing time – 5pm.

Figure 27 Survey

Sunpath

Sunpath diagrams were collected to have an overview of when the sun hits the foyer facing west on vernal and autumnal equinoxes. Equinoxes were chosen given that those are the variables gathered to test the design proposal, since they are representative of half the year where the sun path is symmetrical (equal day and night lengths). They serve as a baseline for solar analysis, by marking the midpoint between solstices, and therefore help assess moderate solar exposure before extreme summer and winter angles. Figures 28 and 29 show afternoon sun exposure, which is of help regarding when to complement the room with needed artificial and direct lighting – in the mornings –, or at least when higher intensity of such sort is required.

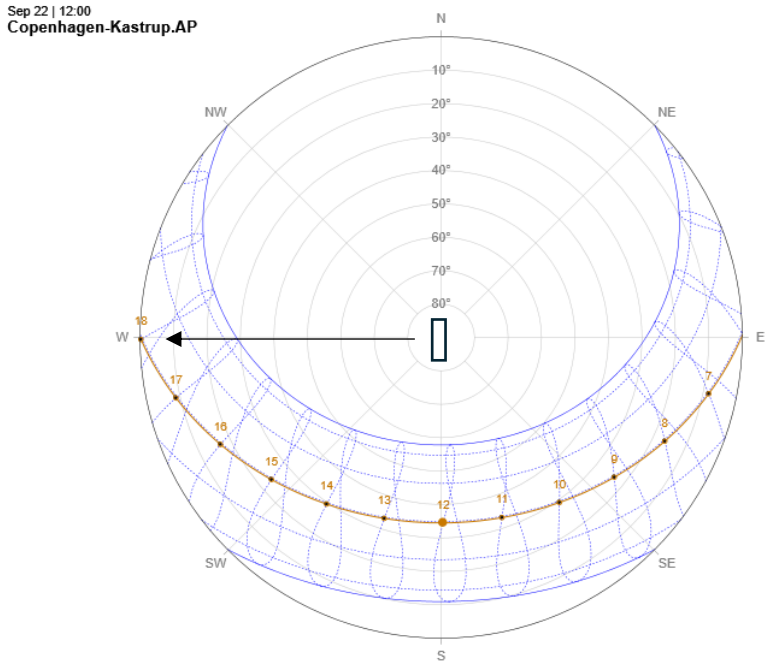

Figure 28 Sunpath diagram autumnal equinox

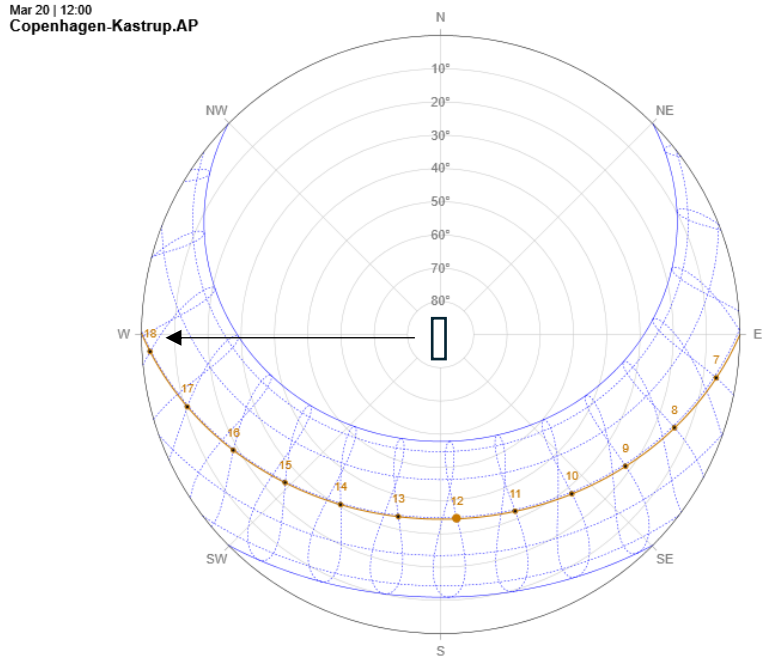

Figure 29 Sunpath diagram vernal equinox

Design intentions – within three criteria

The research question – How can lighting design support visitors' spatial experience, activities unfolding there after opening hours and the grandeur of Thorvaldsen's work by bringing in the dynamic qualities of daylight into the room? – englobes all three criteria and puts them into perspective.

Lighting design bringing the qualities of natural light into the museum foyer and creating a flow of light that provides the most favourable perception of form, represents the first hypothesis.

Living light represents the first criterion and provides the notion of movement into the space. By bringing in direct light tailored to the flow of light from the side windows and changes in intensity based on sky conditions and time of day, dynamic qualities of daylight are being complemented by artificial light. The directionality of light from projectors will be tested to find the right angle to light up the sculptures. According to the "Dynamic lighting balancing diffuse and direct light" paper, an angle ranging from 11.5º to 40º is ideal to create a flow of light, referring to daylight inflow from side windows. However, in this specific context, the aim is to illuminate the hight vertical sculptures, rather than a horizontal task area in an office environment. Tests will be conducted referring to overcast and clear skies at three times of day – 10am, 12pm and 5pm – and therefore, different levels of electrical lighting will be required to complement the variation in light distribution throughout the day under two different sky conditions. The direct light implemented will follow a ratio of 13-52% from directional lighting.

Lighting design bringing the qualities of natural light into the museum foyer and giving the room its needed ambiance, resonant of the changing skylight and constant night sky, represents the second hypothesis.

Living ambiance represents the second criterion and provides the notion of both stillness and dynamism into the space. The ceiling light – a 'living ambiance' that changes in colour temperature and intensity – resonates to stillness, and so does the night sky – a constant backdrop that grounds the townscape in serenity. Both evoke temporal constancy but are also resonant of mental calmness and visual simplicity. Even though it is something dynamic, the changing skylight is much like a flickering candle or a flowing river, that can create a sense of calm despite their inherent motion. A diffuse ceiling lighting will be added to the direct light from the first criteria, with varying colour temperatures depending on if the sky is either overcast, clear or dark. Different light intensities will be tested according to the time of day.

Lastly, the third hypothesis being how can lighting design naturally support the grandeur of Thorvaldsen's work?

Living sculptures represent the third criterion and enhance the need to give dynamism to Thorvaldsen's sculptures, by having the array of lighting fixtures in the room given the right position, so that sculptures get only lit from the side facing the windows and are left in shade on the opposite side, therefore neutralising the colour contrast mentioned in the analysis chapter and the consequent sterile effect. By removing the existent projectors placed on the opposite wall from the side windows the sculptures are being lit according to the flow of light.

The three criteria are based on the DDL principles used in a new way to light up sculptures and the historical space, rather than an office environment as in the DDL papers. The focus is on translating these principles to Thorvaldsen's Museum front hall.

Design proposal

Following my design intentions, I propose a design that brings in the flow of light, with directional lighting to light up the sculptures, and the skylight, with diffuse ceiling lighting to provide ambiance, into the room. Additionally, accent lighting will be provided as it is originally to light the four small statues and reliefs in between the doors along with signalling the five portals after opening hours and during transition hours, if needed.

The directional lighting, as shown in figures 30 and 31, follows the daylight inflow from the side windows at a 70-degree angle and illuminates the sculptural work as light streaming into the room like a fabric, as it was so well described by Lange.

This directional lighting layer provides focused light to enhance the usability of this space – to appreciate the sculptural work, welcome visitors and provide them with a space to gather, help them preparate for their journey through the museum, and giving them an idea of what they're about to see.

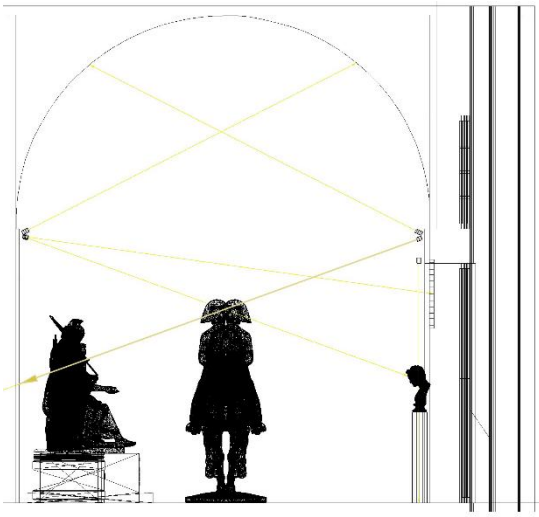

Figure 30 Direct light, directionality

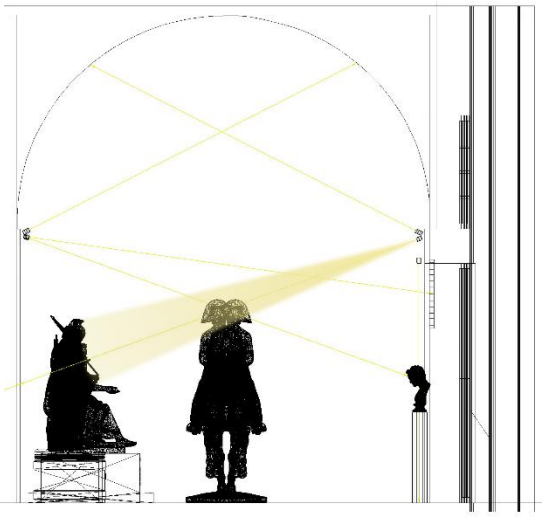

Figure 31 Direct light visual

The diffuse lighting, as shown in figures 32 and 33, is achieved by directing arrays of asymmetric wallwash projectors toward two separate focal points on the domed ceiling. Rather than targeting the geometric centre of the dome, each group of projectors is aimed at points further apart and away from the apex. This deliberate offset creates overlapping light beams that blend smoothly across the ceiling surface, providing a uniform light distribution. Therefore, a luminous ceiling effect will be resulted of this and contribute to an ambient glow that softly bathes the space.

The intentional placement of the beams avoids concentrated hotspots, resulting in a visual environment that enhances spatial legibility and highlights the architectural curvature of the dome. Additionally, by using asymmetrical wallwashers and cross-

aimed beams, the scheme avoids over-illumination at the centre while ensuring even brightness throughout the ceiling and providing a sense of openness of the room.

The ambient diffuse lighting layer provides the needed general, uniform illumination, ensuring baseline visibility and visitors' comfort.

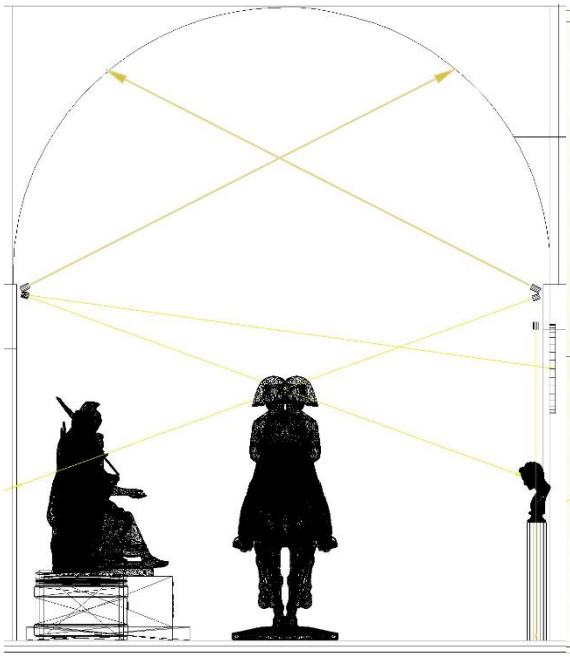

Figure 32 Diffuse light, planning scheme

Figure 33 Diffuse light visual

Figures 34 and 35 show the accent lighting that will be included in the lighting design of the foyer. Although it doesn't follow the daylight inflow from the side windows, this accent lighting is needed to illuminate the small statues and reliefs on the opposite side of the room from the one where the main sculptures are placed. Eight 28-degree angle beamed projectors will be pointing at the centre of the four reliefs and heads of the four columned statues placed in between the five portals.

Lastly, figure 36 shows the accent lighting that will also remain included to signal the five portals at dark and transition hours with an overhead fixture at the centre of each door, with the same 28-degree angled beam.

The accent lighting layer highlights artwork and architecture to create visual interest.

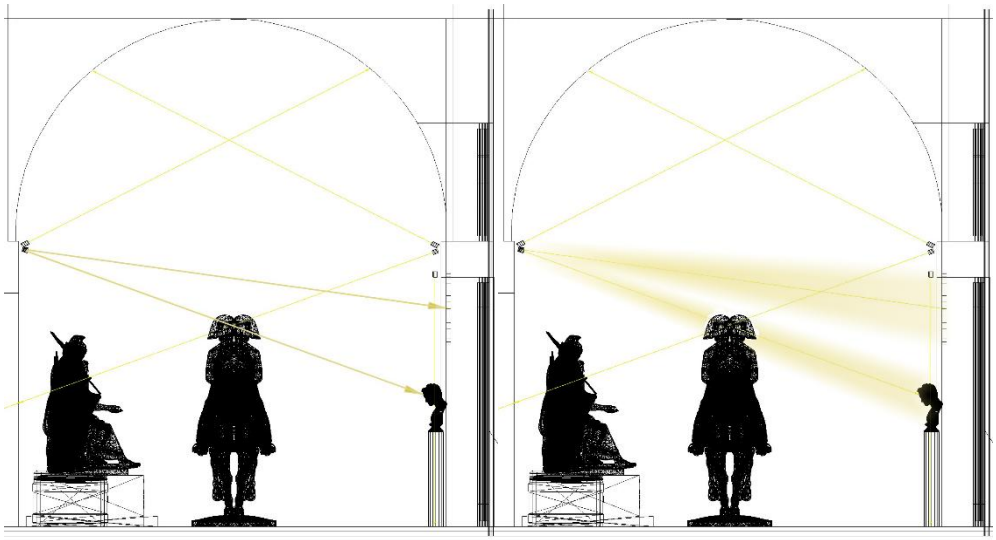

Figure 34 Accent lighting on artwork scheme *Figure 35 Accent lighting on artwork visual*

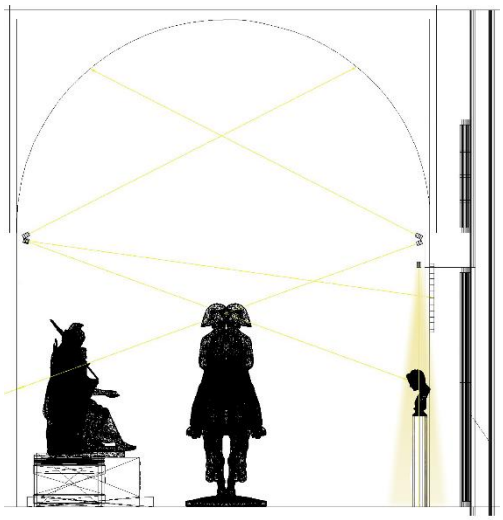

Figure 36 Accent lighting on portals visual

The three-layered lighting design, as shown in figure 37, encompasses directional and diffuse lighting combined and answers to the problems identified, by bringing in the changing skylight, constant night sky and the flow of light into the spatial environment, and ultimately light modelling qualities. By optimally balancing directional and diffuse lighting, the design will sculpt forms, define textures, and create depth, and therefore improve spatial perception and aesthetic appeal.

The changing skylight incorporates daylight variability, ensuring a connection to the external environment and enhancing circadian rhythms. The constant night sky compensates for darkness whilst maintaining a sense of natural ambiance. The flow of light guides light through the space with sequenced fixtures at the specified angle to define movement and spatial hierarchy.

Regarding the diffuse lighting layer, a warmer correlated colour temperature of 4000K will be applied after opening hours during the dark hours, which for vernal and autumnal equinoxes, corresponds to after 6pm. On overcast days, a CCT of 5000K will be applied and on days with clear sky, a cooler one of 6000K will be used to match natural sunlight and contribute to the perceived atmosphere. In terms of intensity, the ceiling light will be dimmed when daylight exposure is higher. Regarding the directional lighting in the room, a warm CCT of 3000K for all conditions will be used. Accent lighting on the doors will be dimmed when it's not necessary and will stay on in transition hours when daylight exposure is lower, as well as at dark hours to compensate for darkness.

Total lighting will reach values of at least 100 lux, noting that it could go up to a maximum of 200 lux for spaces that house moderately sensitive materials, as shown in table 1 of analysis chapter. The walls at Thorvaldsen's Museum are tempera-based – "Analyses on the binding material show that the painters used casein with the addition of drying oil and possibly egg, that is, what we would call tempera (from the Italian word *temperare*, which means to mix) or composite paint."[1] –, which is a moderately sensitive material and therefore exposure values shouldn't exceed 200 lux. According to the EN 12464-1:2021 lighting standards of entrance halls, as shown in table 2, required (minimum value) illuminance for basic functionality is 100 lux and modified illuminance value is 200 lux. The lighting design proposal for Thorvaldsen's entrance hall has its basis on such values.

Parscan in-track spotlights and wallwashers from ERCO manufacturer will be used in the lighting design simulations for Thorvaldsen's Museum entrance hall, that will be shown further on in the Design evaluation chapter.

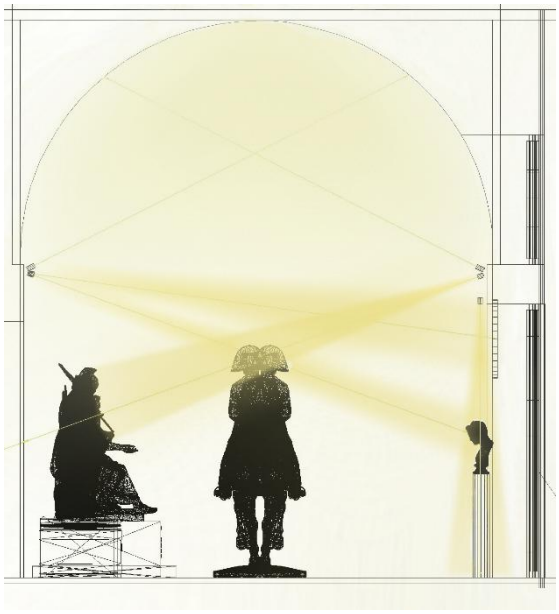

Figure 37 Three-layered design visual

Table 36 — Places of public assembly – General areas

Ref. no.	Type of task/activity area	$\bar{E}_m$ lx		U_0	R_a	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx	Specific requirements
		required[a]	modified[b]				$U_0 \geq 0{,}10$			
36.1	Entrance halls	100	200	0,40	80	22	50	50	30	R_{UGL} only if applicable
36.2	Cloakrooms	200	300	0,40	80	25	75	75	50	
36.3	Lounges	200	300	0,40	80	22	75	75	50	
36.4	Ticket offices	300	500	0,60	80	22	75	75	50	

[a] required: minimum value
[b] modified: considers common context modifiers in 5.3.3

Table 2 BS EN 12464-1:2021 Table 36

Design evaluation

The proposed three-layered design was tested on Dialux evo, under eleven settings, as shown in tables 3 and 4, and figures 50 and 38 to 47. An optimal balance between direct and diffuse light was of focus throughout the simulated tests. The contrast ratio between the two were calculated in all settings where lights were on and results are presented in tables 3 and 4. Daylight percentage out of total lighting was also calculated in all twelve settings encompassing daytime hours.

The qualitative balanced light modelling translated from the DDL concept for office environments to the context of Thorvaldsen's Museum entrance hall has direct lighting in a range of 14-30%, regarding all simulated tests where lights were kept on. Figures 48 and 49 show that lights were turned off for vernal and autumnal equinox days with clear sky at 5pm, because daylight levels were overly sufficient.

In this dynamic lighting approach, the sky-type, time of day and year, and daylight inflow are taken into consideration to bring the dynamic foyer lighting to life instead of only meeting the static illuminance requirement through artificial lighting.

Direct light remained stable at 3000K (warm white), while diffuse light varied between 4000K–6000K (cooler tones), aligning with variability in CCT depending on sky types and ensuring a sense of naturalness into the space.

In vernal equinoxes, direct lighting contributes to 14-21% out of total lighting whereas diffuse lighting ranges between 30% to 59%, during opening hours. Daylight accounts for 20–55% of total illumination during daytime (10am–5pm), peaking at 55% under clear skies at noon.

In autumnal equinoxes, direct lighting contributes to 15-19% out of total lighting whereas diffuse lighting ranges between 35% to 54%, during opening hours. Daylight accounts for 27-50% of total illumination during daytime, peaking at 50% under overcast and clear skies at noon.

At nighttime, the combination of direct and diffuse light sources, with a ratio of 30% from directional lighting, aims to create the desired light modelling effect, and enhance the three dimensionality and overall appearance of the sculptures.

The three-layered system aims to balance functionality and aesthetics through precise control of direct and diffuse light ratios and changes in correlated colour temperature based on sky-type, and therefore creating naturally perceived luminous variations in the spatial environment at hand.

VERNAL EQUINOX							dark
sky condition	overcast			clear			
time of day	10AM	12PM	5PM	10AM	12PM	5PM	after 6PM
CCT (direct)	3000K	3000K	3000K	3000K	3000K	OFF	3000K
CCT (diffuse)	5000K	5000K	5000K	6000K	6000K	OFF	4000K
% (direct)	16	14	21	15	15	__	30
% (diffuse)	46	35	59	37	30	__	70
% daylight	38	51	20	48	55	100	__

Table 3 Variables Matrix based on the standard lighting settings for the DDL concept, vernal equinox

AUTUMNAL EQUINOX							dark
sky condition	overcast			clear			
time of day	10AM	12PM	5PM	10AM	12PM	5PM	after 6PM
CCT (direct)	3000K	3000K	3000K	3000K	3000K	OFF	3000K
CCT (diffuse)	5000K	5000K	5000K	6000K	6000K	OFF	4000K
% (direct)	16	15	19	16	15	__	30
% (diffuse)	44	35	54	37	35	__	70
% daylight	40	50	27	47	50	100	__

Table 4 Variables Matrix based on the standard lighting settings for the DDL concept, autumnal equinox

Figure 38 Overcast 10am vernal equinox

Figure 39 Overcast 10 am autumnal equinox

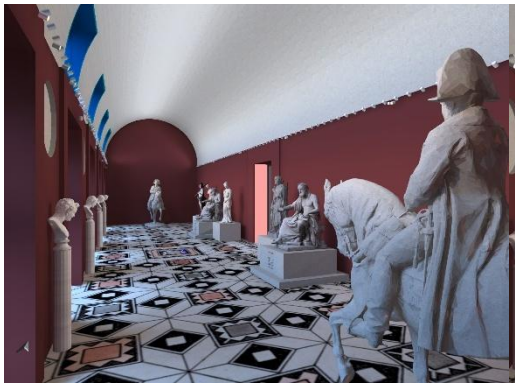

Figure 40 Overcast 12pm vernal equinox

Figure 41 Overcast 12pm autumnal equinox

Figure 42 Overcast 5pm vernal equinox

Figure 43 Overcast 5pm autumnal equinox

Figure 44 Clear sky 10am vernal equinox

Figure 45 Clear sky 10am autumnal equinox

Figure 46 Clear sky 12pm vernal equinox

Figure 47 Clear sky 12pm autumnal equinox

Figure 48 Clear sky 5pm vernal equinox, lights off

Figure 49 Clear sky 5pm autumnal equinox, lights off

Figure 50 Nighttime, after opening hours

Based on the first criterion and following the first hypothesis – lighting design bringing the qualities of natural light into the museum foyer and creating a flow of light that provides the most favourable perception of form –, tests were conducted where the directionality of light followed the requirements according to the DDL concept for office environments. Therefore, figures 52 and 54 go accordingly to the suggested angle of the directionality of the beam of light that should range between 11.5° and 40°. A 40° angle was thereby applied and shown to be unseating to light the task area at hand – the sculptures. A 70° angle was tested after, as represented in figures 51 and 53, and shows a vertically focused illuminance where sculptures are suitably lit and visibly shadowed on the background wall. A clear directionality of light and shadow pattern, without overexposure of light was seemingly achieved with a flow of light at a 70° angle.

Figure 51 Nighttime, directionality 70°, render

Figure 52 Nighttime, directionality 40°, render

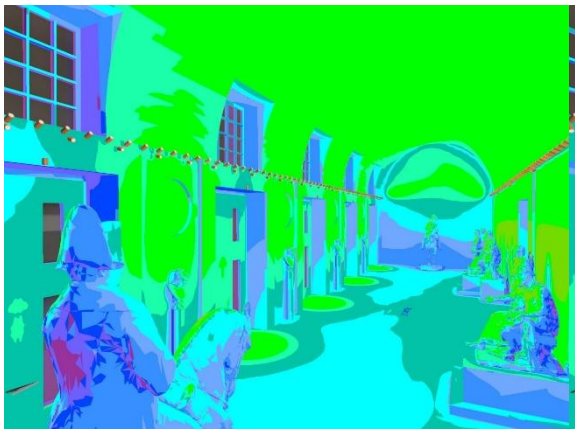

Figure 53 Nighttime, directionality 70º, false colours

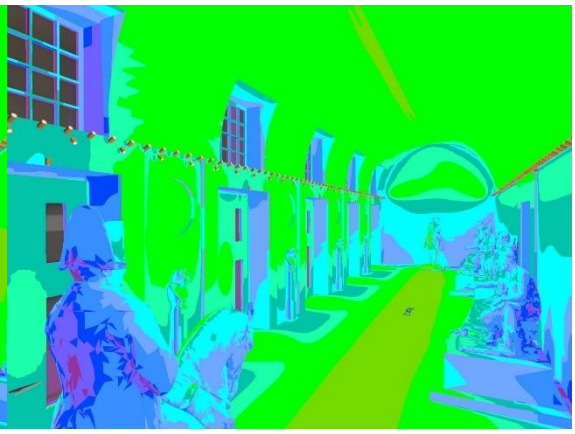

Figure 54 Nighttime, directionality 40º, false colours

Based on the second criterion and following the second hypothesis – lighting design bringing the qualities of natural light into the museum foyer and giving the room its needed ambiance, resonant of the changing skylight and constant night sky –, tests were conducted with and without the diffuse ceiling lighting to serve as a comparison basis. Figures 55 and 57 show the foyer on an overcast day under no ceiling lighting and figures 56 and 58 show how the spatial environment evidently increases in visibility and uniformity under ceiling lighting that ensures a connection to the outside skylight and provides the needed natural ambiance in the room. The openness of the space provided by the ambient lighting increases spatial recognition and aesthetic appeal.

Figure 55 Overcast render, without ceiling light

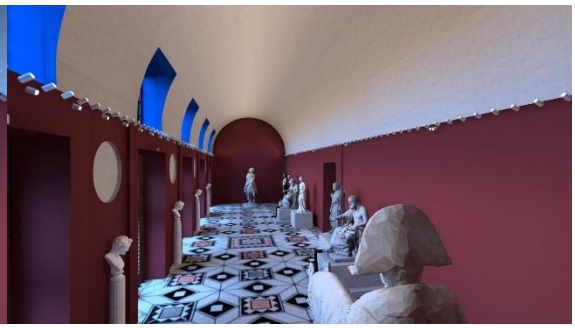

Figure 56 Overcast render, with ceiling light

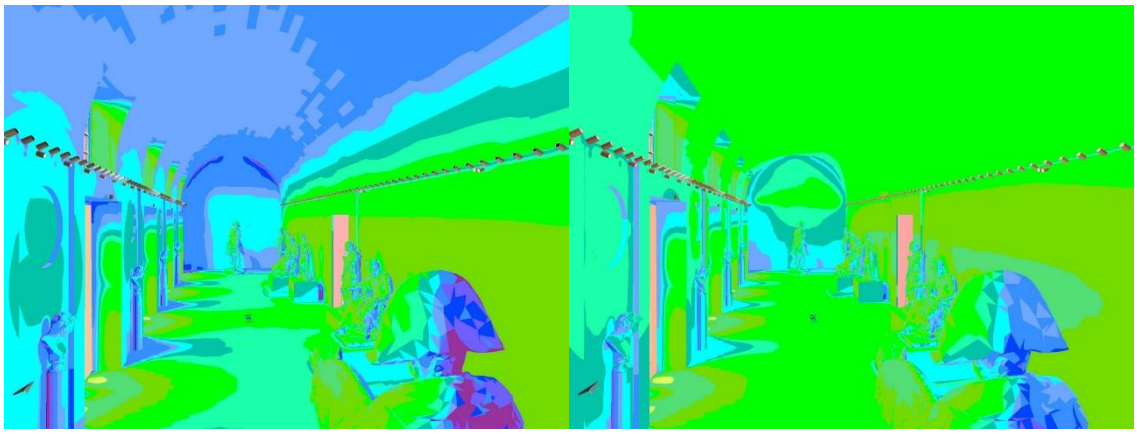

Figure 57 Overcast, without ceiling light, false colours *Figure 58 Overcast, with ceiling light, false colours*

Based on the third criterion and following the third hypothesis – how can lighting design naturally support the grandeur of Thorvaldsen's work? –, figures 59 and 60 show the neutralised colour contrast on the sculptures after the identified problem in the analysis chapter. The test was simulated on an overcast day at midday and both the ceiling and projector-like lighting are turned on. By only having directional lighting on one side of the room simulating and complementing the daylight inflow from the side windows the sculptures appear naturally lit, with one side left in shade, contrary from the current situation at Thorvaldsen's Museum front hall, where sculptures are being lit from both sides and therefore appear sterile. The lighting of the sculptures is therefore aligned with that of an artist's studio, as Thorvaldsen said sculpture in a museum should be, with "a high and broad source providing light from one direction only for statues since more than one source of light prevents the most favourable perception of form", as described by Jørgensen (1984).

Figure 59 Sculpture lit on one side *Figure 60 Sculpture left in shade*

Findings and limitations

The three-layered lighting design – directional, diffuse and accent lighting – effectively adapted the Double Dynamic Lighting (DDL) concept, originally developed for office environments, to the museum context. Direct lighting (14–30%) and diffuse lighting (30–70%) followed the requirements for achieving optimal light modelling effect specified in the DDL concept studies, enhancing the sculptures' three-dimensionality whilst maintaining visual comfort.

An improved spatial legibility achieved with diffuse ceiling lighting (4000K–6000K, varying with sky conditions) eliminated the "dark box" effect, and thereby created a uniform ambient glow that extends towards nighttime to support activities unfolding there after opening hours. Directional lighting at 70° (instead of the office-recommended 11.5°–40°) better sculpted vertical artworks, avoiding flat or sterile shadows and providing the most favourable perception of form.

Moreover, the decision to light the sculptures only from the vaulted windows side to mimic natural light inflow, resolved the unnatural yellow-white contrast from existing dual-side lighting, and therefore aligned with Thorvaldsen's preference for "atelier-like" illumination.

Furthermore, the dynamic system created a living ambiance, with intensity and CCT shifts (4000K–6000K) mirroring daylight changes, and a living light with a stable 3000K CCT, resonant of sunlight tones, that complements the flow of light, brings a sense of movement into the room and fosters a connection to the external environment. First impressions are heightened through balanced light modelling, guiding attention to artworks whilst maintaining a solemn atmosphere.

Regarding simulations, the focus was on equinox conditions with moderate sun angles, excluding solstices, and therefore, summer and winter extremes, which require further adjustments for seasonal changeability. Further tests regarding winter and summer solstices would be required to have a wider understanding of how artificial lighting would complement the daylight under such conditions.

Regarding technical constraints, the study relied on static Dialux evo simulations rather than real-time adaptive controls like sky scanners, which limits validation of dynamic responsiveness. Given that the proposed design was only tested under two different sky conditions, further studies need to englobe further sky-type variability.

On a practical implementation level, upgrading the museum's outdated timer system to a dynamic lighting system would require investment. Additionally, the proposed design assumed closed frontal entrance. If the main five doors were opened as it will be suggested for future work, daylight influx and lighting ratios would need recalibration.

On a last note, subjective preferences, regarding, for example, the CCT shifts, were not empirically tested, and therefore surveys or post-implementation feedback could refine and further validate the proposed design.

Future work

Advanced lighting technologies ought to be utilised, "using live sky-scanner data and illuminance sensors to determine the sky condition and appliance of the designed lighting settings, depending on illuminance levels and the sky-type" [8] to implement the proposed dynamic lighting design.

Future work will also aim at opening the five main doors and therefore altering the current entrance route to increase visitors flux and arrival experience. The dynamic lighting design proposed, permitted with live sky-scanner data and illuminance sensors, will then be prepared to adjust the lighting levels to complement the higher daylight influx and limit the contrast to the outside, when entering straight into the front hall.

Future studies encompass applying the Double Dynamic Lighting (DDL) concept to other Nordic museums by defining concrete design guidelines on how to make threshold spaces that house collections responsive to the dynamic qualities of natural light and changes in sky-type and cloud coverage.

Conclusion

The core of this project, a lighting design for Thorvaldsen's Museum front hall that supports visitors' spatial experience, activities unfolding there after opening hours and the grandeur of Thorvaldsen's work, was achieved by bringing in the dynamic qualities of natural light into the room. Translating the Double Dynamic Lighting concept to this context was imperative to achieve a sense of naturalness in the space and a stronger connection to the outside environment, even more given that the museum and all museums until some point in time were built to be seen under daylighting.

The flow of light and light modelling qualities were key points in achieving a spatial environment responsive and complementary of daylight. The balanced contrast ratios in all settings and the appliance of direct light with its directionality tailored to the daylight inflow from side windows contributed to an achievement in providing the sculptures with natural three-dimensional appearance and shape discrimination.

Shifts in the colour of light provided the space with a living ambiance, resonant of the changing skylight, argued on a basis that people are daily predisposed to the changes

in sky conditions. A still and warmer ceiling light for after opening hours will increase visual comfort during visitors' participation in activities and events in the museum foyer.

The overall combination of all three layers encompassing both diffuse and directional light provides the space with naturalness and is promising of a more welcoming first experience. The project illustrates a potential for complementing the daylight intake with a balance between direct and diffuse light, creating a flow of light and more distinct light modelling effects, in contexts that go beyond office environments where light zones are well discriminated.

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