Aalborg University Copenhagen

Semester:

LiD 10

Title:

"Nature-inspired lighting concept for the enhancement of sculptures and visitor experience"

Aalborg University Copenhagen

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Semester Coordinator:

Secretary:

Project Period:

Spring 2022

Semester Theme:

Master thesis

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Abstract:

Ancient sculptures were intended to be displayed outside and as a result to be illuminated by the dynamics of natural light. Nowadays, these sculptures are part of museums' collections while, almost exclusively, they are illuminated with static electric light. In recent years, the concept of entertainment has been introduced to museum institutions while the visitor experience is in focus when it comes to a new exhibition. This report investigates how dynamic lighting can enhance the artwork while improving the visitor experience. Through extended literature on the Museum visitor experience, the Museum lighting and Illumination of sculptures, the Museum's atmosphere and Exhibition concepts but also Daylight and its Dynamics in combination with relevant analysis of realistic situations, a design concept of sculpture's dynamic illumination was developed and tested at the Royal Cast Collection, Copenhagen. Throughout an evaluation of the physical experiment and people's participation, it is conducted that dynamic illumination can enhance the appearance and presentation of a sculpture while it has a positive impact on people's experience, engagement and interest in the artwork.

NATURE-INSPIRED LIGHTING CONCEPT FOR THE ENHANCEMENT OF SCULPTURES & VISITOR EXPERIENCE

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This Master Thesis project was carried out by Antti Heikka and Panagiotis Stamidis for the MSc program of Lighting Design at Aalborg University, Copenhagen. Before this project, both authors did internships for companies focusing on museum exhibition lighting, which allowed them to examine issues and possibilities within the field.

The project supervisor was Arthur van der Zaag

ACKNOWLEDGMENTS

The authors would like to thank Arthur van der Zaag for guiding us through this thesis project and for lending equipment for the experiment, Henrik Holm for support and wonderful collaboration to set up experiment at the Royal Cast Collection, Scott Rosenfeld and all the other interviewees for participating in our project with the input of your knowledge and views. Moreover the authors would like to thank Aalborg University's Lighting Design department for the wonderful and taughtful years.

– Antti & Panos

1. BACKGROUND

1.1 MUSEUMS' INTEREST IN NEW WAYS OF PRESENTING ARTWORK

Museums vary in architecture, thematology and collections. In the past, people would visit museums for educational purposes, to observe and see the collections but throughout the years, the role of museums has changed. Nowadays, the concept of experience is considered an important feature of museum visits (Kotler, 2001). Visitors expect unique experiences including different events and a multi-sensory presentation of collections (Kotler, 2001). Hale et al (2012) explain in the book “Museum Making”, that what museums have in common is their attempt to create the so-called “narrative environments” that are:

> “experiences which integrate objects and spaces – and stories of people and places – as part of a process of storytelling that speaks of the experience of every day and our sense of self, as well as the special and the unique.” (p. xviii).

Museums and galleries nowadays are interested in improving the experience of the visitors while updating the diversity of exhibits/collections, using new media and ways of presentation. Moreover, the visitors' response is important. In recent years, museums have shown an interest in creating storytelling through their exhibitions by adding “multiple viewpoints, understandings and ‘truths’ in the ways such narratives unfold on-site, and an interest in working with the subjectivity inherent in visitor response.” (Hale et al, 2012, p.81). Without a doubt, the educational purposes for visiting museums are still important in visitors' experience, though entertainment is linked to it. While society is changing and the lifestyle of people is connected more to technological means, museums are looking for new ways of artworks' presentation in order to attract more people (Mattern, 2014).

1.2 THE ROLE OF ELECTRIC LIGHT ON ARTWORK'S PRESENTATION

Lighting has always been a remarkably powerful tool that contributes to the success of an entire art exhibition. It has a great dramatic influence on how the works of art are perceived and interpreted by the visitors (Schielke, 2020). However, museums are challenging environments considering the holistic luminous environment, as different facets might have opposing opinions about the ideal lighting, displayed in Fig. 1.1. The role of the lighting designer has been to find harmony in these needs and communicate the exhibition or exhibit in the most suitable way (Schielke, 2020).

Moreover, lighting is an influential tool for museums to define the exhibition atmosphere, influence the perception of the artwork in the space and increase the sense of drama, whilst contributing to the exhibition's success. However, while doing so, light also interprets the artwork. In his 2020 paper titled “Interpreting Art with Light: Museum Lighting Between Objectivity and Hyperrealism” Schielke asks the following questions:

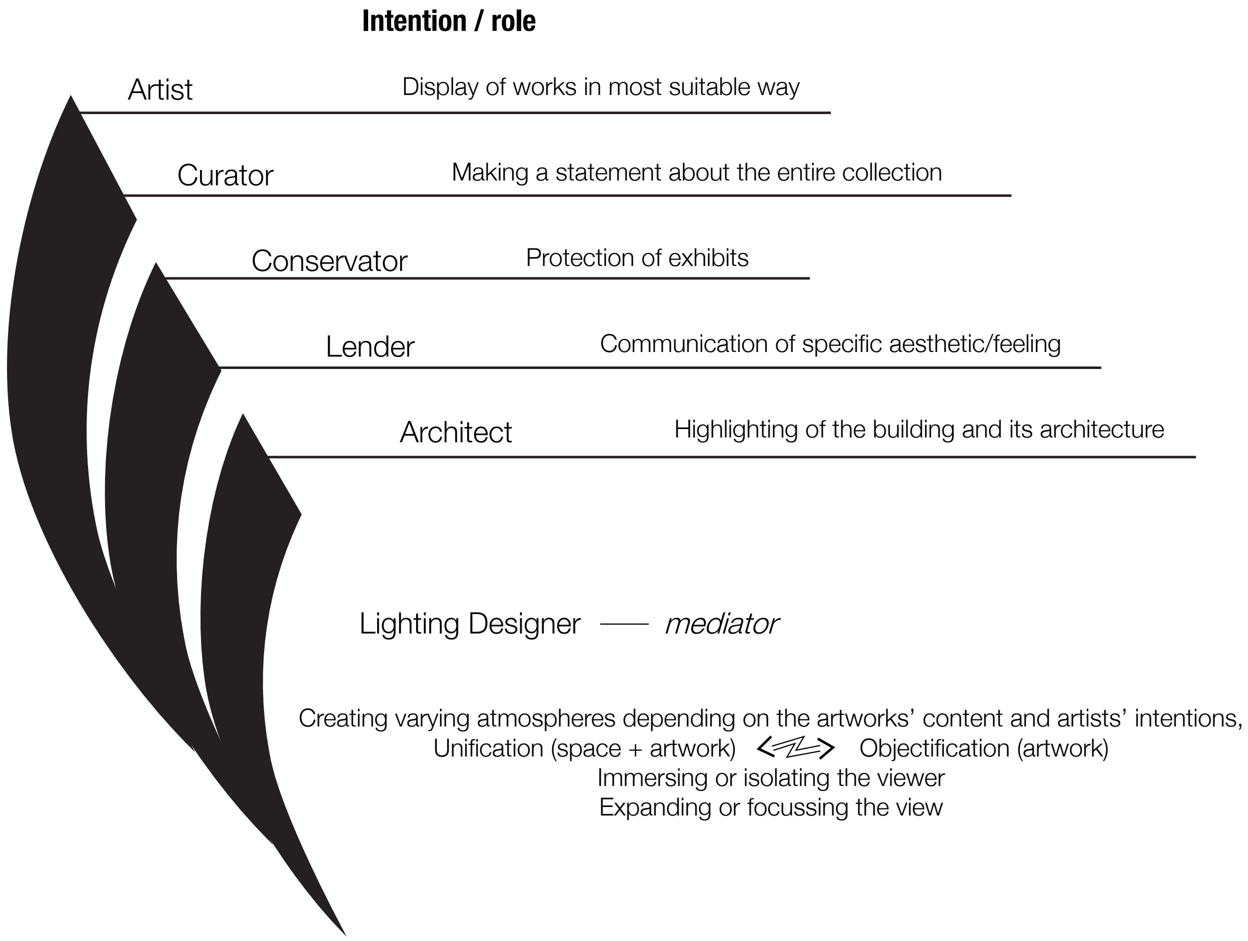


Figure 1.1. What different facets want from museum lighting. Illustration is based on data from Lippert (2009). (Heikka & Stamidis, 2022)

> “Should an individual work serve as the benchmark or, indeed, the primary theme of the complete exhibition? How can the impact and interaction with art be stimulated with light? When does light appear authentic and in what circumstances might it change the meaning of the exhibit?” (p.7)

Schielke also raises a question about to what extent a curator (or lighting designer) can go in modifying the statement of the artwork via lighting? He states that when the aim is authentic presentation, it is a requirement to find out how the artist perceived the artwork at the time of its creation, if the considered lighting concept would falsify the artistic statement and if it distracts from the fundamental reception of the artwork (Schielke, 2020).

Figure 1.2. High contrasts are used to achieve dramatisised, high-profile exhibitions. (Heikka & Stamidis, 2022)

Nowadays as museums have become a popular leisure activity that merges entertainment and education, theatrical rich-contrast presentations are increasingly used to achieve stimulating and entertaining, high profile exhibitions (Fig.1.2). While this makes the artwork the focal point, the darkness of the surrounding space makes the room disappear and creates a nocturnal atmosphere, where lighting brings the artwork "alive". This strongly emotionalises and dramatises the artwork, in the specific static setting that the lighting designer determined when positioning the light source according to the track placement (Schielke, 2020). When discussing how to illuminate artworks, it is often speculated that they should be illuminated in the lighting conditions they were created or intended to be displayed in. Particularly for artworks from before the 19th century, the correct choice would then be daylight, as they were intended to be seen in daylight conditions, as no other human-made light sources apart from candles and other burning sources existed (Saunders, 2020).

1.3 DAYLIGHT IN MUSEUMS

Daylight is a factor that can enhance the satisfaction of people's visit to a museum (Kaya & Afacan, 2017). Its dynamics offer experiences that vary throughout the day. The changes in colour and intensity, variety in highlights and shadows offer a diverse presentation of artworks throughout the day, that encourage people to visit and revisit a museum's space

(Hurlbert & Cuttle, 2019). Lighting designer Florence Lam explained at the International Museum Light Symposium the importance of designing the New Acropolis Museum in a way that could allow as much daylight as possible in the building. This is because the museum's collection mainly includes sculptures which were "created to be seen outdoors and to be illuminated by the subtle changes in light throughout the day. These variations enhance the rich differentiation of the marble surfaces and the viewer's appreciation of the sculpture." (Lam, 2017). In that way, the New Acropolis Museum presents the sculptures under the natural lighting conditions they were intended to be displayed.

However, often in the museum context, daylight intake needs to be reduced greatly due to its high intensity and broad radiation spectrum that can damage artworks as well as cause discomfort to visitors by glare. Therefore museums often use diffuse or prismatic skylights or North-facing windows to utilise the impeccable colour rendering qualities of natural daylight and to allow a view out, while avoiding direct sunlight for conservation purposes. While visible light mostly damages pigments, the ultraviolet and infrared radiation of natural light poses the most risks to materials (Cuttle, 1996). On the other hand, unpainted stone and metal sculptures are not classified as light-sensitive materials (CIE, 2004).

1.4 HISTORY OF MUSEUM LIGHTING

Before museums existed and before statues were taken indoors from their original outdoor spaces, they were illuminated by the dynamic cycles of natural light. According to the Canadian Museum of History (n.d.), the first life-sized Greek sculptures were carved after 650 BC, when Greeks learned the stone carving tradition from the Egyptians and applied it to the North-Mediterranean natural stones marble and limestone. Within two centuries, the Greeks had evolved their distinct sculpting method. In addition to sculpting the form, the statues were often also painted with saturated colours, as seen in Fig. 1.3 (Canadian Museum of History, n.d.).

Figure 1.3. Sculpture Copy with original colours, Glyptoteket Museum, Copenhagen. (Heikka & Stamidis, 2022)

In the past, museum lighting was exclusively about daylight, as it was for long the only light source available. Therefore, light dictated the orientation and architecture of museums and sacred spaces, and already in the centuries before Christ, buildings such as Parthenon in Athens and Pantheon in Rome created the foundation for daylighting museums (Ziabakhsh & Amrei, 2011; Plummer, 2009). Temples were orientated so that statues were highlighted by sunrise, and light entered buildings in an oblique angle (Ziabakhsh & Amrei, 2011).

Over centuries, new daylighting solutions or building layouts emerged and the light was used to reflect the art of the time. However throughout history – until electric lighting became widespread – sculptures were always recommended to be placed in side lighting (Perret, 1929; Bazin, 1967).

Dynamic or interactive light has been tested several times in some museums, for example in Rome where museum visitors were given torches to walk through the exhibition with. This was said to be advantageous for viewing sculptures (Goethe, 1829/2011, p. 493).

Cinematic lighting techniques started penetrating the museum lighting field in the 1930s, but only spotlighting and filtering remained the most used techniques. An experiment imitating sunlight with baby spots, reflectors and coloured gelatin filters was held in 1933 but faced criticism due to undesirable dramatic effect on sculptures. However, it needs to be considered that there were several scientific & technological limitations that may have been the cause of the critique (Burns, 1933; Stein, 1935).

Apart from improvements in daylighting and electric lighting technology to enhance the art, the consideration of visitor experience also developed throughout history. The term first emerged in the 16th century as a recognition of visitors needing a connection with the outer world while being indoors. Four centuries later, wrong lighting was said to cause psychological discomfort, and that top light and lateral light were causing museum fatigue due to glare, reflections and low light levels (Gilman, 1918). Moreover, roof lighting was said to be too flat and uniform (Stein, 1933). Electric lighting was therefore needed in some spaces to improve the atmosphere and experience, and after World War II Laurence Vail Coleman suggested using cool ambient light and warm focal light on the artwork, taking inspiration from natural conditions (Coleman, 1948).

In the 21st century, it became a rule of thumb to illuminate works of art at a 30° angle between the light source and artwork (Saunders, 2020). For sculptures, it was said to optimally reveal form with less overshadowing (Thomson, 2013). However, it is still only a static representation of the work of art. In the past, the dynamism of daylight was widely utilised for lighting sculptures in museums.

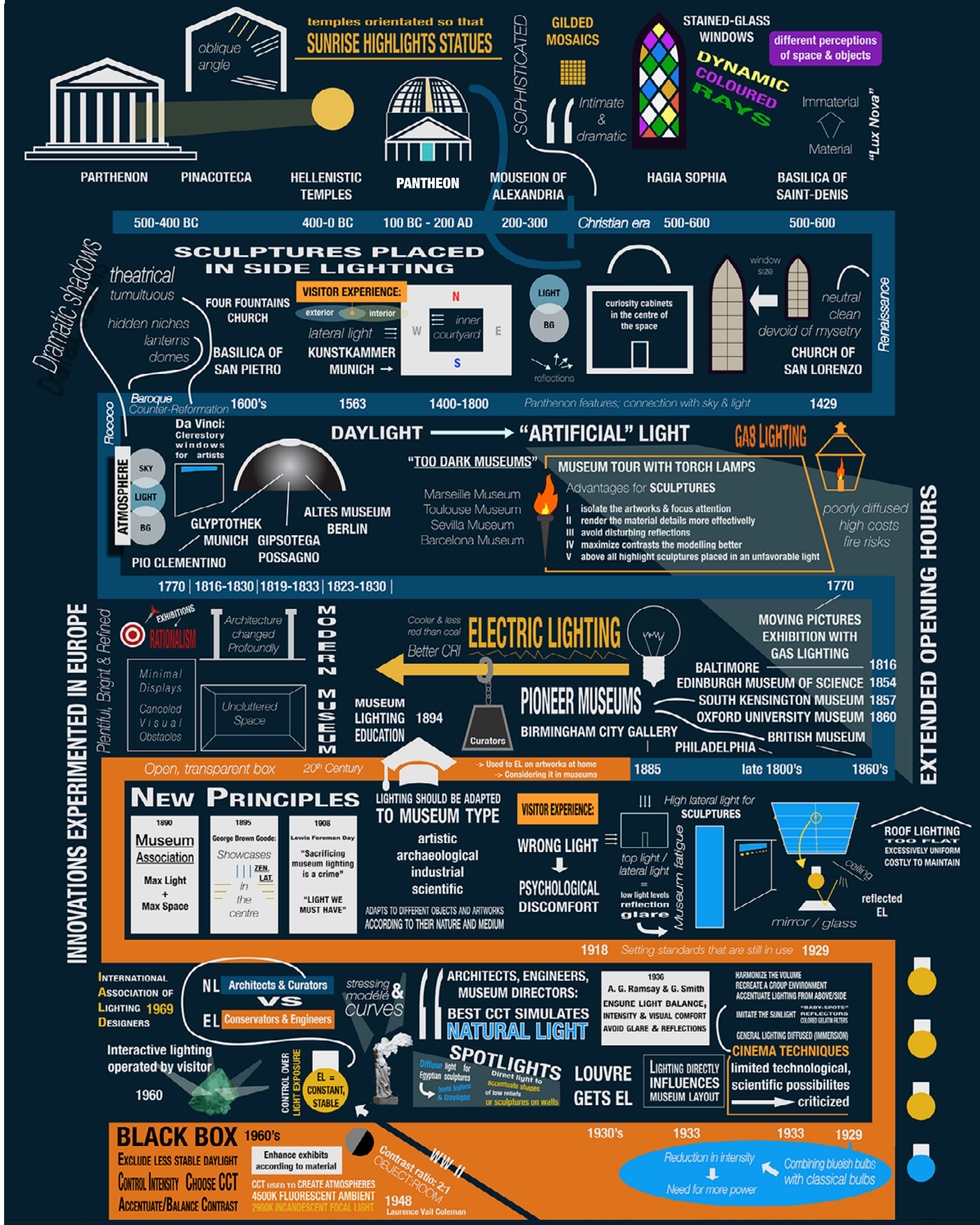


Figure 1.4. Infographic of the history of museum lighting with relation to sculptures and museum architecture until 1960's. Data gathered from Viviana Gobbato's (2021) research paper "On how lighting shaped museums". (Heikka & Stamidis, 2022)

1.5 CONCLUSION – LACK OF RESEARCH

When it comes to research and artworks' illumination, most of the focus seems to be on paintings. Electric light on paintings has been studied from different perspectives, such as their colour appearance and their appreciation by visitors by Feltrin et al (2020) or their sensitivity to light (Dang et al, 2020). In comparison, electric light on sculptures is a topic with less research interest. Most of the recommendations or studies explore the traditional, static illumination on sculptures, as does the study from Smith et al (2021) that explores the complexity of illuminating three-dimensional objects.

Museums aim at perfection. Due to museums' importance in society and the quality of collections, for a museum to do something new, it needs to be strong and highly explored. Through the history of lighting in museums, the authors point out the benefits of dynamic light on sculptures and the evolution of electric light in a museum environment where its capabilities were limited. Nowadays, control systems are highly advanced and keep on advancing, which is why now is the time for another museum lighting revolution. To create a new museum lighting concept that will be accepted, it becomes important to ask questions such as "what are we trying to communicate with the dynamic lighting", and "why do we choose the specific parameters we choose for our design?", "How should the light be dynamic?" Further, the sculpture's connection with light is an appealing subject to explore through questions such as how electric light affects the perception of sculptures or how different, new lighting techniques can enhance their presentation and how would they affect visitors' experience?

This thesis focuses on lighting ancient sculptures in an art museum exhibition to enhance the three-dimensional artwork while improving the visitor experience. More specifically, the focus is on unpainted (or fully faded) ancient sculptures that are made from white marble or limestone, that according to Engineering ToolBox (2012) have reflectance values of 30-70%. As there are no pigments involved, and as the material is not light sensitive according to CIE (2004), there are no conservational issues when it comes to designing light for the artwork. Additionally, the only available light source in ancient times was daylight & fire, which helps us to determine the conditions the artwork was initially intended to be displayed in as daylight conditions. When the artwork was brought indoors, these conditions were lost at least to some extent.

To further examine the current problems and future opportunities with museum lighting and to further define the research question, the following structure was followed: Vision – Literature – Analysis – Research Question – Criteria – Design Concept & Experiment – Discussion – Conclusion

2 VISION

According to the background, the Vision of the project can be formulated:

> ***"Imagine if museum lighting could imitate the dynamics of natural light in order to create a unique experience of sculpture's presentation"***

The Vision consists of three fundamentals that embody the authors' interest in exploring in this report. It is the ***museum lighting*** and how it could imitate the ***dynamics of natural light*** in order to create a ***unique experience of sculpture's presentation***.

3 METHODOLOGY

This thesis follows the Design Experiment Method developed by Hansen and Mullins (2014). It is a transdisciplinary method that unites knowledge from within the fields of Natural Science, Social Sciences and Humanities/Art, while bringing all of these three fields forward. The project starts from a vision, where existing issues, ideas and new potentials are explored, and the basis of the project is founded. Then, the design intentions and the research question are determined by analysis, experiments and theories and by creating three criteria within the three fields of science/art. This leads to a proposal, which will then be evaluated in the next step, to determine how well the proposal fulfils the three criteria. After the analysis of the experiment data, a design solution, referring to the vision and design intentions, will be created. Accordingly, the answers to the research question will conclude the project (Hansen & Mullins, 2014).

The following methods were utilised in order to define the research question and criteria, and to offer us guidelines for our design:

- Literature review
- Spectral analysis of skies
- Analysis of spectrometer measurements and atmospheric observations of the effects of different lighting methods in museums
- Timelapse
- Semi-structured interviews

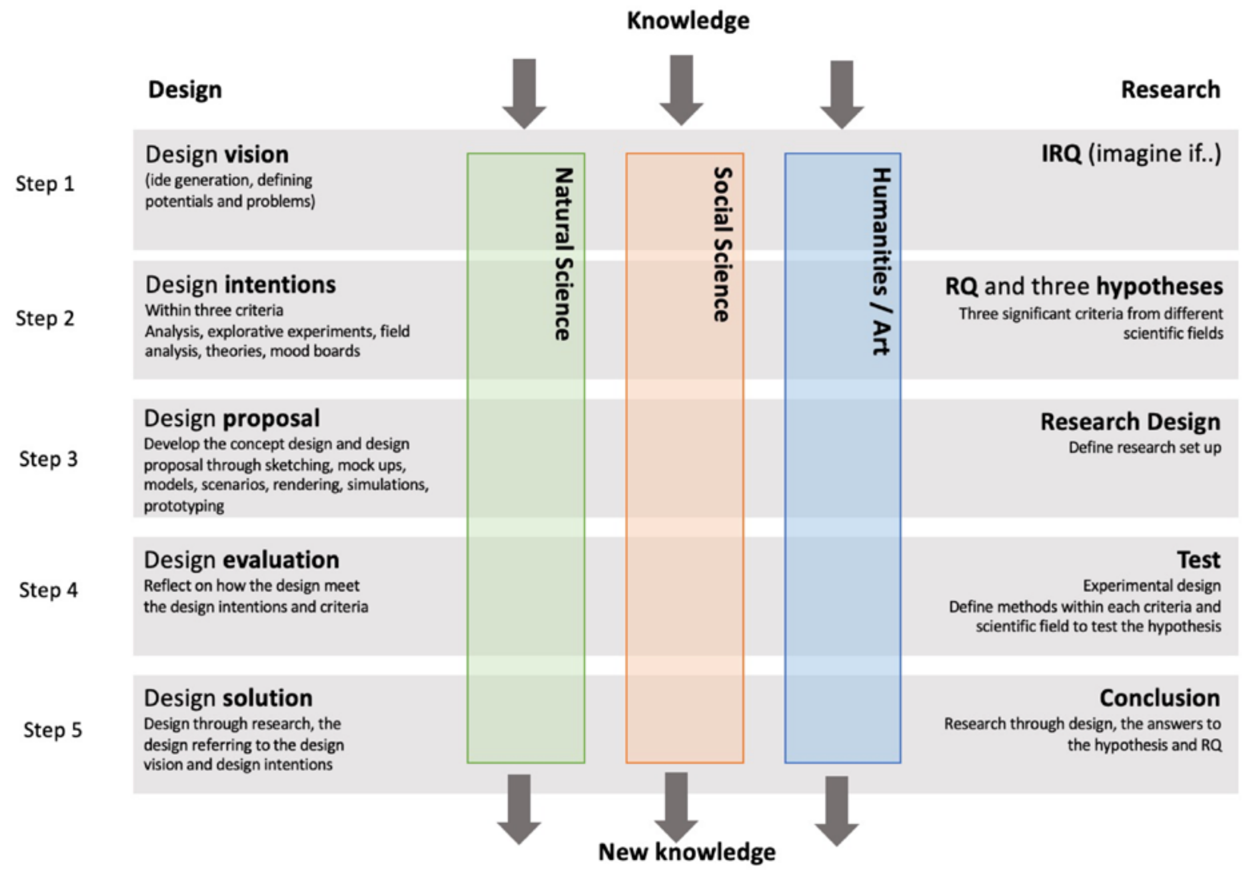


Figure 3.1. Design Experiment model (Hansen & Mullins, 2014)

3.1 EXPERIMENT

Part of the report's methods is a physical experiment. The physical experiment was conducted in order to apply in realistic conditions the design concept, as it is described in Chapter 8.1, but also to find answers to the Research Question and Criteria of the Report. Moreover, people participated in the process in order to understand their personal preferences and experience of two different illuminations on two sculptures. To answer this, a convergent parallel mixed-methods survey with both quantitative and qualitative measures was conducted on the participants. The quantitative and qualitative data were analysed separately but interpreted together (Creswell & Plano Clark, 2011).

In order to understand people's preferences, seven questions were formulated according to a Likert type scale. The Likert scale is widely used in research to understand people's opinions and perceptions (Joshi et al, 2015). A similar approach was used by researchers Leccese et al (2020) that in collaboration with Zumtobel researched the "Lighting and visual experience of artworks" investigating topics related to this report under similar conditions (museum environment). The specific formula of questions is based on a six-point scale, with no neutral option. Further, in order to understand people's experiences, six more questions were created based on the PAD emotional model (Mehrabian & Russel, 1974). The specific formula used in this report is based on the modification by Lee & Lee (2021), where the researchers investigated the "Effects of Coloured Lighting on Pleasure and Arousal in Relation to Cultural Differences". The questionnaire questions were quantitative, but to add a qualitative layer to it, the respondents were asked to write their own comments.

Exploratory interviews were also conducted with some of the participants. Additionally, while the participants were in the experiment space, their behaviour was observed non-systematically – as well as it was possible for us to do (McLeod, 2015). These observations were rather basic and they were conducted for the entire group that was looking at the artwork, which at times was up to 7 people at once. Therefore these observations were treated as generalisations of how the visitors acted between the two scenes, noting down only the most common, shared experiences within the visitors. Including the several qualitative and quantitative methods allowed for triangulation of data in order to achieve valid results.

4 LITERATURE REVIEW

Throughout the Vision, the authors of the report created three fundamental topics:

- (imagine if) Museum Lighting
- (could) imitate the dynamics of natural light
- (to) create a unique experience of sculpture's presentation

In order to get a better understanding of the three fundamentals, this chapter investigates the Museum's Visitor Experience regarding visitors' behaviour and what are their expectations from their visit. In addition, through the topic of the "Lighting of Museums" it is expected to get an understanding of how lighting is applied in a museum environment and specifically on sculptures. The purpose of the next chapter "Museum's Perception of Artworks", aims at getting an understanding of how to manipulate light in a museum environment in order to create an entertaining experience for visitors, with respect to the art. Lastly, since the vision of this report aims to imitate the dynamics of natural light, the last chapter explores the "Daylight and its dynamics", aiming to get an understanding of the natural light characteristics.

4.1 MUSEUM VISITOR EXPERIENCE

4.1.1 THE CONTEXTUAL MODEL OF LEARNING

The museum's main goal in creating an exhibition is to communicate the exhibits in the best possible way in order to be appreciated by the audience while offering an experience (Falk & Dierking, 2013). On the other hand, when people visit a museum they have as their first priority to satisfy their own interests and needs (Falk & Dierking, 2013). Falk and Dierking claim that the museum experience is not only when the audience is in the museum but starts even before their visit and ends much later after they leave it. Museums and visitors are both unique and diverse, and in order to understand the museum experience, Falk and Dierking created a model called the "Contextual Model of Learning", consisting of three contexts that always merge and interact with each other within an experience:

The Personal Context: Each person is unique, with a particular background. According to that, visitors have different motivations for visiting a museum and different behaviours in it. These behaviours and motivations vary among exhibitions, as the theme and design intrigue people uniquely. An integral part of the Personal Context is personal development and learning. Additionally, people's personal interests and experiences affect their interest in their visit. People have a set of pre-defined opinions, interests, desires and expectations that shape their experience within a museum and affect their viewpoint towards an exhibition (Falk & Dierking, 2013).

The Sociocultural Context: The Sociocultural Context relates to the cultural context of the individual and of the museums. People have different cultural backgrounds, are raised in different places, speak different languages and are affected by their society's beliefs and more. As a result, people have different expectations and perceptions of how a museum should be in society. Further, a museum experience is often linked to a social experience

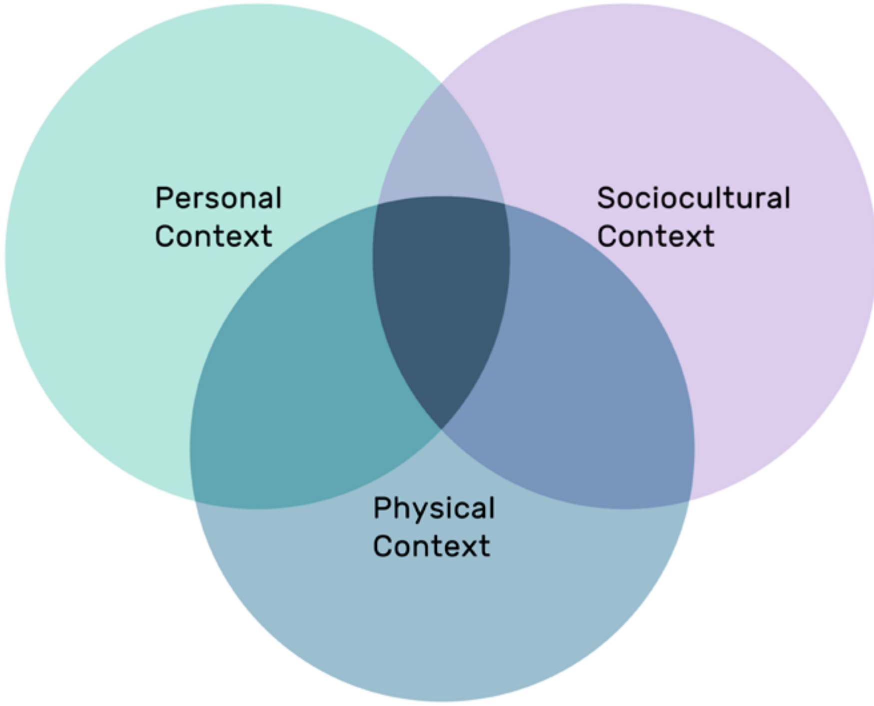


Figure 4.1. The Contextual Model of Learning, applied from Falk & Dierking, 2013. (Heikka & Stamidis, 2022)

where the social interaction within the museum visit has a strong impact. Most people visit museums in groups, and when some visit the museum alone, they often interact with other visitors. How crowded the museum is, with whom someone is visiting, and how the museum staff interact with the audience are some of the aspects that affect the museum visit (Falk & Dierking, 2013).

The Physical Context: The Physical Context relates to the architecture of the museums and how the visitors will perceive the space while walking in it. The design of the space and the placement of the exhibits are factors that influence the experience, making the visit easier or more complex (Falk & Dierking, 2013).

Part of the Physical Context and the museum experience is the fatigue that visitors can experience. Museum fatigue is when "visitors become less and less interested in exhibit objects the longer they view similar exhibits." (Bitgood & Patterson, 1987, p.5). As Bitgood and Patterson explain, people's interest in museums can be decreased when they view analogous exhibits with no contrasts or diversity for instance. But visitors' interest in an exhibition can be decreased because of many reasons. Davey et al (2007) point out the fact that after the first half an hour of someone's visit, their interest decreases. Further, when people are in small areas they can lose interest but also if they have to walk fast or view exhibits for a long time without resting.

The Contextual Model of Learning can be used to understand why people visit museums and what they do, learn and like during their visit. In the next chapter, the subject of experience is defined.

4.1.2 THE EXPERIENCE EXPLAINED

Customer experience is defined as: "a blend of a company's physical performance and the emotions evoked, intuitively measured against customer expectations across all moments of contact." (Shaw & Ivens, 2002, p. 21). Shaw and Ivens describe customer's experience as a blend, which is not only physical or emotional, but both combined. As a result, experience is explained as the emotional state of a person in relation to physical interaction. Individuals compare their expectations in relation to the experience they live (Shaw & Ivens, 2002). Chieh-Wen and Ming-Chia (2012) studied the "experience expectations of museum visitors" and defined five types of expectations. These are Easiness and fun, Cultural entertainment, Personal identification, Historical reminiscences, and Escapism. In their study, 425 people participated, visitors of three different museums: a museum of science, a museum of arts and a museum of history. The five types of experience expectations were developed through factor analysis and questionnaires. In the study, it was found that most participants expect an "easiness and fun" experience (Chieh-Wen & Ming-Chia, 2012). They further explain:

> "When visiting museums, visitors mostly expect to experience easiness and fun. As long as they continue to fulfil their purpose, museums can present exhibitions or activities with easiness and fun, such as providing changeable contrasts, a relaxing environment or combining local features" (p.59).

Furthermore, Chieh-Wen and Ming-Chia (2012) explain that participants who were "visitors enjoying visiting museums" often expect easiness and fun and historical reminiscences. As they explain, this is linked to their previous visits, their impression or previous experiences of modern museums in which they combine historical content with modernisation.

Moreover, Kotler (2001) explains the experience of museums in his paper "New Ways of Experiencing Culture: the Role of Museums and Marketing Implications":

> "Today, the concept, experience has several meanings: involving intense sense–perception as well as emotion and intellect; direct, immediate happening; participatory and sociable happenings; situations that evoke strong responses rather than passivity and spectatorship; intense, visceral excitement; one-of-a-kind, memorable happenings. Whatever the implications, tourists and a large number of infrequent visitors expect a 'wow' experience." (p. 418)

In recent years, the concept of experience has shifted from aesthetical and educational to multi-diverse experiences that people are a part of and that intrigue their feelings. As Kotler (2001) explains, museums organise special events such as nighttime events that attract the young generation and make them a part of the museum in a modernised way. Out-of-the-ordinary exhibitions are another important element that museums need to include (Kotler, 2001). Those exhibitions that are designed beyond the traditional way of presentation, are able to intrigue people. Entertainment in combination with art is the future of museums:

> "A successful future museum will not be an entertainment centre although it will have entertaining elements. It will not be a 'cabinet of curiosities,' although art and artefacts will be important elements." (Kotler, 2001, p. 423).

4.1.3 SUMMARY

- **The museum experience is explained through the collision of three concepts:**
    - **Personal Concept:** People visit museums for personal reasons that differ from each other. Their background, previous experiences, personal interests and expectations affect their museum visit
    - **Sociocultural Concept:** The cultural background of people affects the experience in a museum, while the museums themselves have their own cultural character. Further, the social context of who someone visits the museum, how crowded the museum is etc have an influence on the experience
    - **Physical Context:** the architecture of the museum building and the design of the exhibition can create an easy or complicated, interesting or dull experience for visitors.
- **Museum Fatigue:** it is part of the Physical context and it refers to the loss of interest from the visitors when they view similar exhibits with no interesting elements.
- **Experience** is a combination of a person's emotional state in relation to the physical interaction within a specific context.
- **Easiness and Fun:** It has been shown that "easiness and fun" are the main experience expectations people have from museums. In addition, museums have to design exhibitions beyond the traditional way, by offering entertainment to the visitor. The collision of art and entertainment is the future of the museum exhibition

4.2 MUSEUM LIGHTING

Understanding how people can experience a museum, the following step is to understand what primarily electric lighting design can do to influence this experience. First, the available lighting technologies are introduced, after which a short introduction to the general function of museum lighting is given, followed by the qualities of light that a lighting designer is able to control. Thereupon, the focus is set to the lighting of three-dimensional objects and the nature and influence of shadows on these objects.

4.2.1 MUSEUM LIGHTING TECHNOLOGIES

Museum lighting has for a very long time been about lighting exclusively with white light, be it natural or electric. Since the 20th century, the "advancements" in museum lighting were largely conjoined with technological progressions. Nowadays, as Saunders (2020) writes, there are four different ways to produce light:

- **Incandescence** refers to materials emitting light as they are heated, and the CCT of the white light increases in correspondence to the temperature
- **Electroluminescence**, on the other hand, refers to light emitted by semiconductors or other specific solids, through which electric current is passed through
- **Electric discharge** refers to electric current being passed through a gas to induce it to emit light
- **Photoluminescence** refers to re-emitting radiation absorbed by a material, at a longer wavelength. Fluorescence indicates fast re-emission and phosphorescence a more persistent re-emission.

INCANDESCENT

As mentioned, the first electric lighting method to evolve was incandescent tungsten lighting, and it dominated the museum lighting field for over a century until their energy inefficiency caused them to fade out of use. The typical CCT for incandescent lights was 2700-2800K (Saunders, 2020). They became common in museums by the beginning of the 20th century, and new museums were designed with consideration to accommodate electric lighting. In the beginning, particularly in North America, a common approach was to install reflector lamps over a daylight to supplement daylight, a practice that is still common. Additionally, the incandescent light sources were equipped with lenses and reflectors to spotlight individual objects, and the techniques evolved hand in hand with advancements in theatre and film lighting, for example, a gobo was used in the 1930s to spotlight the Nike of Samothrace in Louvre (Saunders, 2020; Ezrati, 2014).

FLUORESCENT

Fluorescent lights combine photoluminescence with electric discharge in a closed glass cylinder containing an inert gas and mercury. They are available with CCTs ranging from warm 2700K to cool 6500K, and their colour and CCT is determined by the efficiency and proportion of the red, green and blue phosphors that cause the narrow-band peaks in their spectrum, and the perception of white light (Saunders, 2020). Their energy efficiency is dependent on the narrowness of the bands, which in turn means the more energy-efficient the source, the lower colour rendering properties the light source usually has (Thomson; 1985; Saunders, 1987; Saunders, 2020). Fluorescent lights were first developed in the 1930s, and their use in museums began in the 1940s primarily due to their high efficacy. They were used in between the skylights, along cornices and ledges or in lightboxes above exhibition cases. Moreover, different CCTs of light were used to create different aesthetics and to match the cooler CCT of daylight. The light produced by a fluorescent light source is diffused, so to achieve more directionality, considerable reflectors were required. Thus fluorescent lighting was often supplemented with incandescent or halogen spotlights. In the late 20th century, fluorescent lighting decreased in popularity in museum use, but during the last decade, compact fluorescent lights have revived this lighting technology. However, future legislation might cause fluorescent lighting to be considered too energy consuming, when compared to LEDs (Saunders, 2020).

HALOGEN

Halogen, or tungsten halogen, lights operate similarly to the incandescent light, but in addition to the filament, the bulb contains a small quantity of halogen vapour together with an inert gas. This allows for a higher CCT of 3000-3500K, which also results in more emitted UV wavelengths that until the 1990s were filtered out by UV filters and later integrated within the source itself by the introduction of quartz envelopes (Saunders, 2020; Saunders, 1989). Dimming the halogen light results in a lower CCT, but CCTs lower than 2800K should be avoided as the decreased operating temperature results in reduced lifetime if the temperature required for the regenerative cycle that prevents tungsten deposition is not achieved. In addition to the option to dim, the beam of the light fixtures could be often easily altered from a spot-like beam to a more diffused and wide flood beam. Halogen lights became popular in museum lighting in the 1980's and 1990's, and quickly replaced incandescent sources as they consumed less power, ran at a lower voltage (12V/24V), and because they were much more compact and less obtrusive; however they still radiated much of heat. Tungsten halogen lights are approximately twice as efficient than tungsten incandescent lights, which is why their use has not been banned, unlike the use of incandescent lights, and their development is linked to improving their energy efficiency. However, like with fluorescent lighting, the future legislations concerning phasing out less energy-efficient lamps may lead to halogen's decline too (Saunders, 2020).

LED

Light-emitting diodes, i.e. LEDs are nowadays the most widely used light sources, functioning by the principle of electroluminescence. These are primarily based on inorganic semiconductors or organic LEDs (OLEDs). Within the inorganic LED technology, Saunders (2020) mentions that there are two primary ways to produce white light:

1. Combining three (or more) narrow-band LEDs (such as RGB) to produce a multiband spectrum that to some extent resembles the fluorescent spectral power distribution (SPD), leads to significantly lower CRI
2. Combining electroluminescence & photoluminescence by light from a blue LED falling on a phosphor coating that absorbs and then re-emits the radiation centred around the yellow wavelengths region.

It took LEDs a long time to adapt to museum lighting standards regarding light quality, though they had the advantage of emitting only light in the visible range of the spectrum and not the ultraviolet or infrared, that cause damage on some pigments and materials. Early white LEDs had poor and unreliable light quality and beam homogeneity, and a reduced lifetime due to overheating of the semiconductors. Solid state lighting has solved this issue, also resulting in at least ten times higher efficacy than tungsten incandescent lamps. The improved light quality, long life-time and low energy consumption has led to museums to move from halogen lights to this more sustainable approach of lighting. Nowadays LEDs are very easy to control with several control systems, and some products offer tuning of not only intensity but CCT or colour as well. As the intensity is tuned, the CCT usually remains the same, which is another great advantage of LEDs. However, they easily cause flicker, which is why they should be dimmed using a pulse-width modulation method that switches the LED on and off so fast that the human eye does not perceive it. Flicker is something that, if perceived, affects the atmosphere negatively, and hence it should be minimised. In addition to the control of the colour and intensity of the light, LED fixtures are often easy to fit with lenses, filters and gobos to control the beam of light, or tune the spectrum (Saunders, 2020).

An analysis of the visual and atmospheric effects of these different lighting solutions, concerning both daylight and electric light, in spaces where sculptures are exhibited, is presented in Chapter 5.1.

4.2.2 LIGHTING & PRESENTATION OF ARTWORKS

Museums, because of their importance and according to their exhibitions' themes, consist of complex spaces for lighting designers. Lighting in a museum space has to serve multiple purposes. The space has to be illuminated properly for functional and aesthetic reasons, but also to enhance the exhibits in the best possible way. Museums and galleries can be illuminated in multiple ways according to their needs and aesthetic purposes. In 1958, Rawson-Bottom and Harris explained some of the museum lighting objectives such as that lighting should serve functionality, without creating glare that could cause discomfort to visitors. Further, lighting should enhance the exhibits, their colours, textures and general appearance, while it is important to make sure that it does not cause any damage to them. Lastly, modern lighting techniques have to be used in order to present the exhibits in the best possible way while the lighting equipment should be in harmony with the architectural character of the building (Rawson-Bottom & Harris, 1958).

4.2.3 THE CONTROLLABLE QUALITIES OF LIGHT

Scott Rosenfeld who was a part of the Illuminating Engineering Society of North America (IESNA) and is the lighting designer of Smithsonian American Art Museum, explained at the international museum lighting symposium in 2017: "The primary goal of lighting art museums is to optimise the qualities of light to reduce the rate of damage to lighting sensitive collections while allowing viewers to see as well as possible" (Rosenfeld, 2017, p. 37). In his text for the symposium, he emphasises the need for the use of focused electric lighting fixtures. When it comes to illuminating artworks they "allow designers to access all the controllable qualities of light". He further explains the controllable qualities of light that lighting designers should take into account when illuminating artworks are the quantity, distribution, movement, spectrum and angle of incidence (Rosenfeld, 2017).

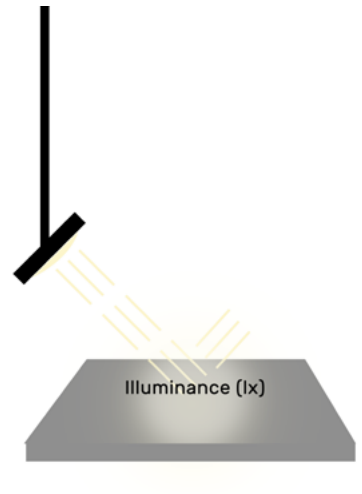


Figure 4.2. Illuminance corresponds to the intensity of light falling on a surface (Heikka & Stamidis, 2022)

Quantity refers to illuminance. Illuminance is the quantity of light, emitted by a light source, on a surface (Descottes & Ramos, 2011). Illuminance is important for the proper visibility of the artworks but is also responsible for their damage. With the use of focal light, the illuminance levels on each artwork can be more specifically set to protect them from damage (Rosenfeld, 2017). Conservation of the artworks is of high importance in museums. Visible light is energy within the visible part of the electromagnetic spectrum that can cause fading of pigments, while the ultraviolet and infrared radiation particularly in natural light poses most risks to materials (Cuttle, 1996). For that reason, the use of electric light is more widely adopted in museum spaces (Cuttle, 1995). Research has shown that LED fixtures, in comparison to halogen lights, are more suitable for museum lighting according to the conservation of artworks, as it causes less damage due to the absence of UV and IR wavelengths in their spectral power distribution (SPD) (Piccablotto et al, 2015). According to CIE 157:2004, there are four categories of materials' sensitivity with recommended illuminance levels, shown in Table 1 (CIE, 2004).

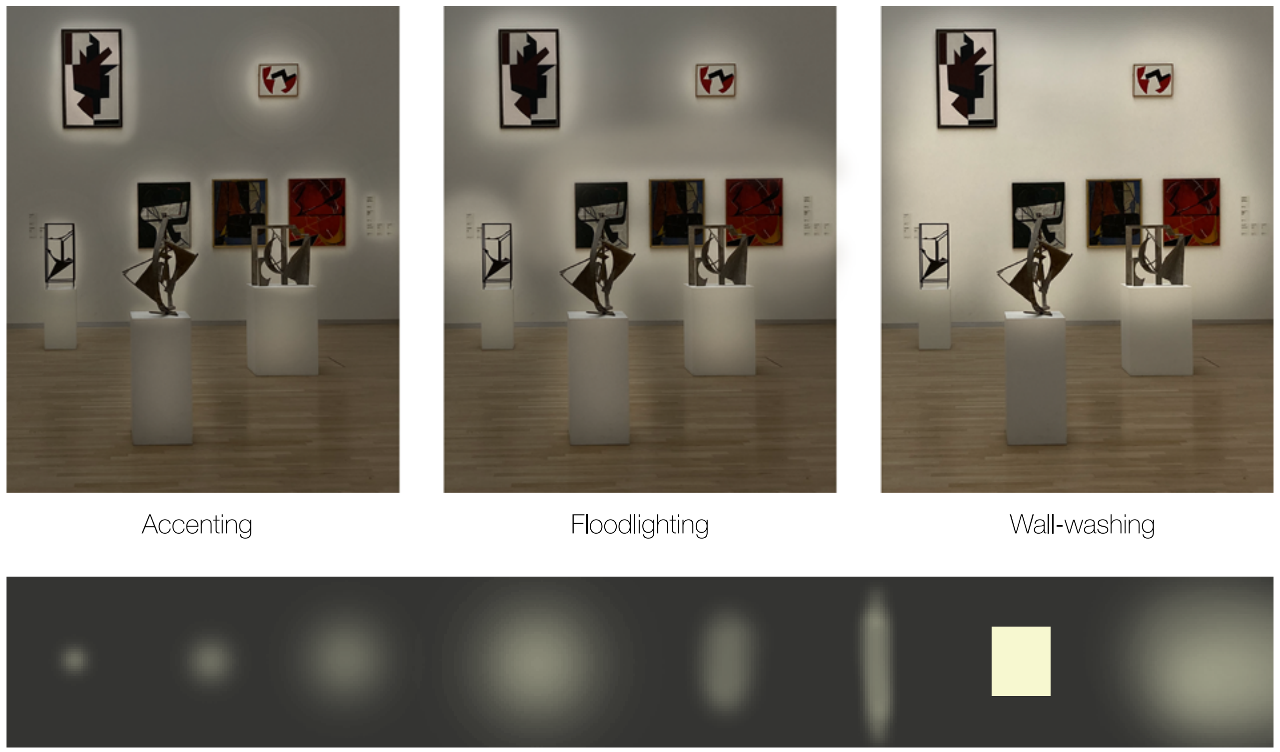
Table 1. CIE's (2004) four categories of materials' sensitivity (Heikka & Stamidis, 2022)

CIE category	Description	Examples	Illuminance level (lux)	Exposure time (hours/yr)
1	Not Sensitive	Most metals, stone, most glass, genuine ceramic, enamel, most minerals	No limit	No limit
2	Slightly Sensitive	Oil and tempera painting, fresco, undyed leather and wood, horn, bone, ivory, lacquer, some plastics	200	600,000
3	Sensitive	Costumes, watercolours, pastels, tapestries, prints and drawings, manuscripts, dyed leather, botanical specimens	50	150,000
3	Highly Sensitive	Silk, fugitive colourants, newspaper	50	15,000

Distribution: "This refers to the size and shape of each light beam (photometric solid) and how these individual beams are distributed throughout the museum to paint the collections and the built environment with light" (Rosenfeld, 2017, p. 38). It is an important quality that can enhance the presentation of the artworks, making them unique elements of the museum. With the evolution of LED technology and the wide range of LED fixtures, the distribution of light can be easily controlled. The ideal use of distribution, according to Rosenfeld, is the one that matches the size of the artwork. The size of the beam usually ranges from 4° to 50°. Though, by adding extra lenses to the light fixtures it is possible to control the distribution of light more precisely, in wider or smaller degrees. Companies like ERCO and Zumtobel refer to different lighting techniques that can be achieved with different types of focused light. The most widely used are wall-washing, floodlighting and accent lighting (Fig. 4.3). Wall-washing technique is used to uniformly illuminate artworks and the space. Floodlighighting is used to illuminate large areas or pieces of art, and accenting lighting emphasises the specific object with a narrow beam of light (ERCO, 2020).

Movement: Movement of light can add playful effects to the atmosphere of an exhibition (Rosenfeld, 2017). With the use of new technologies and systems, exhibitions can be presented more dynamically. Movement, light and art can create an entertaining phenomenon offering an interesting experience to visitors (Schielke, 2020). The movement of light can be achieved in many ways using different technologies. Lights can be pre-programmed to have changes in intensity, colour, distribution or even motion with the use of motors. Rosenfeld (2017) refers to occupancy sensors controlling the light fixtures to turn off when people are not in the exhibition and therefore save energy and protect the artworks from light damage.

Figure 4.3. Types of light beams (Heikka & Stamidis, 2022)



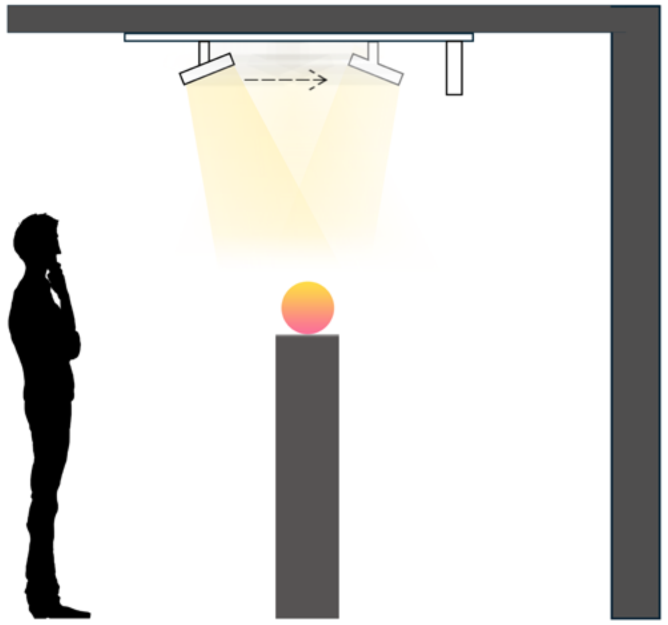


Figure 4.4. Movement of light (Heikka & Stamidis, 2022)

Spectrum: "Choices range from what shade of "white light" is desired to the colour rendering properties of the lighting source" (Rosenfeld, 2017, p. 38). Light fixtures have a variety of white spectrum sources to choose from, and the proper use of the Colour Temperature is essential for the artworks' presentation. Moreover, research has shown that the CCT affects the colour perception of paintings (Feltrin et al, 2020). The lower the colour temperature the warmer the colour of the light and accordingly, the higher the temperature the colder the colour. The choice of the colour temperature determines the appearance of the artworks while it can affect the atmosphere of an exhibition (Dingeldein et al, 2017). Similarly, the colour rendering of the light fixtures plays a key role. The lower the colour rendering index (CRI), the worse or less natural the colours appear. Daylight has a colour rendering (Ra) = 100, under which all the colours are shown at their finest. The existing LED lighting technology has not achieved that number yet, though some LED fixtures can have high-quality values. The recommended CRI value for illumination of objects in museums is Ra ≥ 90 (Dingeldein et al, 2017).

Figure 4.5. Spectrum of light (Heikka & Stamidis, 2022)

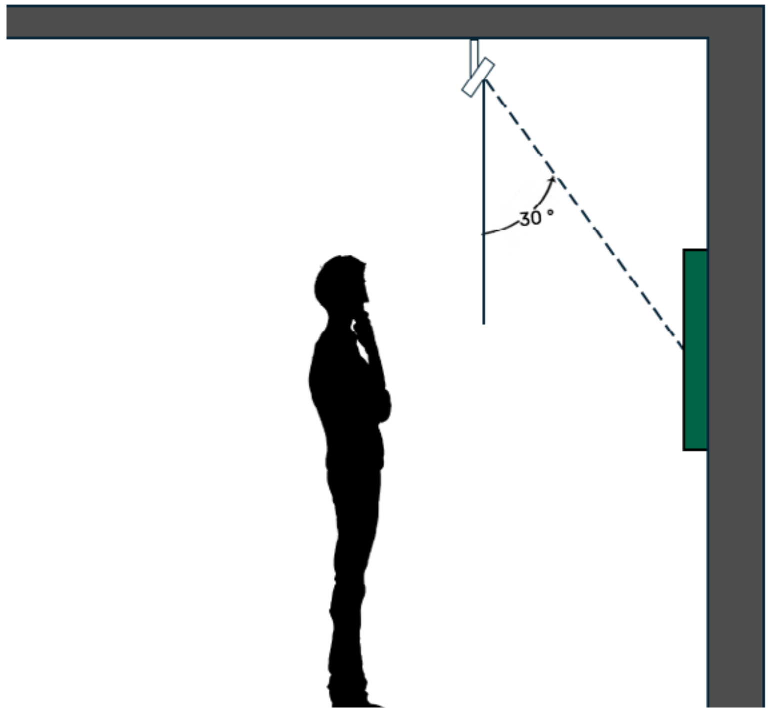


Figure 4.6. Angle of light is often set to 30° in museum lighting (Heikka & Stamidis, 2022)

Angle: Angle of incidence is a parameter that has not to do with the characteristics of the light, but is controlled by the designer. The right arrangement of the light fixtures and their angles enhance the artwork's perception (Rosenfeld, 2017). Usually, in museum spaces, track systems are used for positioning fixtures. Depending on the characteristics of the light source, different recommendations refer to analogous distances and angles from the artworks, to properly illuminate them. Essential is the role of the angle of incidence on three-dimensional objects as it is a tool that can reveal form (Rosenfeld, 2017). Lastly, the angle and position of the light fixtures can cause glare. Glare can create discomfort and affect the experience of the visitors but also the presentation of the artworks. It can be avoided by changing the positions and angle of the light fixtures but also it can be minimised with the use of accessories, like barn doors. As a result, it is crucial to properly control the angle and position of the fixtures in an exhibition space. A typical rule of thumb is to position the lights so that there is approximately a 30° angle (Fig. 4.6.) from the centre of the artwork to decrease veiling reflections and exposure to glare (Saunders, 2020).

4.2.4 THE LIGHTING DESIGN OF THREE-DIMENSIONAL OBJECTS IN MUSEUMS

As it is mentioned in the previous part, the characteristics of the light sources affect the presentation of the artworks. The colour temperature is important when illuminating sculptures, as it can affect the appearance of the object. For that reason, it should be controlled wisely to enhance the object's materiality. Similarly, light fixtures with high colour rendering enhance the object's materiality.

Figure 4.7. At least two light sources with one at a 30° angle are recommended for sculptures to reduce overshadowing (left), while using a steeper angle effectively reveals form and texture by causing stronger contrasts within the object (Heikka & Stamidis, 2022)

According to Rawson-Bottom and Harris (1958) when illuminating sculptures, one dominant light source is required to reveal form. A second light, placed on the opposite side and at the correct angle will support a smooth presentation of the artwork (Rawson-Bottom & Harris, 1958). According to the IESNA lighting handbook, "light from multiple directions models a sculpture, expressing depth by highlighting some areas while allowing others to fall into shadow" (IESNA, 2002, chapter 7). The shadow of three-dimensional objects is a fundamental key to revealing form: " a degree of shadows is a significant visual clue to the solidity of an art object" (IESNA, 2002, chapter 7). By using multiple light sources for three-dimensional objects, it is obvious that multiple shadows would be cast on the surrounding area. Thereby, the designer needs to experiment on-site, with the specific object and light fixtures to find the balance of light and shadows. Another aspect affecting the shadows of three-dimensional objects is the distribution of light. It has been proven that an angle of incidence of 30° is optimal for revealing form with less overshadowing (Thomson, 2013).

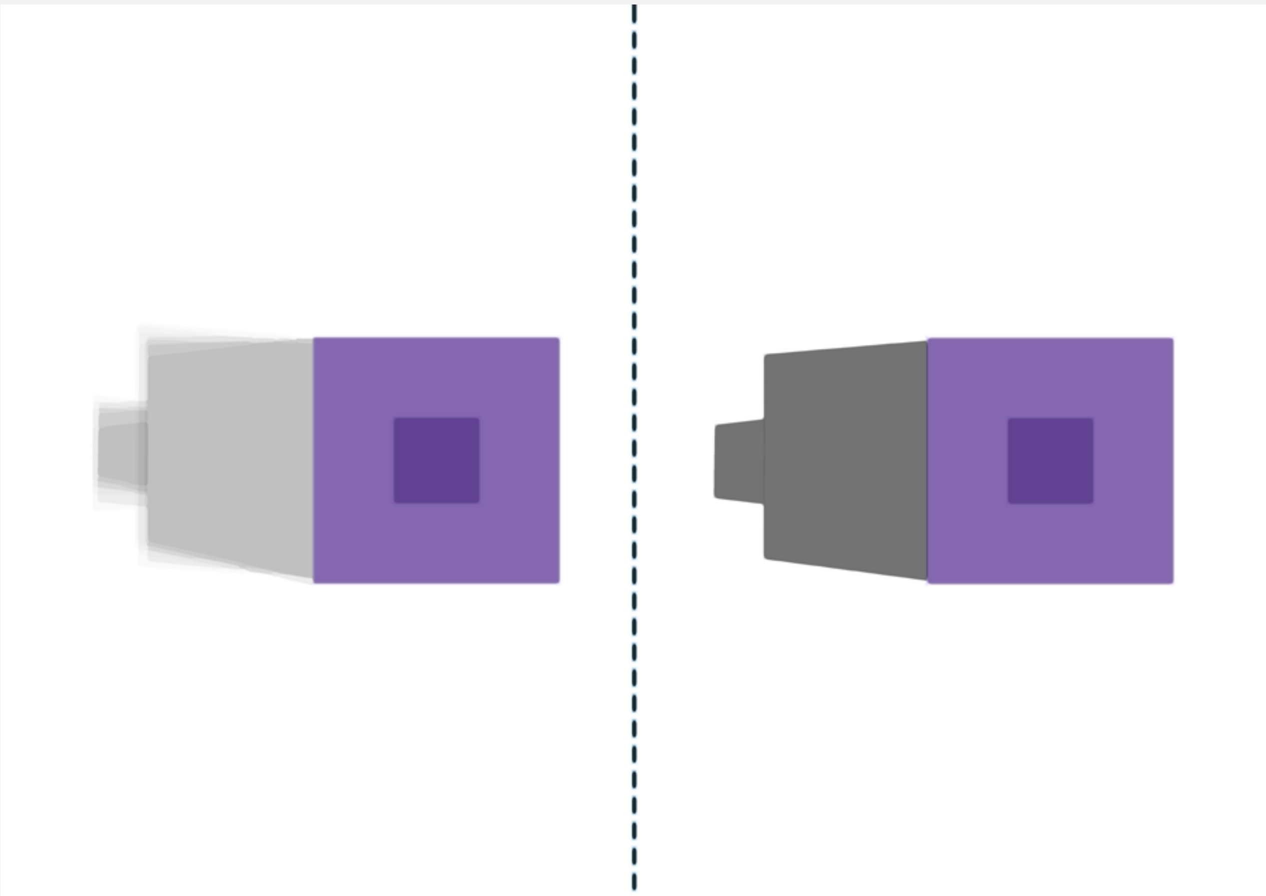
It is usual for sculptures to be illuminated dramatically. A grazing light, illuminating a wall or an object from a steep angle of incidence, will reveal the texture of the sculpture very pronouncedly (Michel, 1996). Sculptures, according to their size, can be dominant objects in a space. By illuminating a sculpture with accent lighting it is easy to create a dramatic presentation, but as Schielke emphasises in his article, the curators must think about how much they can "go in emotionalizing the apparently objective visual language of the artist in an attempt to achieve high-profile exhibitions." (Schielke, 2020).

4.2.5 SHADOWS AND THREE-DIMENSIONAL OBJECTS

> *"We find beauty not in the thing itself but in the patterns of shades, the light and the darkness, that one thing against another creates…Were it not for shadows, there would be no beauty"*
> –(Tanizaki, 2001)

That is the quote from the book "In Praise of Shadows" in which Tanizaki (2001) explains the beauty that can be found in things with light, darkness and shadows. As it is mentioned in the previous part, light and shadows are important factors in revealing the form and texture of three-dimensional objects. Depending on the characteristics of the light source, different shadows appear on objects. The sharpness of the shadow is linked to the size of the light source. A narrow light source, like a spotlight, creates sharp shadows while a larger, more diffuse source, creates soft-edged shadows (Tregenza & Low, 2014). When illuminating three-dimensional objects Tregenza and Low (2014) explain that using a second, lower-intensity light source adds visibility into shadows. Another factor that affects shadows is the distance of the object from the light source. The greater the distance the more divergent shadows are from the object (Tregenza & Low, 2014). In addition, the light's angle of incidence affects the revealing of form. As mentioned in the previous part, an angle of incidence of 30° is optimal for this purpose (Thomson, 2013).

Figure 4.8. Diffuse & sharp shadows (Heikka & Stamidis, 2022)



4.2.6 SUMMARY

- **Museum lighting has multiple purposes:**
  - Functional and Visual
  - Aesthetical
  - Artwork's Enhancement without causing damage
- **The five controllable qualities of light when illuminating an exhibition:**
  - **Quantity:** proper visibility and damage protection
  - **Distribution:** enhances the shape and atmosphere of both the artworks and the space
  - **Movement:** use of technological tools to create a playful exhibition with a variety of changes
  - **Spectrum:** the colour temperature and colour rendering of the light sources affect the presentation of the artwork
  - **Angle:** has to be controlled carefully by the designer to avoid glare in the space, enhance proper visibility of the artworks and reveal the form of three-dimensional objects
- **Specific recommendations need to be taken into account when illuminating three-dimensional objects:**
  - The angle of incidence at 30° of the light source is appropriate to reveal form
  - At least two light sources can enhance the presentation of three-dimensional objects
  - Shadows are of high importance in revealing form and texture to three-dimensional objects
    - Overshadowing should be avoided
    - Shadows can affect the emotionalisation of sculptures

Having gotten an understanding of museum lighting and more specifically how it can be applied to three-dimensional objects, the next chapter analyzes how lighting affects the perception and atmosphere of artworks. Further, it is analysed how different lighting concepts can be used to create a museum experience.

4.3 MUSEUM ATMOSPHERE AND EXHIBITION CONCEPTS

4.3.1 ATMOSPHERE

Philosopher Gernot Böhme (2013) has explained atmospheres are something that can be sensed, they are intangible and yet they can be found almost everywhere: "In general, it can be said that atmospheres are involved wherever something is being staged, wherever the design is a factor - and that now means: almost everywhere." (Böhme, 2013, p.2) An atmosphere can be sensed when entering a room or while walking at the park during the night, and according to Böhme (2013), atmospheres need someone's physical presence in order to be experienced. Atmospheres are perceived differently among people, as their current emotional state but also their background affects the way someone experiences them. Moreover, the perception of the atmosphere is formed from the interaction of the subject with the object. It is the interaction between the person and the things that form the atmospheric conditions. Many factors can create atmospheres, such as the placement of objects in a space, or a smell or sound (Böhme, 2013). Among the factors is the light that without a doubt can create, define and affect atmospheres. Tim Edensor (2015) explains in his article "Light Design and Atmosphere" the role of light in creating atmospheres through three examples of art projects. In his article, Edensor points out the importance of the combination of light, darkness and shadows to create atmospheric experiences. Light can be used as an art element, while when placing it in the right context, the interaction with elements or the environment can create mesmerising experiences (Edensor, 2015)

> "Light expands from a source and can rarely be delimited, as it fades into blackness or blends with other forms of illumination cast across space. This capacity demonstrates how it is an essential ingredient in the relational forces that compose the dynamic amalgam of atmosphere as it shifts and fluxes in intensity and in accordance with surroundings." (Edensor, 2015, p. 347)

4.3.2 ATMOSPHERE AND PRESENTATION OF ARTWORKS

Museums define how they want to communicate their artworks using different lighting concepts and therefore creating different atmospheres. For instance, an exhibition that is uniformly illuminated will be perceived differently than one with high contrasts. As Thomas Schielke explains "With light, exhibition organizers are presented with an influential tool that is able to define the atmosphere for viewing art, establish a sense of drama to support its reception, and generally contribute to the success of the exhibition." (Schielke, 2020, p.7) According to the way that artworks are illuminated, their atmosphere and perception are affected (Schielke, 2020).

Lou Michel (1996) explains in his book "Light: The Shape of Space: Designing with Space and Light" the connection between light and the perception of space or objects. Since human perception is linked to the visual system, light is a factor that affects perception. It can be the way that light falls on objects or how bright objects are, or how the cast shadow patterns affect the perception of things (Michel, 1996). Feltrin et al (2020) explored "Lighting and Visual Experience of Artworks: Results of a Study Campaign at the National Museum of San Matteo in Pisa, Italy". In this study, four different light settings were tested on two artworks, one painting and one sculpture. Participants were asked to fill in a questionnaire

referring to Contrast Perception, Enhancement of the Artwork and Personal Preference. In the case of the sculpture, the use of different light fixtures in different positions created four light settings with a variety of illuminations, highlights and background contrasts (three scenes with high contrast and one scene with no contrast). In the study it was found that people had a significant preference for the artwork's presentation under the settings with high contrast, even though the differentiation between the three scenes with higher contrasts were perceived similarly. The result was similar according to personal preference (Feltrin et al, 2020). Furthermore, these different atmospheres created by the alteration of contrast ratios create different atmospheres that can be represented as lighting concepts.

4.3.3 LIGHTING CONCEPTS: DYNAMIC LIGHTING

Thomas Schielke (2020) proposes an approach with concepts that can be classified into six categories. Each one of them suggests different lighting methods and the use of technological tools that can enhance the artwork's appreciation while affecting their atmosphere and perception. The six categories are presented below:

Objective reception of art: is used to illuminate an exhibition uniformly, presenting the artworks in a realistic, unemotional way. In this concept, space and art appear equally lit.

Subtly emphasising artworks and motifs: is similar to the previous concept while focusing more on the exhibits. A combination of focused and general lighting is used to achieve contrasts in brightness and highlights on the exhibits. The atmosphere remains calm like in the previous category though the artworks are slightly outstanding.

Dramatically displaying exhibits: in this category artworks are prominent. Lighting creates high brightness contrast between the artwork and the room while emphasising and emotionalizing their presentation. This concept is mostly used when illuminating sculptures.

Magically illuminating works of art: is used to emphasise exclusively the artworks. In a dark room, contour spotlights illuminate exclusively the artworks creating a dramatic and artificial approach.

Interpreting artworks with hyperrealism: is used to emphasise the artworks and their details in an artificial representation. Lighting creates high contrast brightness and intensities while in different CCTs.

Dynamically communicating artworks: Is used to emphasise the artwork but also to create a lively atmosphere and entertaining presentation of artworks. Lighting is dynamic, changing in for example intensities, colours and spectrum, while it can be programmed in different ways like time-based control or through an app.

The different lighting concepts constitute important knowledge of lighting practice in a museum in order to properly illuminate the exhibits and the space, enhance the atmosphere and create an experience through an exhibition. The dynamic communication of exhibitions is of great interest in this report and is further analysed in the next chapter.

4.3.4 DYNAMIC COMMUNICATION OF EXHIBITIONS

The dynamic communication of exhibitions has gained in popularity in recent years. In order to attract younger visitors, museums are looking for new ways of presentation (Mattern, 2014) that differ from the traditional way of exhibition. According to Schielke (2020), lighting and technological tools can dynamically communicate artworks while creating a lively atmosphere and attracting visitors' attention.

As Schielke explains, the dynamic communication of artworks can be achieved in many ways. For example, it can bring a character's pulsating spirit to life with pulsating light (Bogner et al, 2005). It can also be to illuminate an entire exhibition using programmable lights that change colour, affecting the total atmosphere of the space and the artworks. Such an example is the exhibition made by David Hockney in the Smithsonian American Art Museum (2003), where the colours of the installation appeared differently according to the colour changes of the lights (Smithsonian American Art Museum, 2003). Another example is softly moving shadows, visible on Fig. 4.9, that elegantly mimic and reproduce the soft swaying movement of seagrass in the exhibition "Oceanista" at the Søfartsmuseet in Helsingør, Denmark, where Arthur van der Zaag designed the lighting (2021). The movement was accomplished by the use of DMX-controlled RGBW moving heads on moving tracks manufactured by Wahlberg.

Dynamic communication can also be achieved by installing sensors in the exhibition space that will allow pre-programmed lighting in different intensities or colours to turn on when someone enters the room, offering an experience of a dark-to-bright environment. Another way of creating dynamic communication of artworks that Schielke explains, is to allow visitors to affect the lighting through their phones, using apps. Dynamic lighting can have a significant impact on an exhibition and for that reason, the lighting designer needs to think about how far they can go with emotionalizing the art. Moreover, the lighting needs to be elegantly designed so that art aficionados won't view it as kitschy if the atmosphere gets too far away from the style of the art (Schielke, 2020).

Since dynamic lighting in museums is a new field the research on this topic is limited. Though, Gobbato et al (2020) investigated the effects of dynamic lighting on the visitor experience at the space "Gallery of Evolution" in the National Museum of Natural History, Paris. The Gallery of Evolution was renovated in 2014 and the original designers' intention was to exclude natural light while they modified the ceiling and the sidewalls for general lighting in combination with spotlights for focused light on the exhibits. In order to create dynamic lighting in that space,

Figure 4.9. Moving shadows at "Oceanista" temporary exhibition in M/S Museet for Søfart, Helsingør, Denmark. Screenshots from a video taken by authors. (Heikka & Stamidis, 2022)

the authors used DMX controllers. Coloured lighting from the ceiling and side walls affected the general space, while the spotlights were changing colour in the white spectrum, focusing on the exhibits (<20 animal figures) and. The authors created seven sequences of dynamic lighting, inspired by various weather conditions which contributed to the general atmosphere of the space: morning, cloudy sky, storm, day, dusk, night, and dawn. In every sequence, focused lighting was adjusted accordingly and one cycle of the dynamic lighting lasted one hour and fifteen minutes. As the authors explain, the purpose of their experiment was to investigate if dynamic lighting at the Gallery of Evolution could create a meaningful and sensory experience for the visitor and if so, to understand to what extent dynamic lighting affects the experience. The authors used surveys, video recordings, an eye-tracking system and conducted interviews with people in order to understand the effects of dynamic lighting on the visitor experience (Gobbato et al, 2020).

The results of their research showed a significant effect of dynamic lighting on the experience. People expressed that they experienced a more relaxing and calmful atmosphere. Further, people felt more focused and connected with the exhibition. As Gobbato et al (2020) explain in their paper, visitors felt that the dynamic, general lighting created a separate environment from the rest of the museum, which enhanced people's focus on the exhibition. Lastly, the use of colour in the dynamic scenes created an atmosphere that triggered visitors' imagination and memories. The luminous atmospheres created different environments that, as people explained, were able to connect and recall personal memories enhancing their experiences (Gobbato et al, 2020).

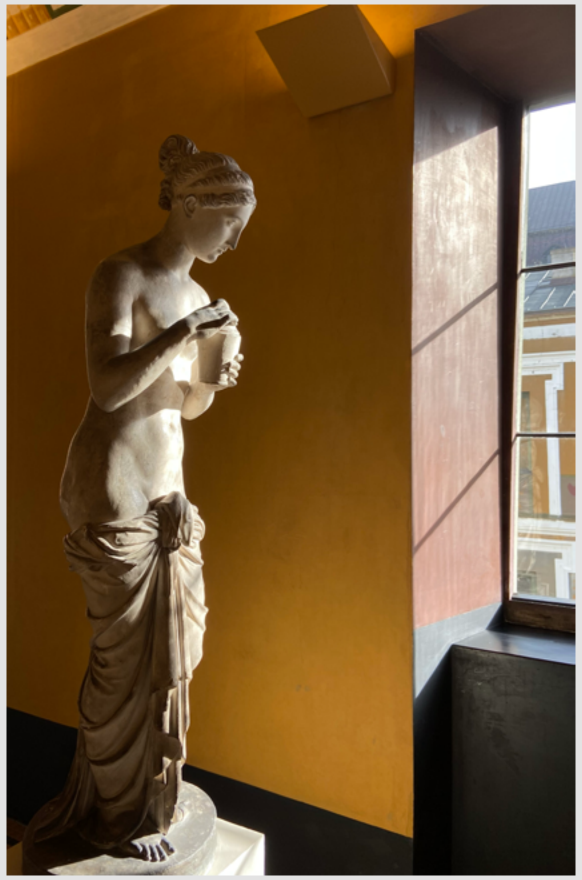


Figure 4.10. Natural dynamic communication (Heikka & Stamidis, 2022)

4.3.5 SUMMARY

- **Atmosphere:**
  - Is subjective while someone's background and emotional state affect the experience of the atmosphere
  - Needs someone's physical presence to be experienced
  - It is the interaction between subject and object
  - Light is a tool that can effectively affect atmospheres
- **Perception:**
  - Is connected with our visual system
  - Light can affect the perception of things for example how light falls on an object or the shadow patterns it creates etc
  - In a museum environment, different lighting concepts would illuminate different the artworks, affecting their perception
  - Specifically for sculpture, the creation of high background contrast enhances their perception
- **Dynamic Lighting in a museum:**
  - Can be achieved in many ways by using different technological means.
  - Light can have movement, changes in colour, and intensity.
  - Dynamic lighting can create unique and engaging experiences at a museum while it can attract more people and keep up their interest in the exhibition.
  - When applying dynamic illumination to artworks someone has to think:
    - The artist's intention
    - How far they can go with the emotionalization of the artworks
    - Not be more dominant than the exhibit
    - Not to create a kitschy environment

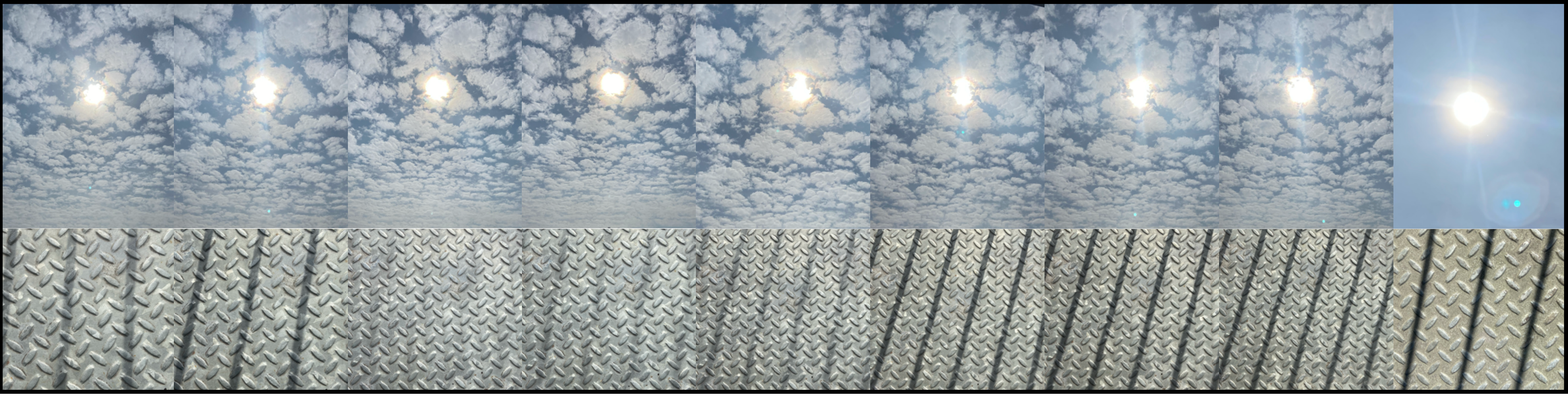


Figure 4.11. Clouds strongly affect the diffusion and sharpness of shadows (Heikka & Stamidis, 2022)

4.4 DAYLIGHT AND ITS DYNAMICS

4.4.1 DAYLIGHT

> "Daylight can be divided into two components: sunlight and skylight. Sunlight is light received at the Earth's surface directly from the sun. Sunlight produces strong, sharp-edged shadows. Skylight is light from the sun received at the Earth's surface after scattering in the atmosphere. It is this scattered light that gives the sky its blue appearance, as compared to the blackness of space. Skylight produces only weak, diffuse shadows. The balance between sunlight and skylight is determined by the nature of the atmosphere and the distance that the light passes through it." (Boyce, 2014, p.28)

Humans are used to complementary shades of shadows, with cool diffuse blue skylight toning the shadows and warm direct yellow sunlight highlighting whatever hits its path. Moreover, daylight has several temporal characteristics, of which the most perceptible are its changing movement, angle of incidence and colour/spectrum (Cuttle 2015; Tregenza & Wilson 2011). As the Earth rotates around itself and the sun, the sunlight's angle of incidence at a specific geolocation changes. Over the course of the day, daylight causes many picturesque moments, particularly the twilight and the moments relating to it. The golden hour and blue hour are the most striking of these, as atmospheric scattering affects the colours of the sky, clouds and direct sunlight (Bikos & Kher, n.d.). The golden hour occurs when the sun is 6 degrees above to 6 degrees below the horizon (Bikos & Buckle, n.d.a). The blue hour, in turn, occurs when the sun is 4 to 8 degrees below the horizon (Bikos & Buckle, n.d.b). The cause of these colourful moments is the Rayleigh and Mie scattering effects that occur in the atmosphere. The former causes the sky to appear blue and refers to light hitting particles smaller than the wavelength of light, such as nitrogen and oxygen, while the latter refers to light hitting larger particles than the wavelengths of light, such as dust, sand, pollen or volcanic ash. When the sun is further away from a specific point on Earth, its colour appears more amber/red as the shorter wavelengths get scattered into more directions by the particles in the atmosphere. Moreover, for example after volcanic eruptions or when winds blow Saharan desert sand to other parts of the world, the sunsets and clouds appear extremely red, as seen in Fig. 4.12 (Lorch & Miah, 2016).

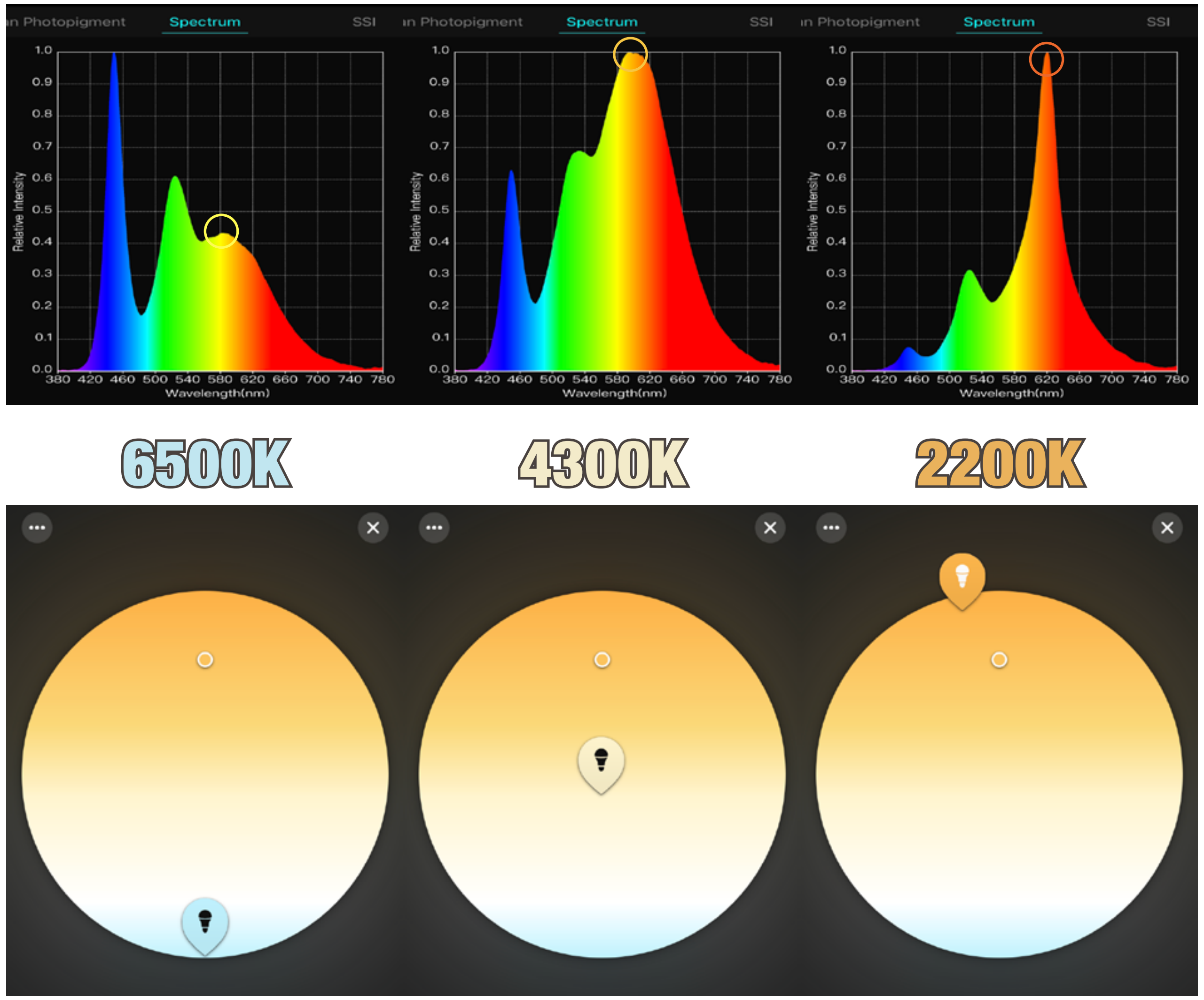
Figure 4.12. Red Sunset in Scheveningen, Netherlands. Photo taken by A.V.V. Heikka, 18.04.2018.

4.4.2 ADAPTATION TO THE DYNAMICS OF DAYLIGHT

The scattering phenomenon is directly linked to how the perceived CCT of direct sunlight changes the further away it is. The perceived CCT changes to a warmer tone as shorter wavelengths of light are scattered more compared to higher, i.e. orange and red wavelengths, that pass easier through larger particles in the air (Lorch & Miah, 2016). While this phenomenon is part of natural light, for electric light to mimic the CCT of white light while achieving great colour rendering, the light sources must follow the principles of how CCT changes in the first place. As can be seen from Figure 4.13, Philips Hue light changes its CCT corresponding to the principle that CCT naturally changes as the yellow-orange wavelength peak of the light source moves.

When using a typical RGB-controlled luminaire, the wavelength peaks have been set and they can only change in intensity, not shift in peak wavelength. As can be seen from Fig. 4.14, a screen of a MacBook Pro, which creates colours by the combinations of RGB channels, changes the tone of #FFFFFF (all RGB channels at max) white towards a warmer tone when entering the "night mode" by the reduction of blue wavelength. This causes us to perceive the #FFFFFF white as more yellow. However, it does not change the CCT of the light, as RGB LED

Figure 4.13. Philips Hue tunable white light changes CCT according to the scientific principle of how CCT shifts, resulting in maintaining a high CRI and a natural perception of white light.



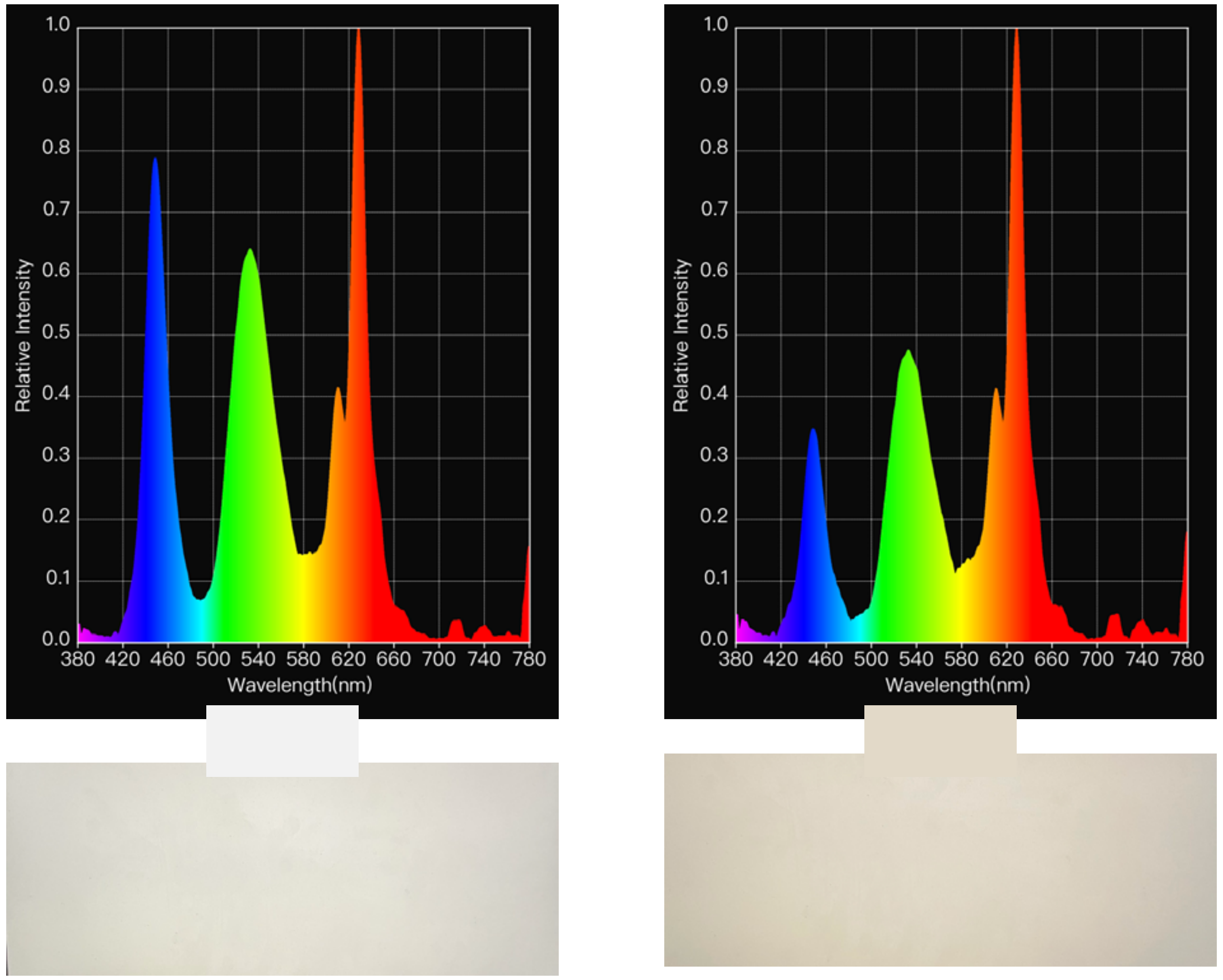


Figure 4.14. The typical peaks of an RGB light source, in this case those of a MacBook screen with a colour of #FFFFFF, i.e. whitest white the screen can produce. RGB sources cannot shift CCT in a natural way as seen from comparison of a) Normal screen mode b) Night mode on with reduced blue peak, making the screen appear yellowish.

lighting is not capable of doing that. While the white light illuminant spectrum and CCT changes, the chromatic adaptation abilities allow us to maintain the colour constancy of objects, which is one of the over 40 functions of the complementary perceptual system (Pridmore, 2009). The chromatic adaptation time between illuminants is suggested to be around 10 seconds (Fairchild & Lennie, 1992).

While the human visual system will maintain the colour constancy of the objects, light sources can still tone objects by their colour, and in nature, these colours can be seen particularly around sunset, when the long wavelengths dominate the relative emission spectrum of the direct sun, and when the clouds get orange-red-magenta-purple shades. Light modelling is defined as how lighting influences the perceived characteristics of an object, and how it reveals or conceals its shape, depth and texture (Rea, 2000). Moreover, the most critical aspects of light modelling are suggested to be distinctness of details, shape and contour (Zaikina, 2016). In addition to revealing the qualities of the object, the shadow patterns and the hardnesses of shadows are integral to take into account when speaking about the modelling of three-dimensional objects and experiencing them naturally (Frandsen 1989; Zaikina 2016).

4.4.3 DYNAMICS OF DAYLIGHT VS ELECTRIC LIGHT

Daylight is dynamic, with various and instant changes during the day and over the year while the weather conditions affect its intensity, colour, diffuseness and direction (Knoop et al, 2020). Sunlight is an enormous source of light at a great distance from earth, it is part of nature and makes it unpredictable and difficult to control in comparison to electric light that is man-made. For that reason, several characteristics of daylight cannot be "re-created" by electric light. Daylight has a continuous spectral power distribution with wavelengths ranging from approximately 290 to 2600 nm. Meanwhile typical general electric lighting has less variety in the SPD (380nm – 780 nm) which can be continued or not, depending on the light source. Moreover, daylight has constant variations in the spectral distribution, intensity and colour in comparison to electric light that is static (Knoop et al, 2020). Though, with the use of LEDs and light technologies, light can be pre-programmed to change in colour and intensity. Lastly, because of its great distance and size, daylight has parallel beams that electric light cannot achieve. That fact also affects the difference in shadows created by daylight and electric light. (Knoop et al, 2020).

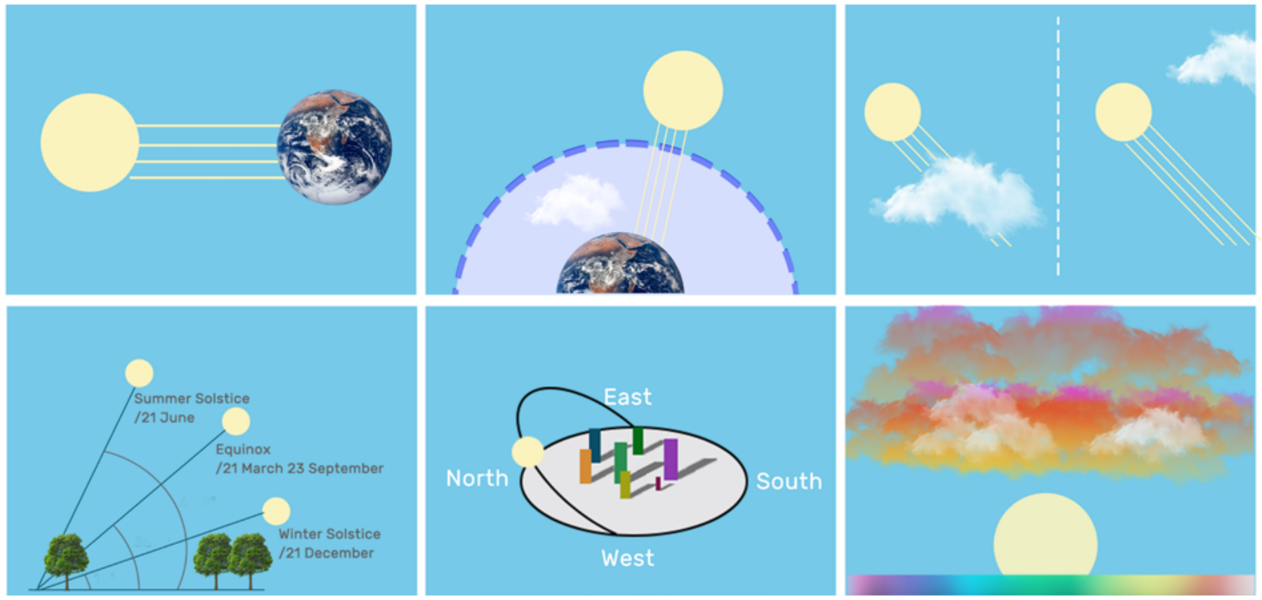


Figure 4.15. Artistic representation of qualities of daylight (Heikka & Stamidis, 2022). From upper-left:

- Natural light has parallel beams
- Natural light is a combination of the skylight and sunlight
- Natural light is unpredictable and dynamic according to weather conditions (instant variations)
- Sunlight is different according to the time of the year and geographical location
- Sunlight is different according to the time of the day (instant variations)
- Sunlight has a continuous spectrum

4.4.4 DAYLIGHT AND SHADOWS

As Peter Tregenza and Michael Wilson explain in the book, "Daylighting, Architecture and Lighting Design" sunlight creates crisp shadows. According to the position of the sun, shadows differ in length and colour. When the sun is low in the sky, long shadows occur in comparison to when the sun is in its highest point on the sky. The crispness of the shadow is influenced by the thickness of clouds in front of the sky. Additionally, the skylight is diffuse light coming from all directions that creates soft-edged shadows (Tregenza & Wilson, 2011). Throughout the day and seasons, the weather conditions and time affect the shadows dynamically, since a clear sky with the direct sun could change to a cloudy sky. As a result, if someone was observing a sculpture outdoors, they would be able to see all the different shadows that move throughout the day revealing different details and textures. All those unpredictable variations are something that electric light cannot recreate (Tregenza & Low, 2014). Specifically, for sculptures that are on a larger scale and were intended to be presented outside, sunlight is the only light source that can reveal their beauty holistically because it is a gigantic source at an enormous distance and such conditions cannot be supported in a museum or a gallery space (Tregenza & Low, 2014).

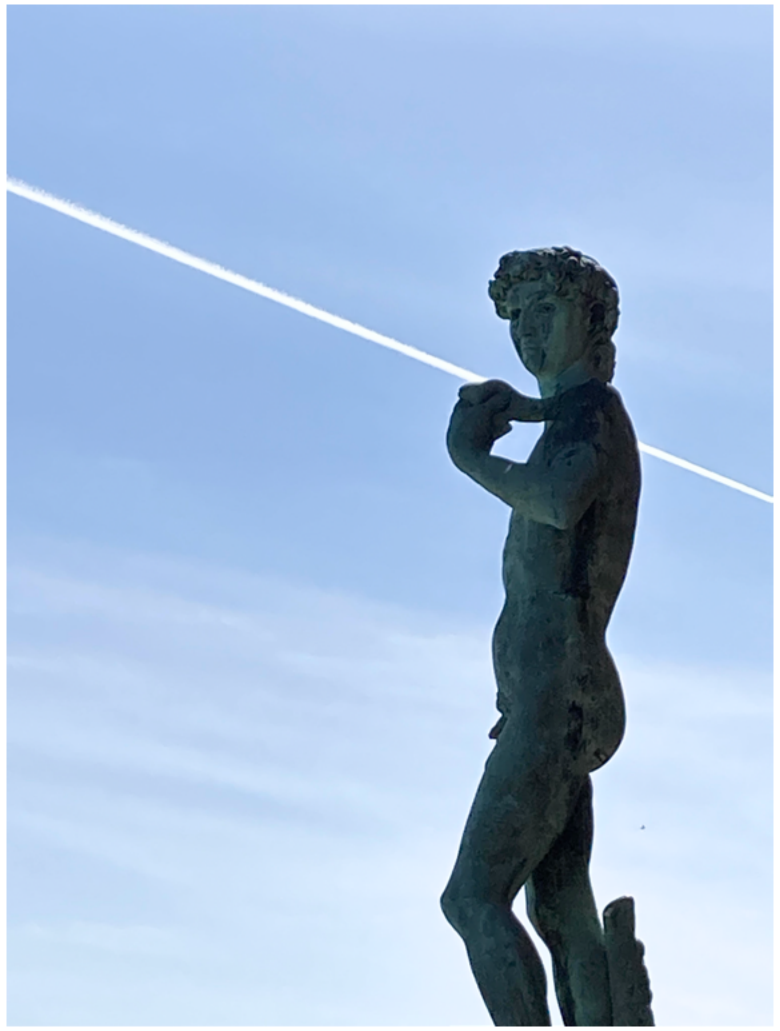


Figure 4.16. Bronze copy of Michelangelo's David in front of the Royal Cast Collection, Copenhagen, Denmark. (Heikka & Stamidis, 2022).

4.4.5 SUMMARY

Natural light:

- Is a combination of skylight (diffuse light) and sunlight (direct light)
- Has parallel beams of light
- Is unpredictable and has different dynamics while it is affected by the weather conditions
  - Variations in spectral distribution, colour and intensity
- It has a variation of changes in CCTs throughout the day, time of the year and geographical location
  - Some white-tunable LED light sources can shift the yellow wavelength peak naturally like daylight, but RGB sources are not capable of doing that
- It has a continuous spectrum
- Variations to shadows
  - Skylight gives soft-edged shadows and different sunlight crispy shadows
  - Different lengths of the shadows throughout the day

Having gotten an understanding of the three Vision's fundamentals through the literature review, in the next chapter the analysis is presented. In order to get a deeper understanding of the information presented above, four different situations were analysed. Firstly, by visiting three museums in Copenhagen we aimed to get an understanding of how museums utilise lighting, what are the techniques, technologies and qualities of light applied on sculptures' illumination. The next chapter analyses multiple natural light conditions on different times of the day. By taking spectrometer measurements and pictures of the sky, we aimed to get an understanding of the variations of natural light while capturing its multiple dynamics. In addition, a timelapse is presented and analysed, aiming to get an understanding of how natural light affects three-dimensional objects. Lastly, we conducted interviews with four professionals working in museums. By analysing these interviews we aim to understand the museum context from various expert viewpoints.

5 ANALYSIS

5.1 DOCUMENTATION OF MUSEUMS & ANALYSIS OF EFFECTS & ATMOSPHERES

All spectrometer measurements were taken with Asensetek Lighting Passport.

5.1.1 GLYPTOTEKET

The New Carlsberg Glyptotek is a renowned museum in central Copenhagen. As the name implies, Glyptoteket displays primarily sculptures. The museum was inaugurated in 1897 from the architect Vilhelm Dahlerup and got new extensions in 1906 (Dahlerup's Winter Garden & Hack Kampmann's extension & Central Hall) and 1996 (Henning Larsen building) (Glyptoteket, n.d.). The museum was initially intended to be a daylight institution with limited electric light, which was widely introduced only in 2015 (Ny Carlsberg Fondet, 2015). Since the beginning, the idea of Glyptoteket was to offer Copenhageners a beautiful oasis where they can experience sculptures as close to their natural habitat as possible. This is why the museum emphasises the use of natural light and why the winter garden (Fig. 5.1) features plants from the Mediterranean climate. Similarly, the Central Hall (Fig. 5.2) got its inspiration from classical Roman forum, where statues of citizens and emperors stand harmoniously in between the columns (Glyptoteket, n.d.).

Figure 5.1. Glyptoteket's Winter Garden (Heikka & Stamidis, 2022)

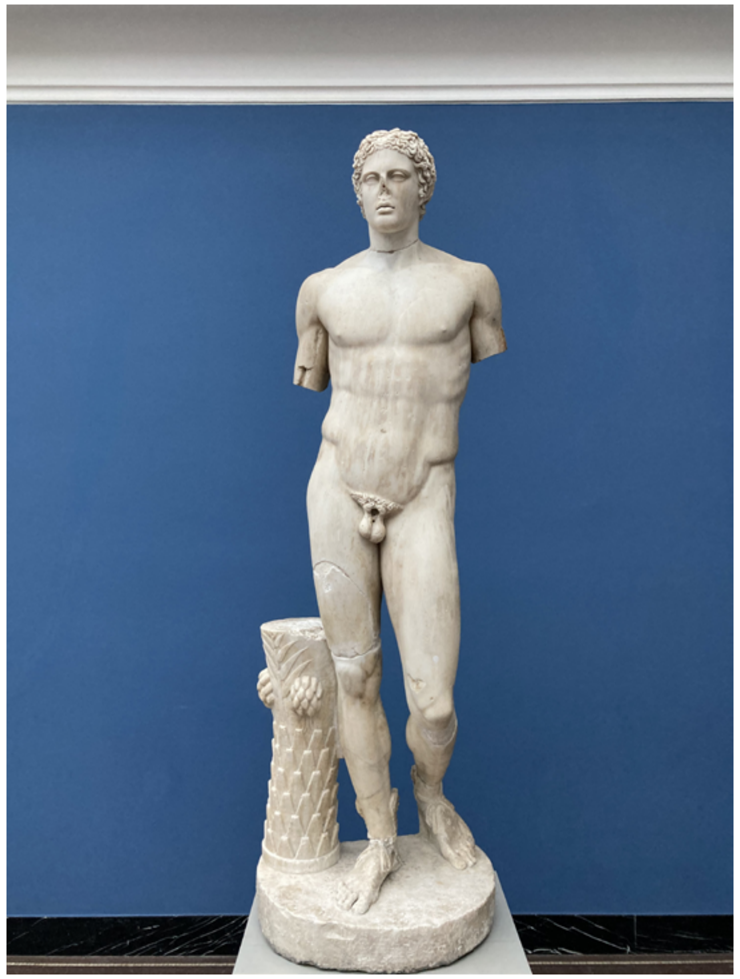
Figure 5.2. Glyptoteket's Centrall Hall at day and at night (Heikka & Stamidis, 2022)

As Glyptoteket is a museum primarily focused on displaying sculptures, they utilise daylight in most of their rooms. In the daytime the rooms have a very calm, spacious atmosphere and the sculptures seem like they belong to the room, that they are one with the space. Skylights made of prismatic or milky glass let diffused daylight in, while the architectural forms, materials and the fine wall colours enhance the feeling of being in an aesthetically outstanding space. The sculptures are a part of the holistic visitor experience of visiting an architecturally significant building such as the Glyptoteket. At daytime, the artwork and space complement each other, creating a harmonious environment in which it is pleasant to abide. The sculptures are illuminated only by diffused natural light that models the object uniformly, with exceptions particularly in rooms where the daylight opening is on a wall instead of ceiling.

Figure 5.3. Glyptoteket's Egyptian room blocked from daylight (Heikka & Stamidis, 2022)

Due to the large size of the museum and exhibitions consisting mainly of similar-looking sculptures, museum fatigue begins to take effect after 45 minutes of walking through the exhibitions. For us two, this shows as increased walking speed through the exhibitions and less attention paid to the individual artworks. The vast number of exhibits, their similarity with each other and the uniform lighting may be the cause of this. However, the Egyptian room that is completely blocked from daylight probably due to conservatory reasons offers a refreshing experience. Moreover, the fact that you can go into an outdoor space in the Henning Larsen extension and consume food or beverages in the cafe by the Winter Garden helps relieve the symptoms of fatigue.

To see the objects illuminated by electric light after sunset, we left the museum to give our brain some resting time, get some fresh air and enjoy a cold beverage. After we returned, the sun had set and the atmosphere had changed (Fig. 5.4).



DAY

NIGHT

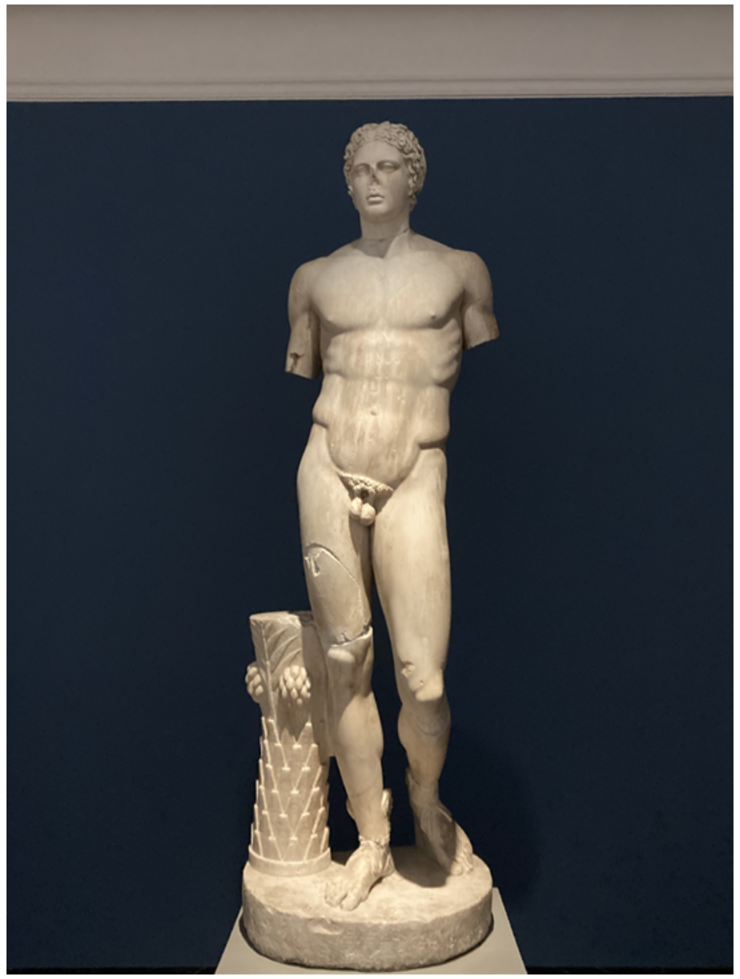


Figure 5.4. Glyptoteket's exhibition hall at day and at night. (Heikka & Stamidis, 2022)

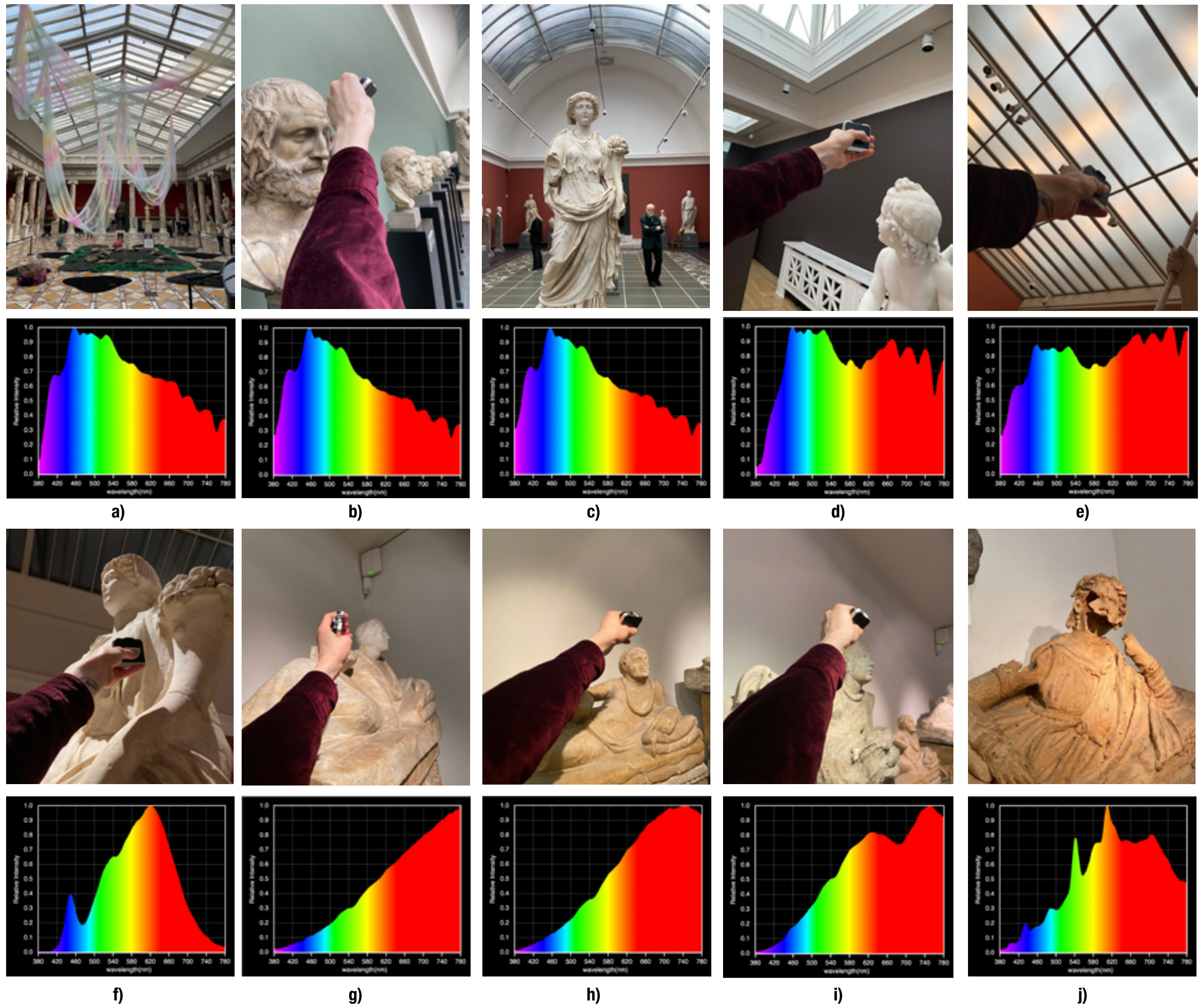


Figure 5.5. Spectrometer measurements from Glyptoteket. CCT & CRI values in Appendix. (Heikka & Stamidis, 2022)

DAYLIGHT CONDITIONS AT GLYPTOTEKET

Looking more closely at the daylight conditions in Glyptoteket, minor variations between the rooms transpire. In the Central Hall where they hold events, single-layered prismatic skylights cover the entire ceiling, allowing ample daylight into the hall (Fig. 5.5a). As the measurement of the sky's spectrum outside is not available, it is difficult to judge the spectral transmittance of the window.

However, when looking at the rooms with double skylights, it can be seen how particularly green wavelengths are reduced, along with higher wavelengths (Fig. 5.5b,c). In the other room with a child angel statue, the SPD of the transmitted daylight misses wavelengths in the yellow part of the visible spectrum as well as the violet & ultraviolet (Fig. 5.5d). While the absence of ultraviolet light can be explained with its absorption by the glass, the reduced intensity in the mid-range of the visible spectrum might be the cause of the cloud cover and the sunset occurring twenty minutes after the time of the measurement.

Glyptoteket also has rooms that are equipped with skylights that are clearly very diffusing, and have electric light sources behind them to illuminate the space by diffused ambient light even when the sun is not shining (Fig.5.5e). As we have no measurement of the space after sunset,

we cannot know the SPD of the light sources placed behind the skylights. The atmosphere in the room is still and a little dull due to the strong diffusion and absence of focal light.

The more layers of skylights and diffusion of light, the more the atmosphere transforms into feeling like an overcast day, as Lam also explained in his 1977 book "Perception and Lighting as Formgivers of Architecture". When the majority of sculpture-filled rooms are illuminated with daylight, the feeling of drowsiness and tiredness begins to settle in. The lack of dynamism that characterises a bright and sunny day, often associated with Mediterranean countries, does make the atmosphere calm, still and harmonious but fails to keep the interest up.

ELECTRIC LIGHTING CONDITIONS AT GLYPTOTEKET

The electric lighting utilised in Glyptoteket is exclusively static by nature. They use LED, halogen and fluorescent light sources in their exhibition spaces. In the further rooms with lower ceiling heights they have implemented halogen lighting and in some rooms combinations of halogen focal light + fluorescent ambient light. Some of the light sources have a decreased light quality, which can be seen from the spectrometer measurements on Fig.5.5g,h,i by the negative peaks in the spectrum when compared with the ones in top condition. This results most likely from their lifetime.

Glyptoteket primarily uses Erco's Parscan LED luminaires on suspended track systems. The track systems are aligned with the building architecture and blend in the surroundings with their white colour. The luminaires are also coloured white and have a high CRI of around 90. Many of the lights are narrow beam spotlights, and others have different kinds of optics depending on the application. The quality of light is excellent and due to the high ceiling height, narrow beams can easily be utilised even for larger, human-scale objects, leading to more natural lighting situations.

In the Egyptian area, Erco lights that were equipped with a cyan filter lighted two bronze sculptures and made them stand out from the other exhibits. The colour adds mystery, mysticality and intrigue, and makes the statue seem as if it had a patina. In the downstairs of the Egyptian section, the light levels are low likely for conservation purposes, which advantageously enhances the mystical, nocturnal atmosphere and makes you feel as if you were seeing the objects inside a pyramid. The light source has a warm CCT of 2800K, and the spectrum resembles an LED version of incandescent light.

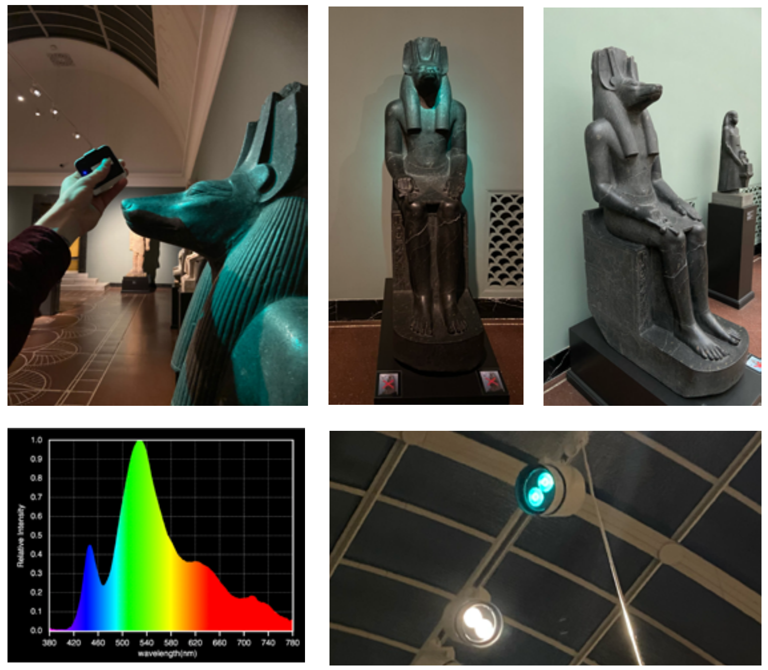
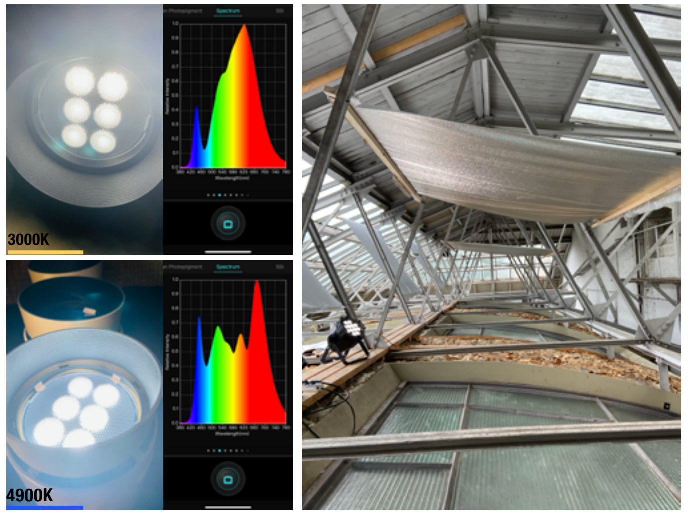


Figure 5.6. Images of the cyan-green lit Egyptian statue at night and at daytime, and the spectrometer measurement of the light source (Heikka & Stamidis, 2022)



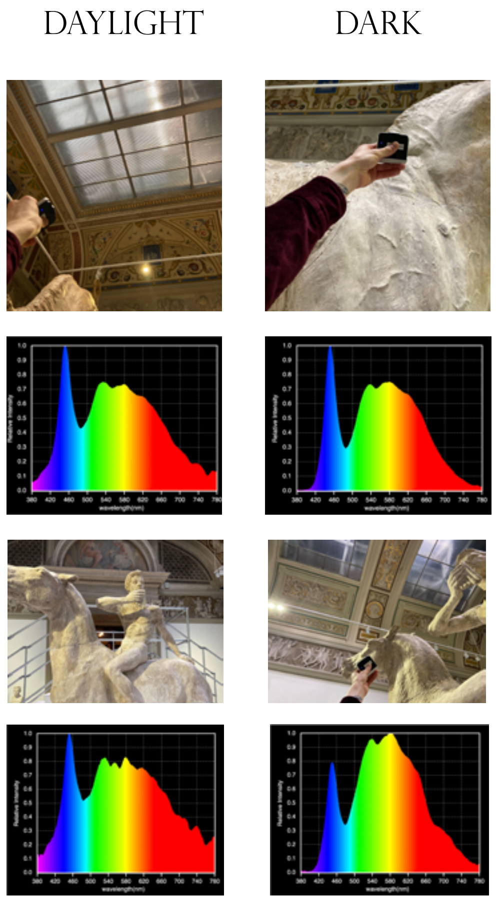


Figure 5.7. (above) Light sources used in the Anne Marie Carl-Nielsen exhibition where Udstillingslys designed the lighting (Heikka, 2021). Left: Erco lights ; Right: RGBW fixtures.

Figure 5.8. (right) Spectrometer measurements from the Anne Marie Carl-Nielsen exhibition at Glyptoteket. CCT and CRI values in the Appendix (Heikka & Stamidis, 2022).

In the exhibition hall where there is a temporary Anne Marie Carl-Nielsen exhibition, the lighting has been designed to mimic daylight. This has been done using RGBW lights installed in the space between the double-layered skylights (Fig. 5.7) pointing towards a reflector fabric, which in turn reflects the light into the exhibition space through one skylight layer. In addition to this diffuse ambient light, filtered Erco spotlights are used to highlight some of the artwork. The original CCT of the light source is 3000K but with a blue filter, the CCT increases to 4900K. In addition to cooling the white light towards “daylight white”, the CRI of the light source has improved from 88 to 94 (Fig. 5.7).

When entering the exhibition, we felt the daylight atmosphere and were surprised how realistic it looked. However, we also perceived that something was not right – the atmosphere seemed slightly too artificial and the light had a greenish tone. The spectrometer measurement in Fig. 5.8 (below right) reveals why this sensation is in fact true: the green-yellow part of the spectrum is represented significantly stronger than others, and there are less red and blue wavelengths, which is not common to occur in nature, as can be seen in Chapter 5.2..

Another reason for the artificial-feeling perception might be that the cyan part of the spectrum is not represented as strongly as others, due to the negative peak typical for LED lighting. In reference to Pridmore’s 2009 extensive paper about “Complementary Colors Theory of Color Vision: Physiology, Color Mixture, Color Constancy and Color Perception”, this might have something to do with how we perceive colours. Moreover, as the sculptures, walls and floors are white, we perceive more green surfaces.

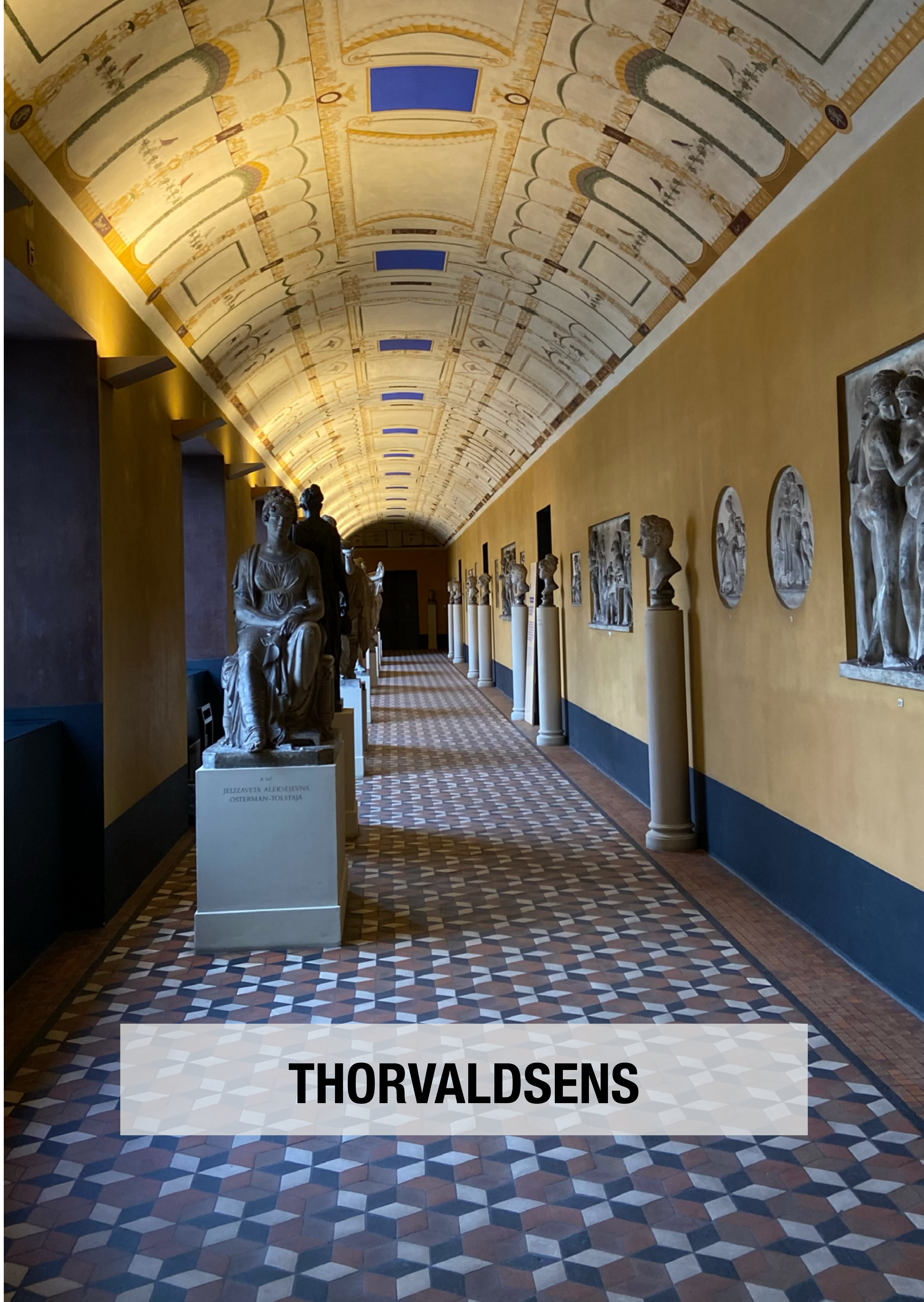


Figure 5.9. Thorvalsdens Museum (Heikka & Stamidis, 2022)

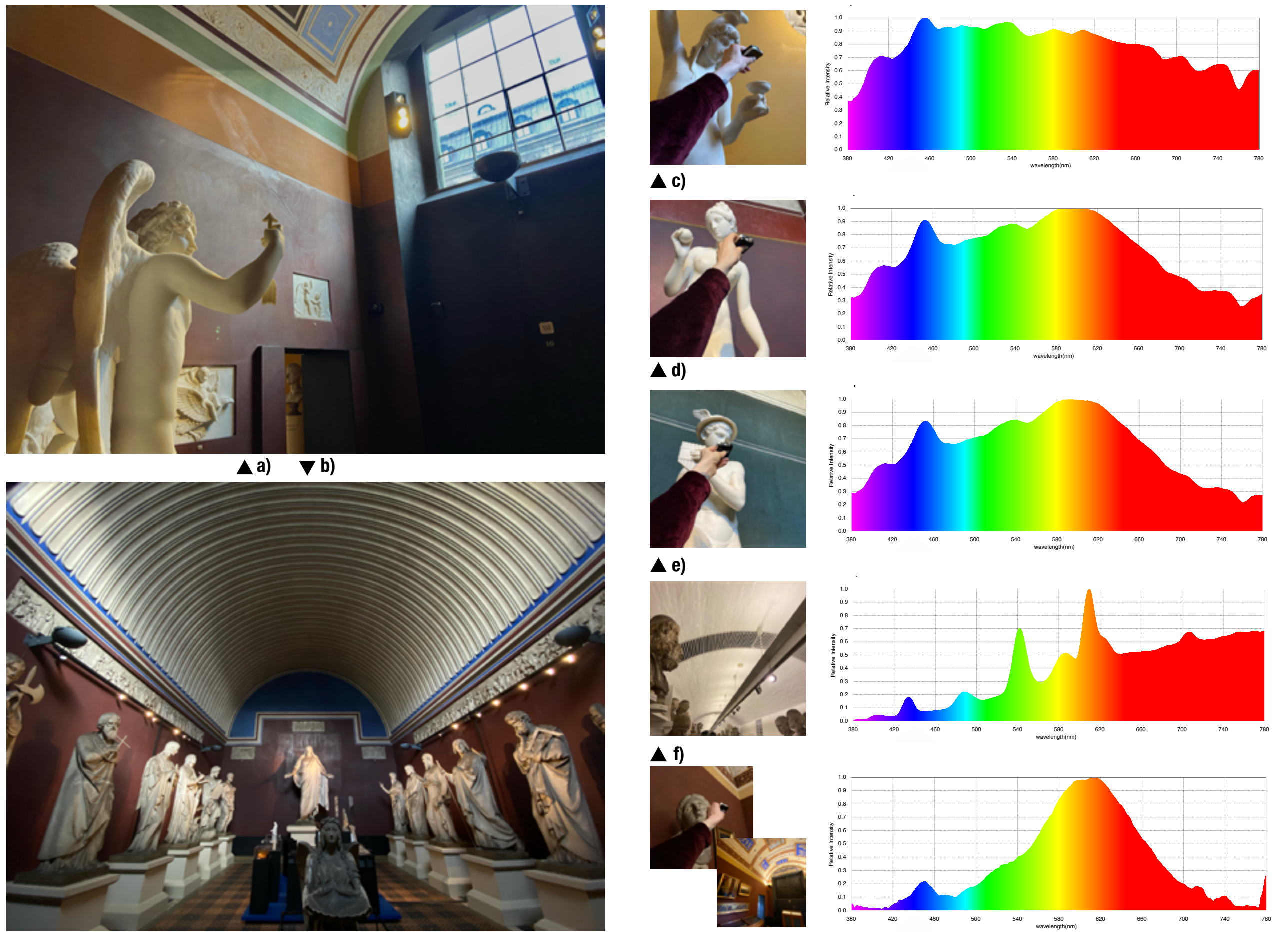


Figure 5.10. Pictures & Spectrometer measurements from Thorvaldsens Museum. a) Clerestory widows + electric lights b) Jesus & 12 Apostles in a space with Clerestory windows + electric lights c) – f) spectrometer measurements from different rooms (Heikka & Stamidis, 2022)

5.1.2 THORVALDSENS MUSEUM

Thorvaldsens Museum, completed in 1848, was Denmark's first art museum. It was established in time between the inventions of gas lighting and electric lighting, but when daylight was still the dominating way to illuminate museums (Danish Design Review, 2018). It can be noted that the architectural layout resembles the Renaissance-era museum Kunstkammer in Munich, which also featured an inner courtyard to maximise daylight intake from lateral openings and to allow the visitor a view and a connection with the outside (Meadow & Robertson, 2013).

We visited the museum on a mostly sunny late-February morning, and could observe the direct sun shining in on some of the sculptures, which was a beautiful effect and made us feel more connected to and attracted to the works of art. It made us appreciate the sculptures more, and made the atmosphere feel natural and serene. However what struck us the most was how beautiful the museum was, and how many of the sculptures were placed in their own rooms, each equipped with a window and spotlights placed on the window's sides, resulting in all light coming from the direction of the opening. In comparison with Glyptoteket, the museum had electric lighting switched on during the daytime in all of the rooms. The lighting is clearly intended to come from the direction of the window. In the hallways, the only electric light sources are lights beside the windows' top sides. They point towards the ceiling, that reflects the light into the space

Figure 5.11. (Left): Sculpture illuminated by diffuse skylight and diffuse electric light (Heikka & Stamidis, 2022), (Right): Overlapping shadows due to two light directions (Heikka & Stamidis, 2022)

in diffuse reflections. The top of the ceiling is decorated with blue-painted squares, resembling skylights. Unfortunately, the light sources create hotspots on the walls, which is slightly disturbing at least during our visit at daytime.

The general atmosphere in the museum was enjoyable, and all works of art are given importance. Due to the small size of the museum, we did not experience museum fatigue even though the exhibits were very similar to each other. None of the rooms were overly filled with sculptures, which definitely made it easier to give time for engaging with each artwork and dedicate time to examine them from all sides. Moreover, the entire museum was coloured with pleasant, saturated colours. The dark tones of the paints allowed the silhouettes of the sculptures stand out clearly, while the shadow was still distinctly casted on the wall. As they used spotlights installed on both vertical sides of the windows, this resulted in the undesired effect of casting two overlapping shadows. The light sources used in these individual rooms are LEDs with a high CRI (Fig. 5.11, right).

5.1.3 STATENS MUSEUM FOR KUNST

Denmark's National Gallery, Statens Museum for Kunst (SMK), was established in 1896, when electric lighting was still only used by a few pioneer museums around the world. For that reason most of the rooms have top lighting to allow daylight into the exhibition space. Nowadays, some of the skylights also have fluorescent tubes behind them to provide the space with more light even on darker days. New electric lighting was installed by Philips in 2011 (Koninklijke Philips N.V., 2011). However, overall they use many different kinds of light sources around the entire large museum. The museum received a new modernist extension in 1998, expanding the museum towards the Østre Anlæg (Arkitekturbilleder.dk, n.d.). The old façade was maintained, and the space beside it under the skylights typically hosts the "Sculpture Street", on which several plaster sculptures are placed (Fig. 5.12). Unfortunately due to a temporary exhibition, the sculptures were not there. In addition to daylight, the Sculpture Street is lit by warm CCT LED light sources (see Appendix).

When entering the museum, a grand entrance hall with plaster sculptures in the middle welcomes the visitor (Fig. 5.13). Top lighting illuminates the space by double-layered skylights, and the cool ambient light is complemented with warm LED light sources installed in the metal bars in between the glass panels. It is clearly visible that the skylights are dirty, decreasing the amount of transmitted natural light. Moreover, from the spectrometer measurement it can be seen how the proportion of natural light entering the space is actually very small, as the spectrum curve is distinctly similar to that of a warm white LED. This also transmits to the atmosphere, which instead of feeling airy, cool and pleasant feels like just a grand indoor space, as the daylight effect is lost. The low quality of the light makes the space feel a little dusty, and the sculptures lack modelling.

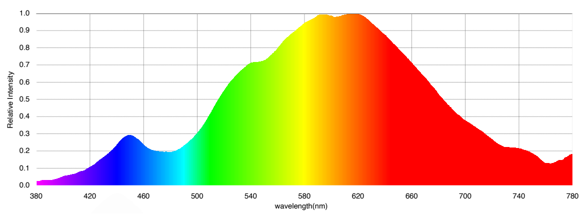
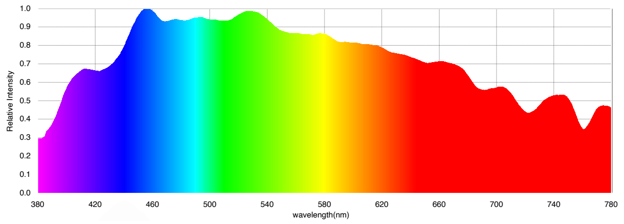
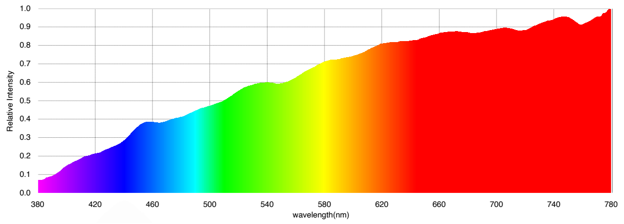
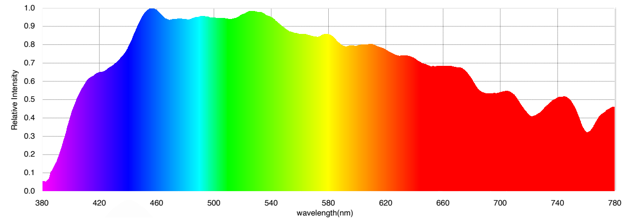


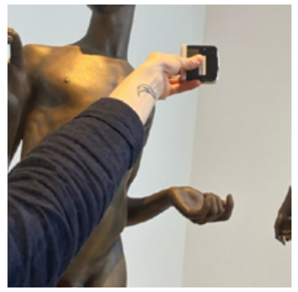
Figure 5.13. Entrance hall of SMK (Heikka & Stamidis, 2022).

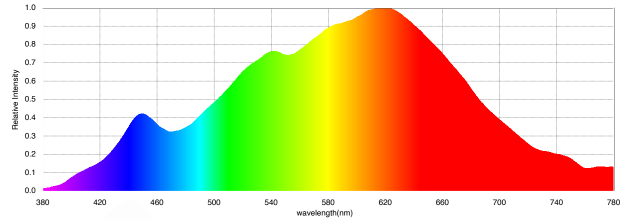
◄ **Figure 5.12.** Statens Museum for Kunst (Heikka & Stamidis, 2022).











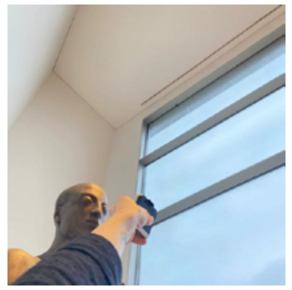


Figure 5.14. Spectrometer measurement from the NW-facing window. Halogen direct + Daylight diffused (Heikka & Stamidis, 2022)

Figure 5.15. Spectrometer measurement from the NW-facing window. LED direct + Daylight diffused (Heikka & Stamidis, 2022)

Majority of the sculptures close to the NW facing window are lit by natural light only. However, some are lit also by focal light, either halogen (Fig. 5.14) or LED (Fig. 5.15) light sources. Even though the CRI of the halogen light source is higher, its direction and intensity are not sufficient to achieve a desired effect on the sculpture. In fact, it seems that the lighting is not meant for the statue as it highlights the figure's knees, shins and feet. Due to the higher intensity of the direct warm LED lighting, the effect looks very embellishing and realistic on the bronze sculptures, particularly on the one on the left in Fig. 5.15. The other two sculptures have their faces more overshadowed.

Figure 5.16. Translucency of marble appears in direct focal light. Image from Throvaldsens Museum (Heikka & Stamidis, 2022).

5.1.4 CONCLUSION

Museums Analysis

- Museums utilise both daylight (primarily diffused skylights or North-facing lateral windows) and electric light for illumination of sculptures
- Electric lighting
  - Technologies: LED, halogen, fluorescent
  - CCTs: 2400-8000K
  - Distribution: direct & diffuse
  - The narrower the beam, the better the light enhances the texture and modelling of the sculpture
  - Halogen light sources gave the truest effect of sunlight
  - RGBW lights are not commonly used as they create an artificial feeling due to strong peaks in SPD
- Static lighting (diffuse zenithal/top natural lighting or direct electric lighting) was the primary way of illumination
- In many cases the lighting was not ideal
- Museum fatigue was felt particularly when exhibition spaces were similar to each other in terms of lighting environment and filled with similar objects such as in Glyptoteket; having variety in exhibitions or a relaxation space helps in relieving the symptoms
- Daylight improves the spatial experience of visiting a museum. It makes you feel more open and awake, and makes the space feel airy and bright, connected to nature.
- Direct sunlight enhanced sculptures and increased the engagement with and appreciation of them
- Strong contrast ratios give the most natural and enticing effect
- Saturated and dark background colours were more pleasant and flattering than light background colours with lower contrast ratios. Dark backgrounds are beneficial for the enhancement of sculptures' form and silhouette, and improve the atmosphere.

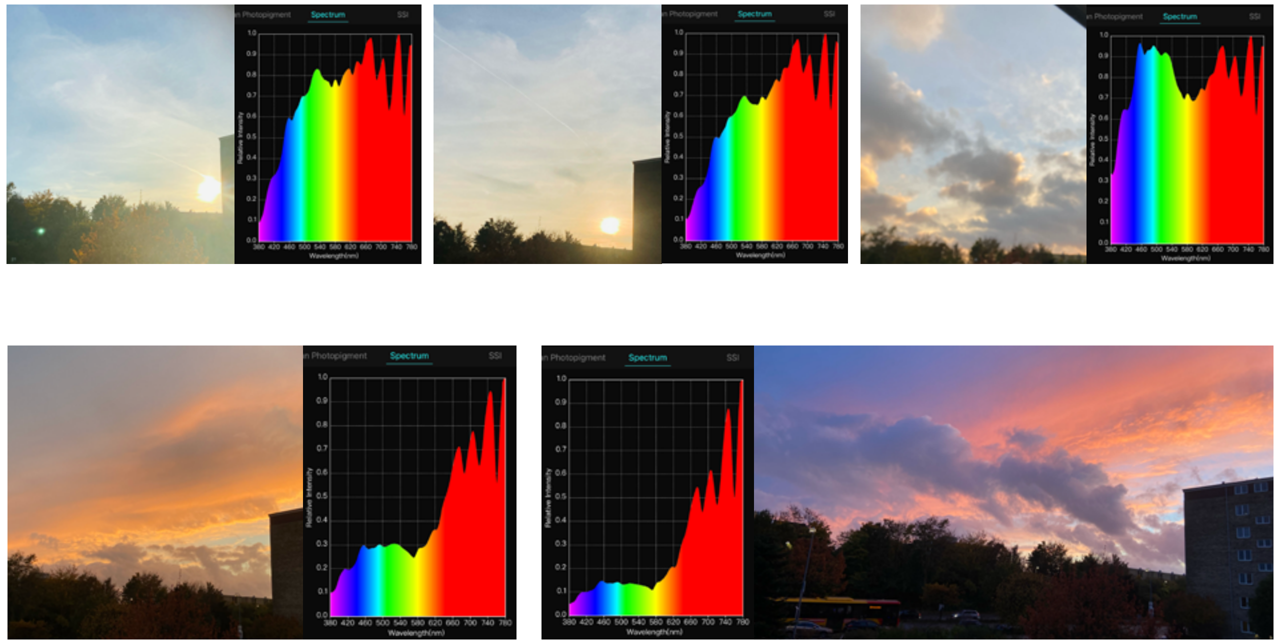


Figure 5.17. Sunset skies and their corresponding spectrometer measurements (Heikka & Stamidis, 2022).

Figure 5.18. Red sunset from The Hague, Netherlands. Photo taken on 27.09.2016. by A.V.V. Heikka.

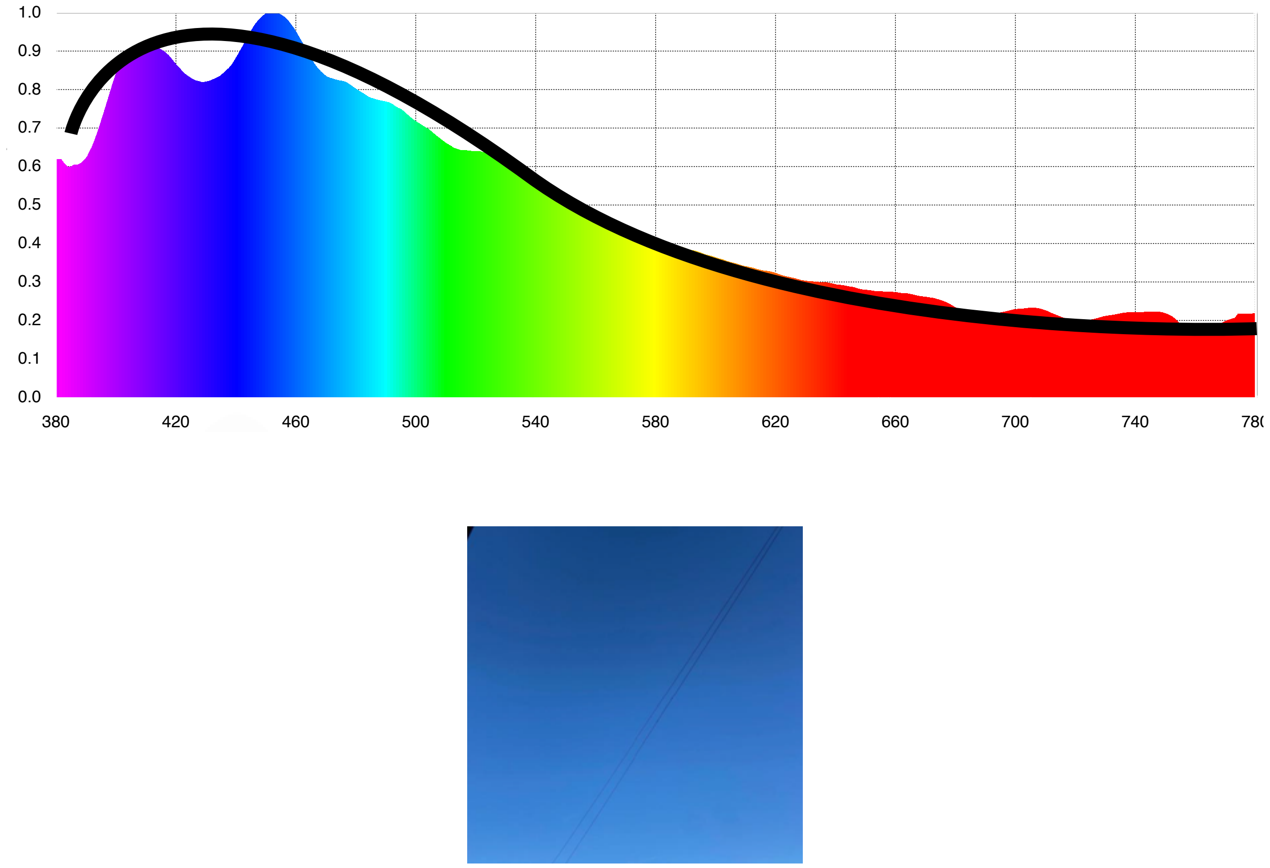


Figure 5.19. Rayleigh scattering can be observed from the spectrometer measurement of a blue sky (Heikka & Stamidis, 2022).

5.2 DAYLIGHT ANALYSIS AND MEASUREMENTS

Daylight spectrum and intensity varies greatly throughout each day depending on several aspects such as time of day, season and atmospheric conditions such as cloud cover, their thickness, height and shape, and the atmospheric aerosol and particle content. Some of these variations can be seen on the next page from the spectrometer measurements taken in Copenhagen. It can be seen for example how different types of cloud covers cause changes in spectrum, how blue the blue sky is (due to Rayleigh scattering, Fig. 5.18) how the CCTs range from 4600 K (Fig. 5.19l), to 21,000 K (Fig. 5.19r) and how the measured intensities range from 1 lux (Fig. 5.19a,b) to 76,000 lux (Fig. 5.19d). The natural light becomes cooler the closer it gets to noon or midnight, and due to atmospheric scattering, the direct sunlight becomes warmer the closer to horizon the sun is. Clouds, on account to reflecting all wavelengths of light somewhat equally, can make the sky either much brighter or darker than the blue sky. Whether they darken or brighten the sky depends on the cloud cover's thickness and sky coverage. Due to clouds, the intensities can also change rapidly, such as in Fig. 5.19.e,f when the illuminance doubled by increasing by over 16,000 lux within 20 seconds. In addition to brightening or darkening the sky, clouds can tone the sky in amber, red and magenta tones around sunset, as can be seen from Fig. 5.16 & Fig. 5.17.

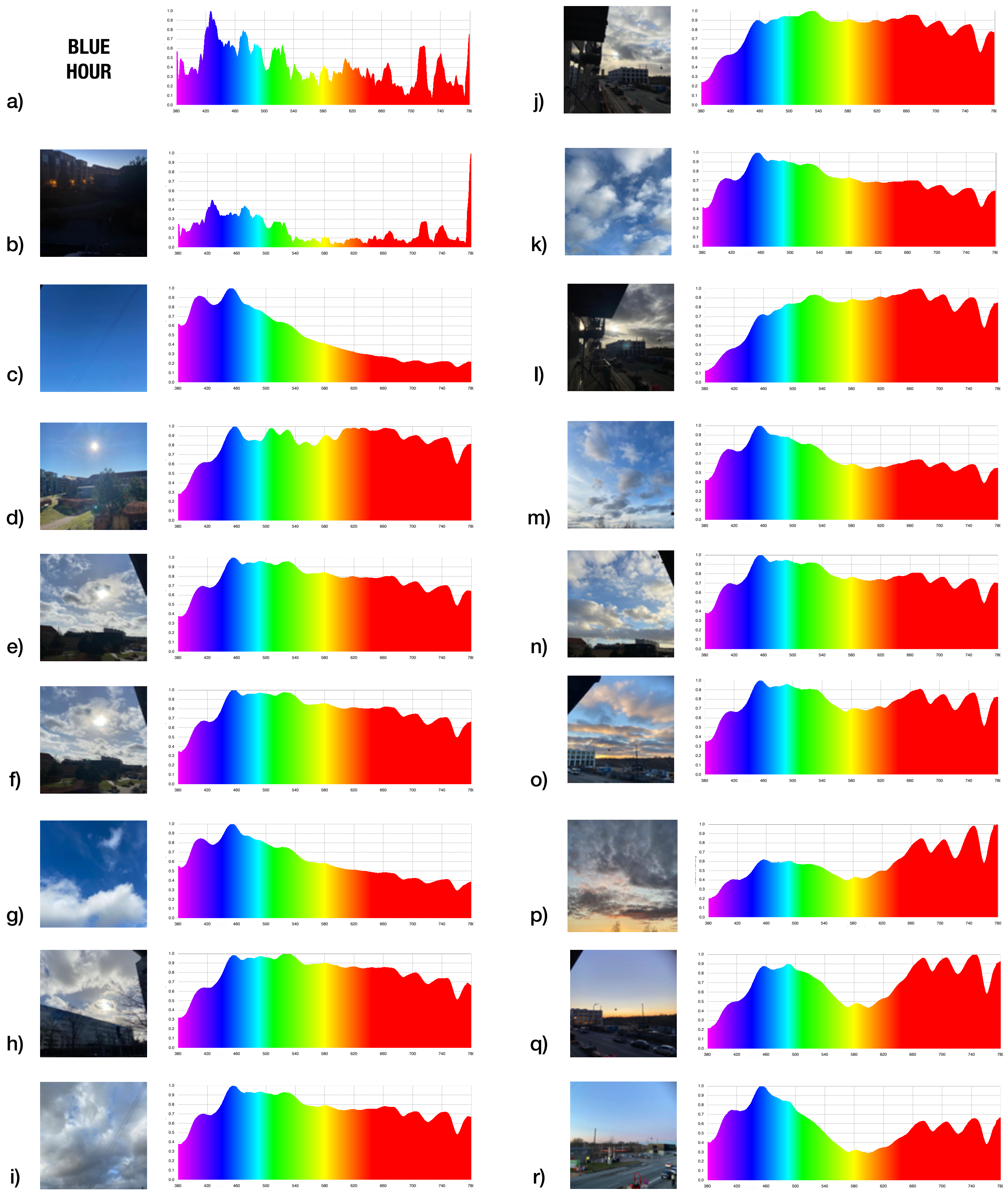


Figure 5.20. Spectrometer measurements of skies taken in Copenhagen, Denmark. The time of day and corresponding CCT & CRI values can be seen in Appendix (Heikka & Stamidis, 2022).

5.2.1 CONCLUSION

Capturing and measuring different sky type conditions a deeper understanding was obtained according to the:

- **Variations in weather conditions that affect the light.**
- **Unpredictable weather conditions.**
- **Colourful sky and clouds create different atmospheres.**
- **Natural light varies in intensity according to the weather conditions.**

5.3 TIMELAPSE

In addition to the previous chapter of the daylight analysis and measurements, a timelapse was conducted in order to get an understanding of how natural light affects and interacts with objects throughout the day.

The timelapse took place at Nea Mihaniona, a small city in Thessaloniki, Greece, on the 15th of March, 2022. The weather conditions on that day were sunny with a clear sky (no clouds). As can be seen in the picture Fig. 5.21, the sunrise was at 6:40 and sunset at 18:35, with the duration of daylight being almost 12 hours. The timelapse was conducted on the rooftop of a private residence that offered the opportunity to record almost a full cycle of the day, without obstacles or overlapping shadows from the surroundings. The timelapse was recorded using two different cameras that were taking pictures at different times of the day. One was "GoPro Hero Session" that was taking one picture per minute and the second one was "Canon PowerShot sx60 hs" that was taking one picture per hour and almost every minute at sunset time.

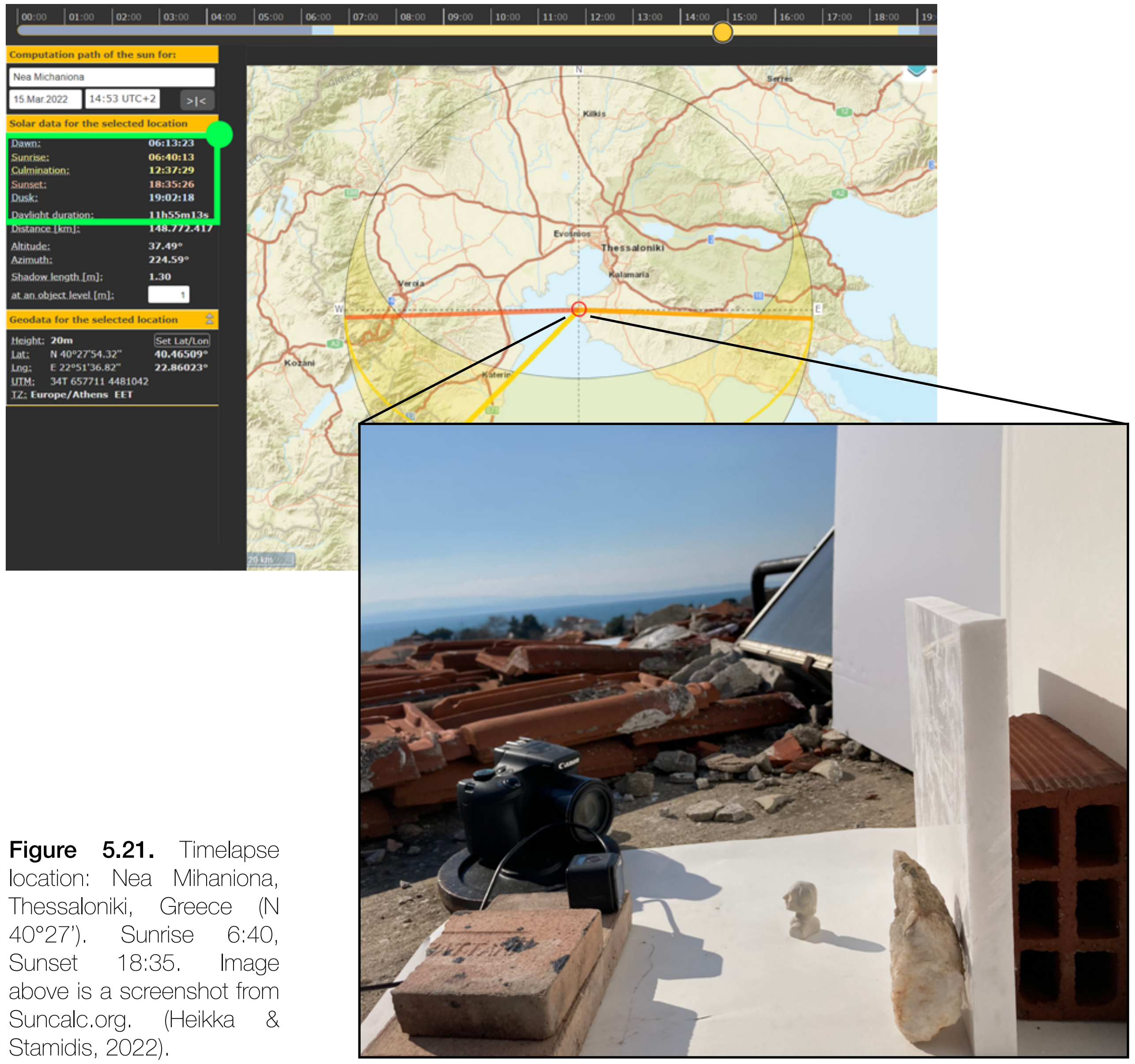


Figure 5.21. Timelapse location: Nea Mihaniona, Thessaloniki, Greece (N 40°27'). Sunrise 6:40, Sunset 18:35. Image above is a screenshot from Suncalc.org. (Heikka & Stamidis, 2022).

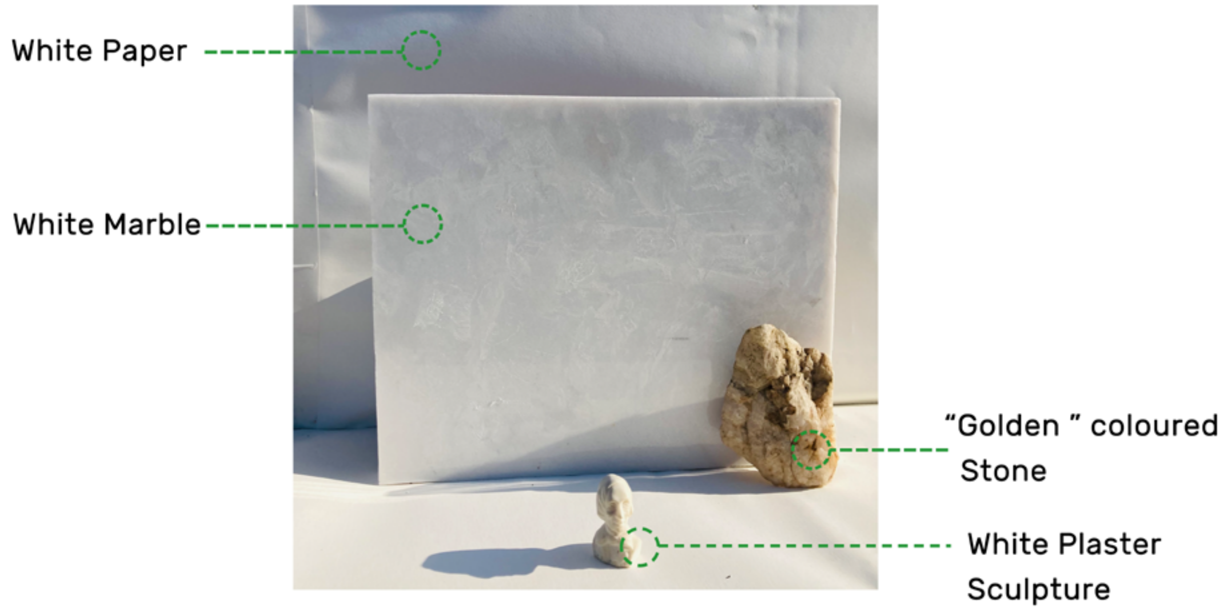


Figure 5.22. The materials used in the timelapse (Heikka & Stamidis, 2022).

Since the interest of this report is to explore how to create a unique museum visitor experience by illuminating a sculpture with electric light while it is inspired by natural light, the objects for the timelapse were chosen accordingly. The first one was a "mini-statue" made out of white plaster, which is a common material widely used by sculptors nowadays. The second is a white marble plate, which was one of the common materials for sculptures in the ancient times and the third one is a "golden coloured" stone that has an uneven surface but also colour in comparison to the other objects. By choosing these objects we were aiming to observe the relation between light and objects while understanding and analysing, under realistic conditions, the different characteristics of natural light mentioned in the "Literature Review". With the white marble, we could observe how this material interacts with daylight and the different colour appearances caused by natural light. Secondly, the stone could give us an understanding of how natural light affects a coloured object with an uneven surface.

Most importantly, the sculptured figure could give us an understanding of how a sculpture is affected by natural light, the variations in colour appearances from the natural light but also the different shadow patterns throughout the day while observing how they affect the sculpture's perception. The objects were facing south in order to capture a full day cycle (from sunrise/east to sunset/west). The timelapse is presented in the image below and it is further analysed within two main topics of "Colour and Appearance" and "Shadows".

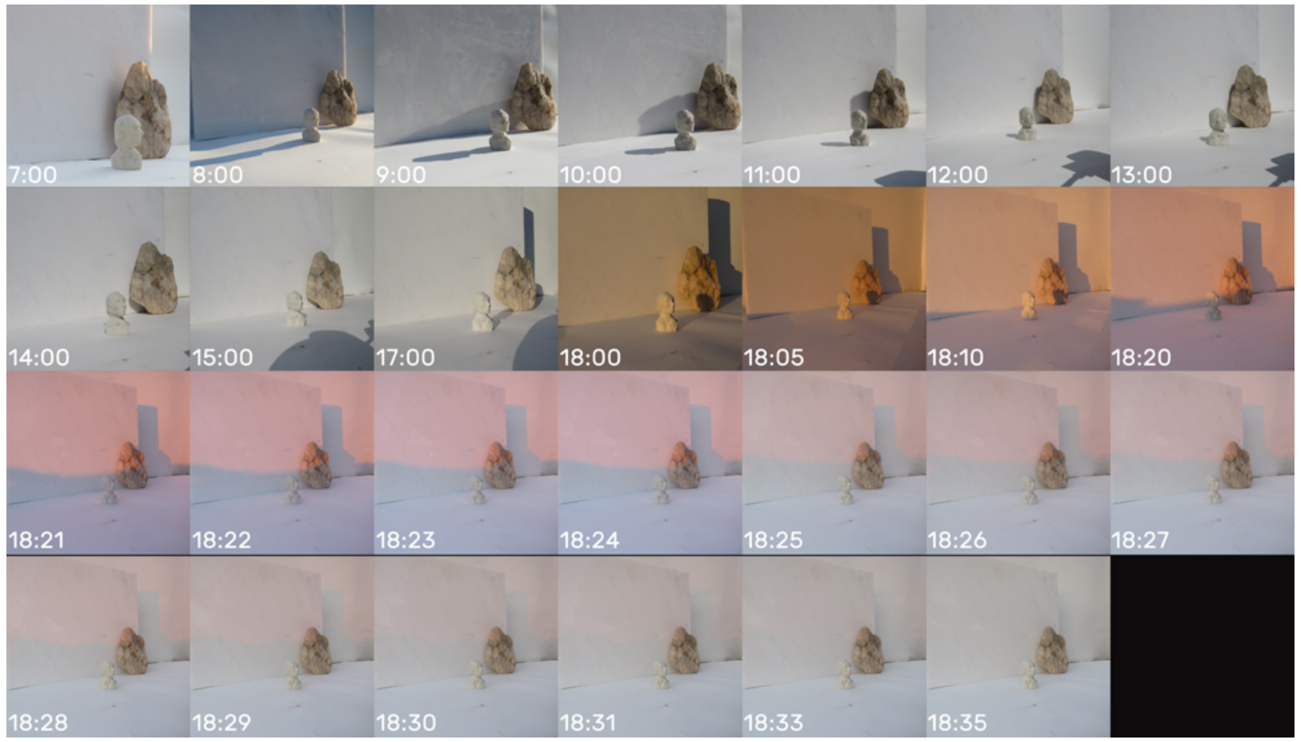


Figure 5.23 Photos from the timelapse with timestamps (Heikka & Stamidis, 2022).

COLOUR AND APPEARANCE:

In the very first image, where the sun is not high enough yet to hit the sculpture, the cold white light of the skylight illuminates the objects creating a homogenised atmosphere. An hour later, the sun is in a higher position, and the objects seem to be illuminated by warm white light, where "golden" tones highlight appear on their surface. While the sun moves towards noontime, it is noticeable that the light becomes neutral and at noon it is cold white. After 12:00 it can be observed that the direct sunlight turns again to neutral till the golden hour when the light transforms from warm white to warmer and then through a variety of pink/peachy tones.

Observing the different objects and their illumination by sunlight, the dynamics of natural light are remarkable. The different colour appearances offer multiple presentations of the objects. The diffuse, morning cold white skylight turns to a smooth, warm white direct sunlight where "golden" highlights appear on the surface of the objects, enhancing the appearance of the sculpture. Similarly, the changes in the white tones from morning to afternoon, offer different appearances. As sunlight moves during the day, different parts and sides of the sculpture are highlighted, offering a dynamic presentation. During sunset, it is fascinating how the colour of the sun and the sky continuously affected the appearance of the objects. The warm white sunlight shifted to multiple tones of pink and peachy transforming the sculpture accordingly, offering a dynamic appearance that was changing minute by minute.

Lastly, one can notice in the timelapse pictures the interaction with light and objects and how the natural light creates multiple atmospheres, according to the changes in colour. The most unique experience of atmosphere seems to be during sunset time when the colour combinations of natural light affect the objects holistically, creating a dynamic and playful atmosphere.

SHADOWS:

As it is mentioned in the chapter "Daylight and its Dynamics" of the literature review, shadows vary during the day. At 7:00 when the objects are illuminated only from the skylight, shadows are diffuse and soft, while the sculpture seems to lack form due to diffuse illumination. An hour later, the position of the sun is almost parallel to the objects creating long shadows. While the sun moves to noontime, the shadow's length is gradually shrinking. It can be observed that at noontime the shadow of the sculpture obtains its shorter length and later, while the sun moves towards the West, the shadow grows in length. During sunset, the sculpture is under a shadow of a larger obstacle and due to the skylight, it gains diffuse shadows that cause a loss of form.

Moreover, it is interesting to observe the different shadows on the facial characteristics of the sculpture. While the sun moves throughout the day, different shadows are cast on the face, allowing some parts to be highlighted and some others to fall in shadow. It is remarkable how those characteristics affect the appearance of the sculpture and the variety of its presentation during the day. As it is mentioned in the literature review, the shadow is an important element to reveal the form of three-dimensional objects. This can be seen from the images. In addition, it can be observed that the parallel beams of the natural light create equal shadows in directionality for every object of the setup. Lastly, the colour of the shadow seems different during the day, while in the morning sun the colour of the shadow seems to be bluer in comparison to noontime when it is darker, and the golden hour when it is light grey.

Figure 5.24 Side light at sunset casts long shadows (Heikka & Stamidis, 2022).

5.3.1 CONCLUSION

In the conclusion of this chapter, it is important to point out the dynamics of natural light observed in a realistic context.

- The colour variations of the sunlight throughout the day offered different representations to the objects.
- The colour of the sunlight shifted from warm-white, in the morning, to neutral-white and then cold-white at noon. After noon the colour of the light shifted to neutral-warm and to amber during sunset time.
- During sunset, the objects were affected in their appearance minute by minute.
- These variations affected holistically the atmosphere of the objects, offering playful, calm and enjoyable atmospheres.
- The changes in shadows add numerous perceptions to the dynamic presentation. While the sun was changing in position, the shadows had different lengths throughout the day while different parts of the sculpture were highlighted or fell into shadow.
- Skylight created diffuse shadows while sunlight created hard shadows.

5.4 INTERVIEWS

The last part of the analysis is the semi-structured interviews conducted with four professionals in the museum field. A format of questions was used as the core of the interview, while many of the questions were redefined according to the interviewee and their profession, leading to an open discussion. The purpose of the interviews was to get an understanding of the museum context, the current museum lighting conditions on artworks and also to discuss visitors' experiences and touch upon the subject of dynamic lighting in museums. The main topics from each interview are presented below. The people we interviewed were:

1. **Artist:** Contemporary artist, focusing on contemporary sculptures, Copenhagen
2. **Exhibition Designer:** Scenographer, Graphic designer and Exhibition designer in museums, Copenhagen
3. **Director:** Director at Museum with the majority of collection being sculptures, Copenhagen
4. **Lighting Designer:** Scott Rosenfeld; Lighting Designer at a renowned museum institution in the USA, with 11 years of experience at the Museum Committee, IESNA

1 The first interview provided us with information about an artist's point of view toward an exhibition. During the interview, he pointed out the importance of the artwork's illumination and the different lighting requirements for specific artworks. His art focuses on contemporary sculptures and for him, it seemed important that the artwork's illumination needs to be under a particular context. According to the exhibits, different lighting concepts need to be applied, as sometimes uniform lighting can enhance the general exhibition while other times, spotlights need to be used in order to create shadow patterns.

> *"It is important to have good lighting at the exhibition. When it has many spotlights it gets more theatrical. In general, I prefer diffuse lighting. Though for sculptures, I prefer spotlights because they give a theatrical perspective."*

Furthermore, when discussing the use of dynamic lighting for artworks, he explained that it can be a creative approach, though it has to be under the right context in order to make sense and to create storytelling as "it could be too much".

> *"Dynamic light [in exhibitions] is perfect sometimes but in some others, it can be too much. It makes the ideas stand brighter, but sometimes it can be not so interesting. It has to be under the right context and circumstances."*

What is important to understand from this interview is the artist's intention and vision with their artworks. According to their vision, artists have different requirements regarding the artwork's illumination at an exhibition. Lighting should also create a storytelling for the entire exhibition. According to the artist, dynamic illumination of artworks can be a great idea but only if it is used under the right circumstances as sometimes it could be too dominant, adding visual complexity.

2 The second interview was conducted with the Exhibition Designer. One of the main topics of the interview was the priorities of an exhibition and which elements enhance visitors' experience.

> *"When it comes to a new exhibition we should take into account what is the concept, who is the artists and the theme they are working on, how they want to communicate it and most importantly what's the story"*

Similarly to the artist's interview, the Exhibition Designer points out the importance of taking into account the artist's intention and importantly how they want to communicate the artworks in an exhibition. It is valuable to understand the theme of the artworks, the materials the artists work with and what is the experience they want to create. She further continues by explaining that when creating an exhibition, there should be interesting elements that can intrigue visitors. She explains:

> *"It is interesting to make people curious about an exhibition, it has to have something (element of the exhibition) to "stop" you and attract your interest."*

> *"The audience should be easily guided in a space. Make a playful game so that someone can easily follow the exhibition. Make it interesting for people"*

The visitor's experience is emphasised by the Exhibition Designer who explains that an exhibition should be easy for someone to follow but also to include elements able to attract the visitor's interest. This can be related to the information from the previous chapter on the "Contextual Model of Learning", museum fatigue is explained as the visitor's loss of interest in an exhibition when there is no diversity.

Moreover, while we were discussing illuminating artworks with dynamic lighting the Exhibition designer was explaining that dynamic illumination can be interesting in an exhibition while enhancing the works of art. Though, she points out that the concept should be clear for people to understand it:

> *"Dynamic lighting can give something interesting in an exhibition and highlight different elements."*

> *"It is important to make people understand and trigger people using new ways while telling narratives. If you make a "surprise" it should have a clear concept."*

In addition, as the Exhibition Designer explains, museums create exhibitions to offer people an experience, "to see things…and feel things." But when illuminating objects, lighting designers should think about how far they can go in the emotionalisation of and suitability to the artwork, as light should enhance the exhibits and not overshadow them. While discussing the idea of dynamic lighting on sculptures, the Exhibition Designer suggested that it could be made in a room. That way, the sculpture and light would create a unique experience for the visitors, as a single concept that would not overlap with the rest of the exhibition.

> *"Museums want you to see things, experience things and feel things."*

> *"You should think: How does it work as an installation? How far does it go?"*

> *"If you dynamically illuminate a sculpture as part of the scene, you could do it in a room. It would be like you make a little theatre room… If you make a system like that you should make clear what is happening now in relation to this specific sculpture. It has to be clear: This is the story now!"*

Through our interview with the Exhibition, Designer is important to understand the visitor's perspective. As it is mentioned in the Literature Review, an exhibition should include some elements that can enhance the visitor experience in order to increase their interest in the exhibition. Dynamic lighting is a way that can add diverse perspectives to the illumination of artworks, but it should be part of the museum's approach and easy to be understood by the visitors. For that reason, it could take place in a single room, so as not to collide with the rest of the exhibition but to add a playful element.

3 The third interview was conducted with the Museum Director in one of the oldest museums in Copenhagen with sculptures to be the main exhibits The topic of the interview was the exhibition's priorities and their lighting. When discussing the exhibition's priorities she explained:

> *"It is a priority to add new ways of presentation like videos, new lights and to include sound."*

She further explained the light effects on exhibitions:

> *"Light affects the visitors' experience. It can give you a much more aesthetic and artistic experience. When you highlight details or fabrics or the materials the sculptures are made with, it can create an engaging experience. In our museum, I would love to use light in a more scenographic way. The current lighting feels a bit flat and it does not highlight the artworks, but installing new lighting is very expensive."*

For the Director, it is important when designing a new exhibition to add new ways of presentation. To include elements that can add extra layers of interest to the exhibits. One of the elements is light. As she explains, light can be designed in a way that can offer an engaging and atmospheric experience. Though, she points out the financial aspect. Purchasing new lighting equipment can be a substantial cost according to the fixtures' characteristics, and not every museum institution can afford such an investment.

What is important to understand from this interview, is that applying new ways of presentation to an exhibition is important and specifically light is capable of creating aesthetic and engaging experiences. In addition, from a realistic perspective, investing in high-quality lighting equipment can be difficult for some institutions.

4 The last interview was with Scott Rosenfeld, a Lighting Designer with much experience on museum lighting. During our discussion about light and sculptures, he pointed out the importance of the sculptures in our society and through time. Sculptures are objects that were created thousands of years ago but that people still feel fascinated about. As a result, a lighting designer has to understand that they have to be communicated in the best possible way to be appreciated by museum visitors. In a museum environment, professionals from different fields collaborate to create a new exhibition. As Rosenfeld further explains, a lighting designer has to illuminate the exhibits according to the curator's, or many times, the artists' vision.

> *"These objects have their lifetime. They have a much longer time than we do. And we collide at the galleries. Our job as designers is to make this collision as powerful as possible so that the meeting with the object can be significant."*

> *"Lighting designers in the field that we are in really wanna make sure that we are being sensitive to what these objects are, and we not making about ourselves, but we are really there to serve the curator and the objects, the artworks."*

In addition, Scott Rosenfeld explained the importance of background in enhancing the form and presentation of a sculpture. Furthermore, it is crucial for a lighting designer to understand the relationship between sculpture and light. The sculpture's facial expression, position, movement of the limbs, the body position etcetera have to be taken into account as key elements.

> *"When illuminating sculpture, I have understood that the background has a greater impact than the spectrum and angle of the light."*

> *"What is the sculpture's relationship with the light? Do they wanna be seen or do they wanna hide? So what is the person doing in the sculpture? Is it a light expecting face? Is it revealing this face? What is the relationship between light and art?"*

From the last interview, it is important to understand that when illuminating sculptures, designers need to respect sculptures' long history in human society and be sensitive towards them. It is essential to read a sculpture and find its relation with light to illuminate it properly.

5.4.1 CONCLUSION

Artists have a specific vision of their artworks' illumination and as a result a lighting designer should follow.

- An exhibition
  - Needs to have elements that can intrigue visitor's interest
  - New ways of presentation that can attract more people
  - Lighting that creates aesthetical and engaging atmosphere

- Dynamic illumination of artworks should:
  - Be made under the right context that can be easily understood from visitors
  - Be designed carefully so not to add visual complexity
  - In the case of dynamically illuminating a sculpture could be placed in a room so to not overlap with other exhibits

- When illuminating a sculpture it is important
  - To understand the relation of the sculpture and light
  - Read the sculpture carefully, the facial expressions, body position, movement of the limbs, to illuminate it properly
  - The background can reveal form and shape

6 RESEARCH QUESTION

Through Chapter 4 "Literature Review", ample knowledge was gained from a theoretical perspective and studies regarding the museum visitor experience, museum lighting, lighting of three-dimensional objects, the museum atmosphere & exhibitions concepts and lastly daylight & its dynamics. In addition, in Chapter 5 a variety of information was gathered from qualitative and quantitative methods by analysing the lighting conditions and atmospheres in three museums in Copenhagen, observing and measuring multiple sky types but also conducting a timelapse and interviews. As a result, regarding the information from those chapters, the Research Question of this report can be formulated:

How can the museum visitor experience and presentation of sculptures be enhanced by electric lighting, inspired by the dynamics of daylight?

7 CRITERIA

By formulating the research question, three criteria can be defined that the lighting design of this report should fulfil. The three criteria can be specifically defined according to the information and knowledge gathered from the previous chapters.

LIGHTING SHOULD BE DYNAMIC.

The first criterion refers to dynamic lighting. As mentioned in the literature review, "Dynamic communication of Artworks" is a lighting concept that can add a playful and entertaining atmosphere to an exhibition (Schielke, 2020). It is a lighting concept that can be made in multiple ways by adding movement, changes in colour and intensity to the light (Schielke, 2020). Since the research question refers to "lighting design inspired by the dynamics of daylight", the lighting should be designed by following the characteristics of natural light as explained in Chapter 4.4 "Daylight and its Dynamics" and observed in Chapter 5 from "Timelapse" and "Daylight Analysis and Measurements". Lastly, information regarding dynamic lighting from the Interviews should be taken into account.

LIGHTING SHOULD ENHANCE THE VISITOR EXPERIENCE.

The second criterion refers to the visitor experience and its enhancement by the lighting design. In the Literature Review, the visitor experience is explained through The Contextual Model of Learning (Falk & Dierking, 2013) while Chieh-Wen and Ming-Chia (2012) found that museum visitors expect experiences of "easiness and fun". Similarly, Kotler (2001) explained that the concept of entertainment is included in the museum experience. While Shaw and Ivens (2002) defined experience as a blend of an emotional response in relation to a physical reaction under a specific context, the lighting design of this report should create an experience that can intrigue the interest of visitors and offer entertainment while taking into account the knowledge presented above and information gathered from the interviews.

LIGHTING SHOULD ENHANCE THE ARTWORK.

The third criterion refers to the enhancement of the artwork. Through literature review, information has been gathered according to recommendations on proper illumination of sculptures. Such information is suggested by IESNA (2020) referring to the use of multiple light sources to enhance the presentation of the sculpture by highlighting different details but also pointing out the importance of the sculpture's shadows in revealing its form. Furthermore, Scott Rosenfeld (2017) refers to the five controllable qualities of light that a lighting designer should take into account when illuminating artworks. In addition to the literature review, information gathered from the analysis of the three museums and from the interviews need to be taken into account.

8 DESIGN CONCEPT & EXPERIMENT

8.1 DESIGN DEVELOPMENT

This chapter introduces the concept of enhancing the representation of ancient Greek & Roman sculptures with respect to the artwork and its time, as well as to the entertainment of the visitors. A variety of information was gathered from chapters 4 "Literature Review" and chapter 5 "Analysis" which are implemented in the concept. Moreover, the concept is represented in reference to Scott Rosenfeld's (2017) five controllable qualities of light: movement & angle, spectrum, distribution and quantity that lead to a united design.

MOVEMENT & ANGLE

In order to achieve a dynamic illumination of a sculpture, the characteristics of natural light need to be taken into account. As it is mentioned in the literature review chapter 4.4.1 "Daylight and its Dynamics", natural light is a combination of sunlight and skylight (Boyce, 2014). Moreover, IESNA (2020) suggests the use of multiple light sources to properly illuminate a sculpture, highlight different details and reveal its form. Therefore, the electric light could be divided into two components and positioned by taking inspiration from the sun's path:

- Focal light (sunlight)
- Ambient light (skylight)

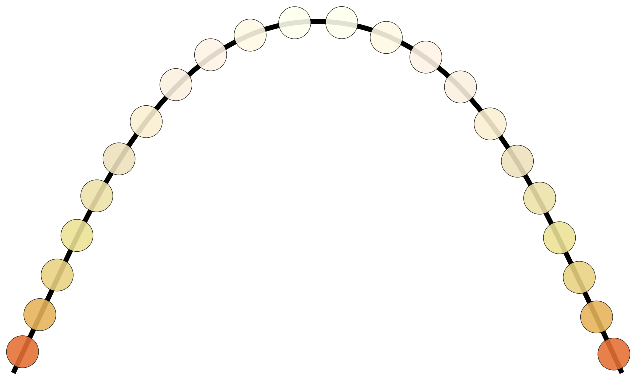
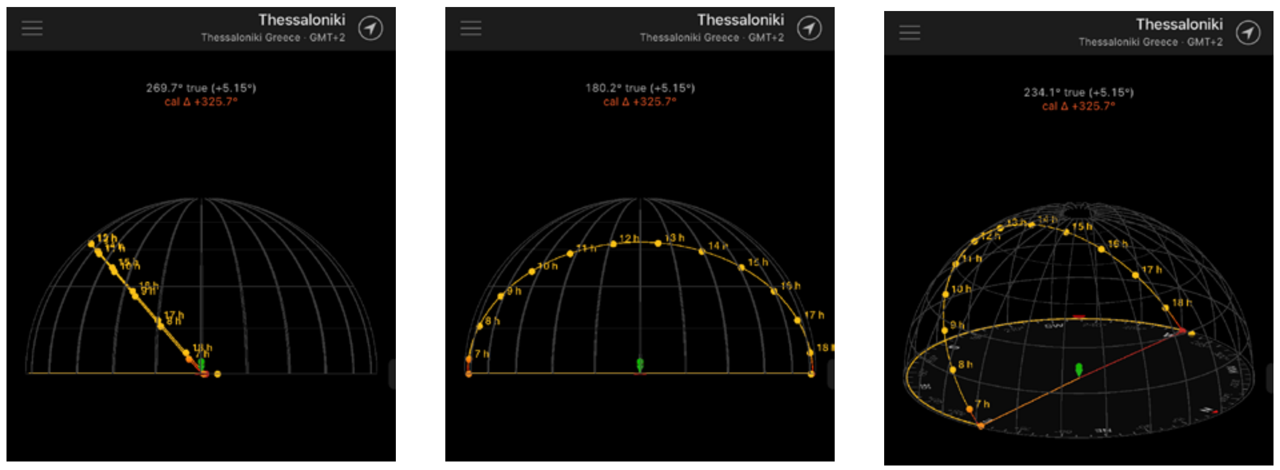


Figure 8.1. Movement of the sun (Heikka & Stamidis, 2022).

Figure 8.2. The sun path & position in Thessaloniki on the equinox. Screenshots from SunSurveyor app. (Heikka & Stamidis, 2022)



Focal light:

Light should follow the movement of the sun, preferably on equinox at ≈ 40° latitude (Fig. 8.2) with light sources positioned as accurately as possible so that the sunrise takes place from exactly the left arm side of the sculpture and sets exactly on the opposite, right-hand side of the sculpture. The movement of the sun can be achieved in two ways:

1. With multiple fixtures placed on a rack system, offering various static lighting "scenes" that cross-fade into each other, representing the different positions of the sun throughout the day.

2. With the technology of moving head light fixtures on moving tracks. That way the light will have a constant movement that can represent the sun's movement more accurately.

Ambient light:

Ambient light, as the skylight, should be diffused and positioned above the sculpture. The skylight as a natural phenomenon is affected by the weather conditions resulting in different light conditions. For instance, the skylight is different when the sky is overcast, clear or during sunset. For that reason, the ambient light should be a combination of different light sources able to represent these variations. For example, the ambient light can be represented:

1. In case the space architecture includes multi-layered skylights, the light sources that will mimic the skylight phenomenon could be placed in between them. In this case, the spectral transmission of the glass should be taken into account to be able to provide the skylight colours as naturally as possible.

2. In a united custom fixture built by multiple LED sources that illuminate a light-diffusing material. As a result, the LEDs could be controlled individually offering more control over the multiple variations that occur according to the specific sky types needed to be represented.

Placing the light according to the movement of the sun's path will follow the cycle of natural light, highlighting different sides of the sculpture as would happen in real life. By adding movement to light, the shadows would correspond accordingly. The focal light, while changing in position, would provide different shadows of the sculpture while highlighting different parts of it. In addition, the ambient light would provide diffuse shadows to the sculpture and tone them blue. One of the inspiring aspects of the design concept is the timelapse conducted in Thessaloniki, Greece. As a result, the sun's path in that area was chosen to define the placement of the fixtures. Moreover, Equinox, as the name implies, is the date when night and day are equal in length, and the winter and summer solstices, i.e. shortest and longest days are furthest away. Therefore the equinox can be treated as the median path of the sun, offering us a guideline for our design.

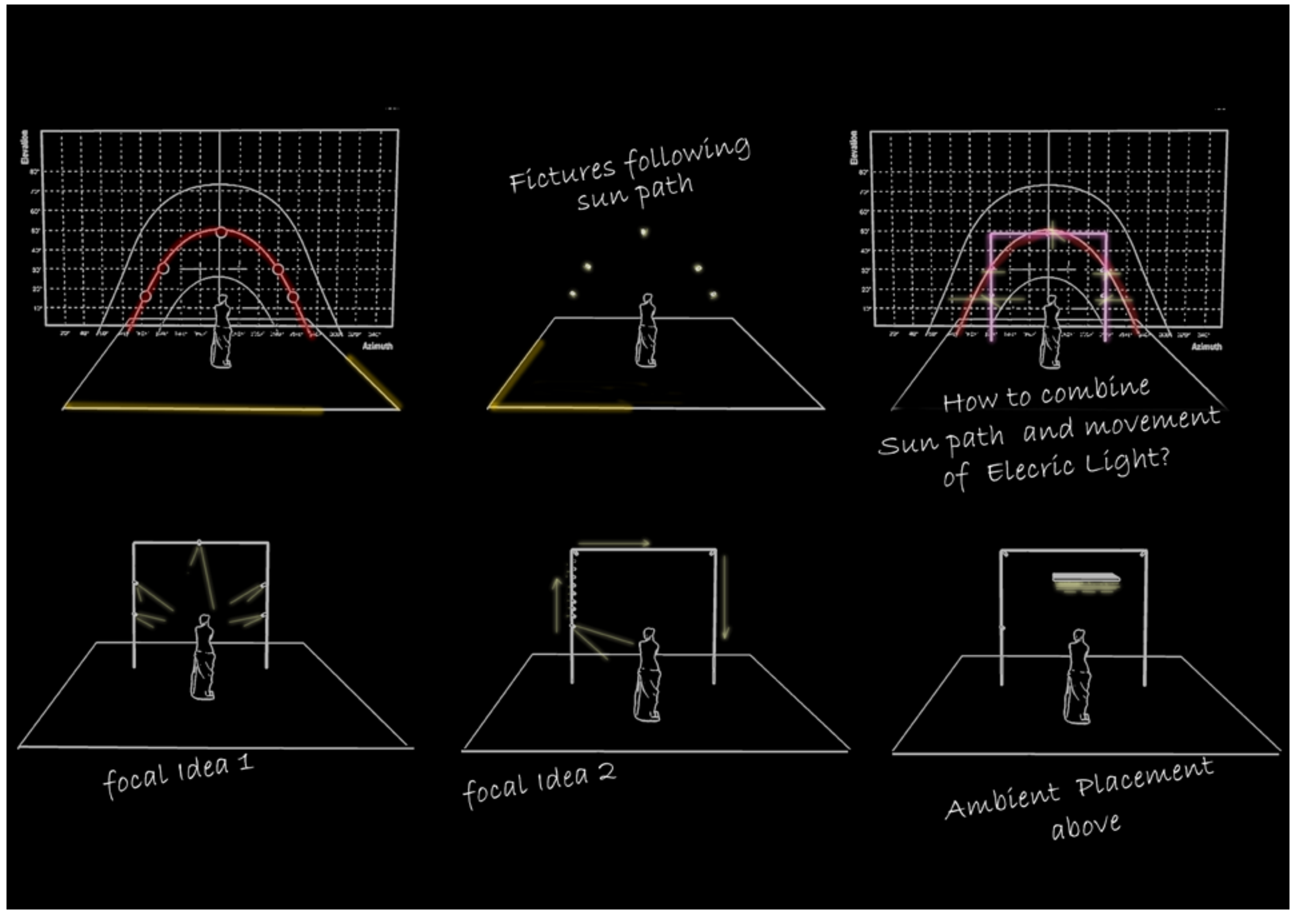
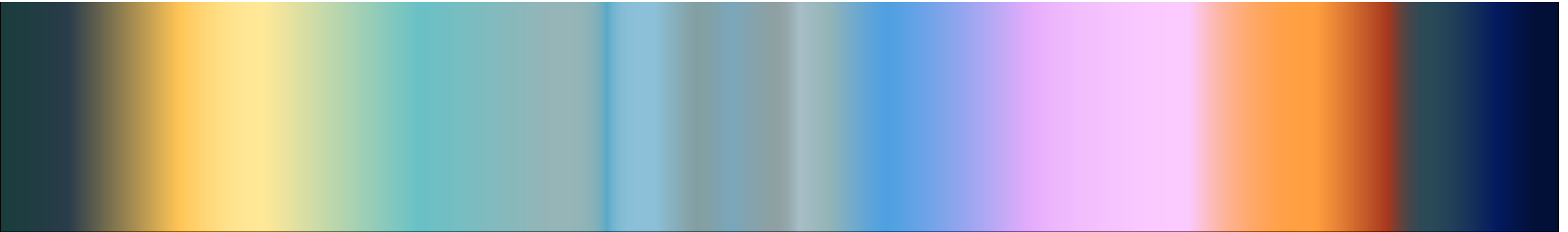


Figure 8.3. Artistic representation. Idea generation of possible eclectic light positioning (Heikka & Stamidis, 2022)

SPECTRUM

The CCT and colour rendering of the light fixtures affect the presentation of the artworks (Rosenfeld, 2017). The changes in CCT of natural light correspond to a specific time of the day, for instance at noon the CCT is the sunlight is cold white. For that reason, electric light could create different "scenes" that correspond to the specific time of the day. The spectrum of both focal and ambient light should change according to the "scene" represented at a time. Emphasis should be given to the picturesque moments that take place around sunset. Moreover, natural light has a CRI = 100, under which objects are presented in the best way. Electric light cannot easily achieve such CRI but light fixtures need to be chosen wisely, with as high CRI as possible, preferably < 90.

Figure 8.4. Artistic representation of spectral variations of the sky within a day (Heikka & Stamidis, 2022)



Focal Light:

The light fixtures used for the focal illumination of the sculpture need to be able to change CCT from 2000 K - 6000 K. As was observed and described in Chapter 5.3 "Timelapse", sunlight has a variety of CCTs throughout the day. The CCTs of the sunlight start with amber light during the early morning and while the sun moves towards noon it transforms to warmer, to neutral and in the middle of the day to cold. While the sun moves towards the west, the CCT changes from neutral to warm and during sunset, to amber. For electric light to mimic the characteristics of sunlight, it is recommended to follow the sequence/characteristics above.

Ambient Light:

Skylight has significantly more variations in spectrum than direct sunlight, which is due to sky conditions and atmospheric scattering (Bikos & Kher, n.d.). The skylight changes in colour from very blue (Fig. 5.20c) to white (Fig. 5.20i), and around sunset it can appear with strong tones of orange-red-magenta (See Appendix for photo documentation of sunsets). Moreover, after sunset, the horizons appear complementary to each other (Fig. 5.20q,r) According to the spectrometer measurements from Chapter 5.2. "Daylight Analysis and Measurements", the CCT of skylight varies from 4600K to 21300K. Consequently, the ambient light must be able to produce this variation in the spectrum. Current tunable-white light technology does not achieve this, which means that RGB light sources are indeed required to increase the perceived blueness of the sky. Tunable white LEDs with high CRI, or high-CRI intensity-tunable LED sources with a CCT of around 6500-17000K should be included. Additionally, the inclusion of LEDs that produce factually cyan light within the typical negative peak spectrum of LEDs, 460-500nm, would lead to achieving a more daylight-like SPD for the ambient light and possibly increasing contrast and depth perception abilities as it is close to the peak sensitivity of the eye's rod cells (Saunders, 2020; Bowmaker & Dartnall, 1980).

In order to achieve the variations in the spectrum, the light fixtures need to be chosen wisely. The fixtures for focal light should be able to white tunable and achieve from amber to cold white. The ambient light is described as a fixture able to achieve a variation in colours, especially in sunset scenes, as it was described before. The specific characteristics of the fixtures are presented in the Chapter "Light Fixtures"

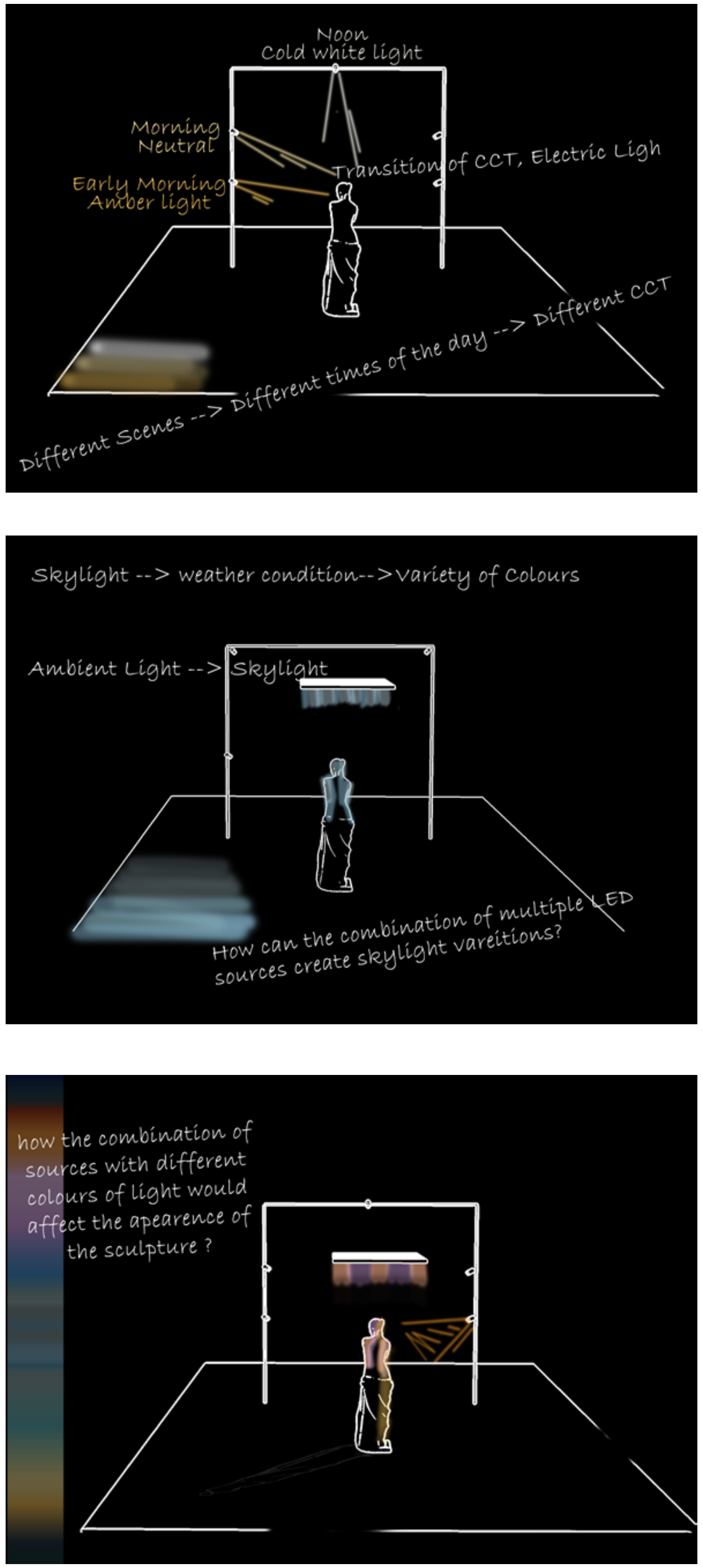


Figure 8.5. Artistic representation. Idea generation of the spectrum and how focal light, ambient light and their combination could possibly affect the sculpture (Heikka & Stamidis, 2022)

DISTRIBUTION

As it is mentioned in the Chapter 4.2.3 "The controllable qualities of light" Distribution: "refers to the size and shape of each light beam (photometric solid) and how these individual beams are distributed throughout the museum to paint the collections and the built environment with light." (Rosenfeld, 2017, p.38). Sunlight and skylight have different light distributions, with sunlight being the direct light and skylight being the ambient light. As a result, electric light should be designed as:

Focal Light:

The distribution of light primarily affects focal light, as clouds of various thicknesses can obstruct direct sunlight. Therefore, the distribution of light should relate to various different sky types. Moreover, sunlight has parallel light beams that the current electric lighting technology cannot achieve. Thus, for example in scenes with unobstructed direct sunlight, focal light should utilise as narrow a beam as possible to achieve a situation closer to reality. For scenes that include clouds in front of the sun, the focal beam should be set to a wider beam angle than the scenes with unobstructed sunlight. In this case, the light beam resembles a floodlight.

Ambient Light:

The light distribution of ambient "skylight" does not vary nearly as much as direct sunlight. Ambient light must remain diffused with equal light distribution at all times, though small spectral variations in distribution should be included. These variations should be used to transmit the complementary colours of horizons at sunrise and sundown, and to include the aforementioned spectral changes in clouds that occur at twilight and when taller, darkening clouds are in the sky.

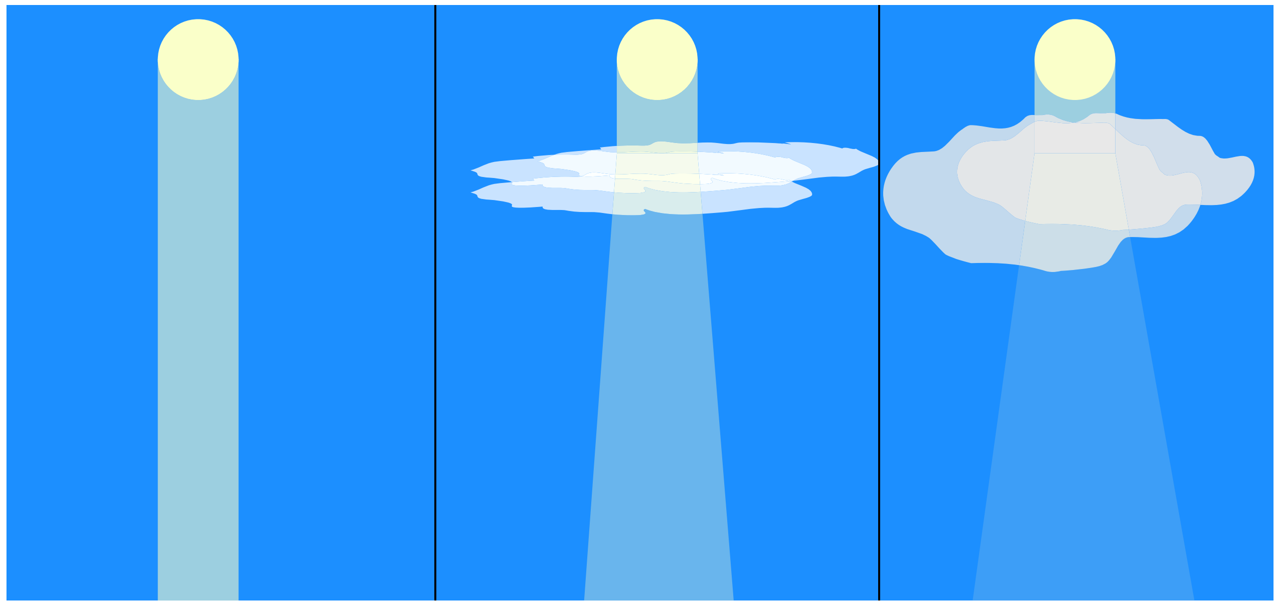


Figure 8.6. Artistic representation of how distribution of direct sunlight is affected by the cloud layer in front of the skylight (Heikka & Stamidis, 2022)

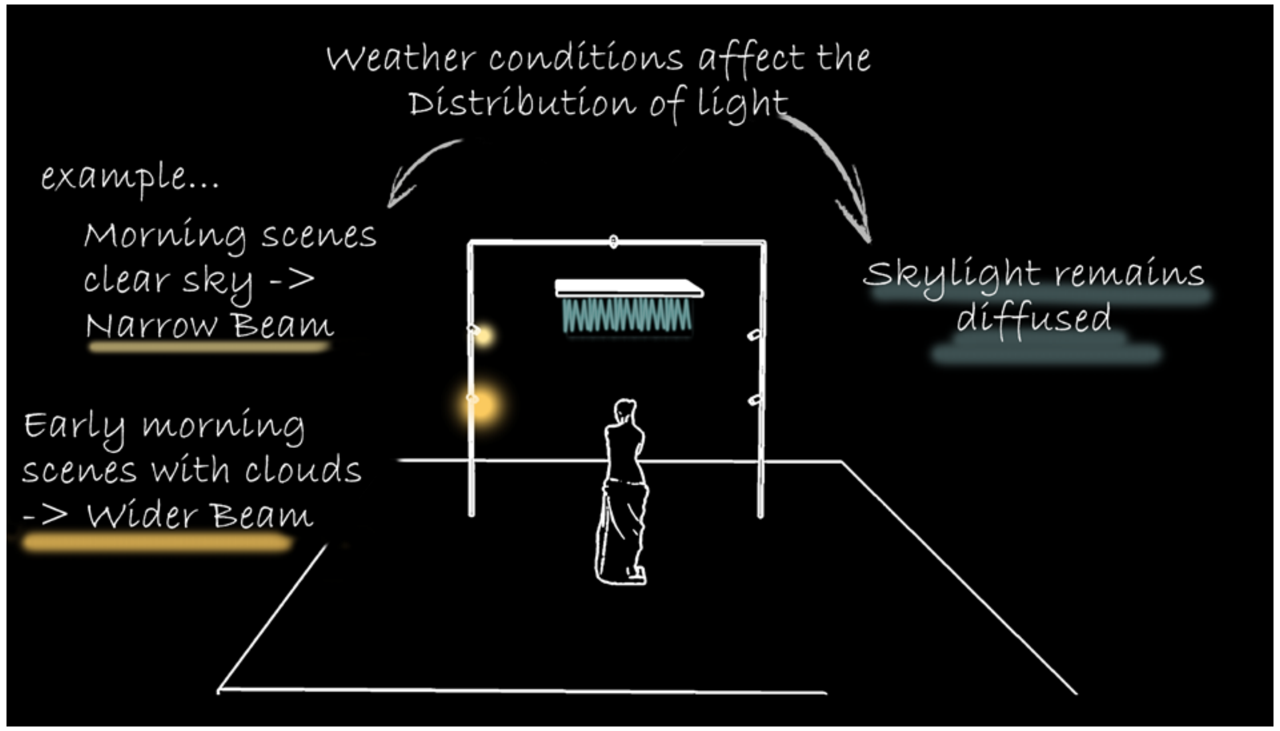


Figure 8.7. Artistic representation. Idea generation of the focal and ambient light distribution (Heikka & Stamidis, 2022)

QUANTITY

In accordance with daylight, the focal light in most conditions should provide a much higher light intensity than the ambient light. As was observed in Chapter 5.2. "Daylight Analysis and Measurements", the intensity of sunlight is different throughout the day, while it was observed that the higher the position of the sun, the higher the light intensity. The only exceptions are when the sun is behind thick clouds, yet slightly visible, and while the rest of the sky is covered by visibly white clouds that still reflect the sunlight in all wavelengths of light. If the sky was mainly blue, its intensity would not be as high, as the sky is blue and does not reflect all wavelengths of light equally, like clouds do. For example, in clear sky conditions, the focal light should illuminate the sculpture by over 16 times the illuminance of ambient light*. Ideally, all the scenes should be adjusted to correspond to each other in terms of the quantity of light. In practice, this means that the highest illuminance levels of focal light should take place when the sun is at its highest position, and the rest of the scenes should not exceed these illuminance levels for focal light.

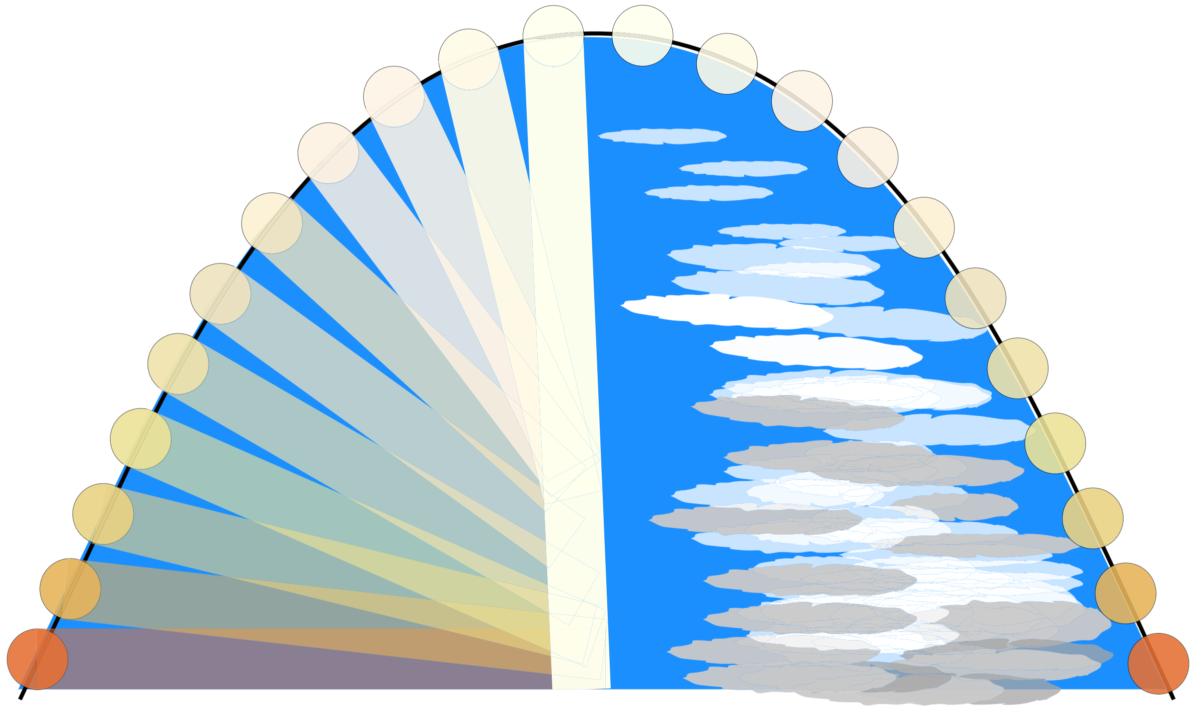


Figure 8.8. Artistic representation of light intensity of focal and ambient light (Heikka & Stamidis, 2022)

LIGHT FIXTURES

To achieve these controllable qualities, several criteria presented below are set for the focal and ambient light.

The **focal light** should fulfil the following criteria:

- As high CRI as possible (preferably >90)
- Have a tunable CCT from 2000-6000K
- Possibility to diffuse light to reach the effect of sun behind the clouds
- For static scenes this can be done via filtering or adding lenses; moving heads should have the option to change beam angle and sharpness
- Produce only one shadow

The **ambient light** should fulfil the following criteria:

- True diffusion among the space (no specular reflections)
- Achieve CCTs of 4600-23000K
- Have individually controllable RGB LEDs for sunset & twilight clouds and complementary tones of horizons at sunset
- Include intensity-tunable cyan LEDs within the spectrum of 460-500 nm to harmonise the ambient light spectrum when using LEDs with a negative peak in this wavelength area

SPACE

In reference to the interview with the exhibition designer and the artist, the space of such a concept should be as empty as possible so that the dynamic nature of the lighting and its influence on the artwork does not cause an overwhelming sensation. Additionally, as Kotler (2001) suggests, a successful future museum should not be an entertainment centre, but should include entertaining elements. With regards to this dynamic exhibition concept, it should not be used in the entire museum, only in one or few parts of the museum. As the exhibition designer mentioned in the interview, to adjust such a concept in a single room could be like creating a “theatre room” where the lighting is fixed but the sculpture that is on the “stage” could be changed. In the interview with the Scott Rosenfeld, he suggested that the background has a significant impact on the illumination of a sculpture – even more than the spectrum and angle of the light. As mentioned in Chapter 4.3.2, a dark background enhances the presentation of sculptures and is more preferred than a light background with lower contrast differences. The museum visits showed that in spaces where dark, saturated colours are used, the more pleasant and flattering it is for the benefit of the sculptures and general atmosphere. Therefore the space should be a space without daylight and with a dark background as possible, such as a ”black box”, so that the silhouette of the sculpture is clearly visible and the light can be more controlled while minimising visual distractions and interreflections.

The variety of the information presented in this chapter is combined together to a design concept through a physical experiment, which is further analysed in the next chapter.

8.2 EXPERIMENT

In order to answer the research question while creating the concept described previously, a physical experiment was conducted at the Royal Cast Collection (RCC). By conducting the physical test we tried to investigate how dynamic lighting affects the presentation of sculptures under the specific concept. Part of the research question is the enhancement of the visitor. By including participants in the experiment process we aimed to determine whether visitors could spend more time looking at and interacting with the artwork, engaged more with it or found it more attractive and appealing in the dynamic setting compared to a static setting in another sculpture. Therefore we needed to find an exhibition space that would allow us to illuminate two of their sculptures in a static and dynamic setting. This experiment would be used to evaluate how well our design fulfils the three criteria, and what kinds of improvements should be done based on the feedback respondents gave.

In collaboration with Henrik Holm, we conducted the experiment at RCC which is a part of SMK. As the museum is not normally open to visitors, we got the chance to get more participants on a day when the museum had been booked by a group of students from the Master of Arts in Archaeology, University of Copenhagen. The group was in our interest to be included in the experiment process, not only due to its size but because we considered them to be one of the most critical groups towards this seemingly more theatrical and entertaining, new way of lighting a sculpture.

Due to the Easter holidays, the installation of the lighting system had to be done within one day – the day before the experiment. To be able to install and fine-tune everything in our design on time, preparations had to be done well earlier to define the design parameters. Moreover, the space turned out to pose many limitations to our idealistic intentions. Firstly, we could not test moving lights, as their track length was bigger than the height of the space’s ceiling. Secondly, there was not any closed space available we could use and lastly, because of time and equipment limitations, we could not create the ambient light fixture as it was described in the previous chapter. As a result, we needed to adjust to the conditions, and create the concept under those limitations.

Figure 8.9. Royal Cast Collection (Heikka & Stamidis, 2022)

8.2.1 EXPERIMENT SPACE – ROYAL CAST COLLECTION (RCC)

Royal Cast Collection (RCC) is a museum in Copenhagen, Denmark. It is a part of Denmark's National Gallery SMK and houses over 2000 gypsum copies of artworks around the world. The museum is typically closed to the public and opens only for special events. Due to the vast museum collection, the space is filled with sculptures almost everywhere.

While we wanted to illuminate two sculptures for comparison and to create the dynamic lighting concept, the choice of the sculpture and the area of the experiment is explained next.

Figure 8.10. Selected plaster gypsum sculptures for the experiment. Apollon (spreading death) on the left, and Venus de Medici on the right. The original versions of both sculptures were made in the 1st century BC (Heikka & Stamidis, 2022)

Sculptures:

The selection criteria for the sculptures were the following:

- Human-scale & not too tall because of low ceiling height (so that angle of light could be set as accurately as possible)
- All limbs intact with at least one extended to cast interesting shadows.
- Equally interesting so that the experiment would yield reliable results.

The chosen sculptures were Apollon (spreading death) and Venus de Medici, both originally from Ancient Greece. Apollon (spreading death) was 1900mm tall with its podium and extended over 700mm in width. It was to be lit by the static museum-lighting scene. Correspondingly, Venus Medici was 1850mm tall with its podium, extended over 550mm in width, and was to be lit by the new dynamic concept. A piece of white fabric was used as the background for both of the sculptures due to its neutrality, and to create similar conditions for both spaces.

Space of Experiment:

In addition to choosing the sculptures, we needed to choose a suitable space for the experiment. The space had to fulfil the following requirements:

- Placed as far away from a window as possible to have as much control of the lighting but also to exclude the influence of daylight.
- Placed in an area with as little clutter as possible near the experiment area so the shadows (from the sculptures) would not overlap with other objects around.
- Possibility to illuminate both sculptures ideally (according to regulations and standards)
- Extra space for the possibility to walk around the sculptures.

The RCC spans over three floors that vary by height. The ground floor had a height of 3.8 metres, and the upper floors had a lower height of 3 metres (2,5m to the beams). As the downstairs space had significantly taller sculptures and more daylight, we selected an area from the first floor near the elevator in the centre of the building. The space next to the elevator was 4.1 metres in-depth, and 4.6 metres in width. The adjacent space, calculated until the stairs, was a little larger by 4.4 metres in depth and 4.85 metres in width.

Figure 8.11. Experiment space (Heikka & Stamidis, 2022)

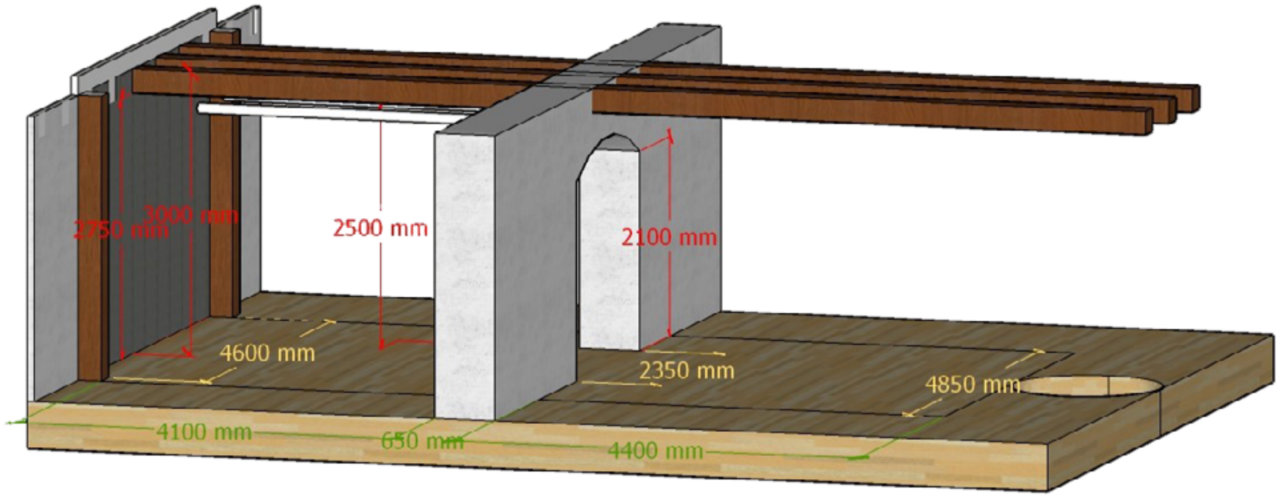


Figure 8.12. Experiment space (Heikka & Stamidis, 2022)

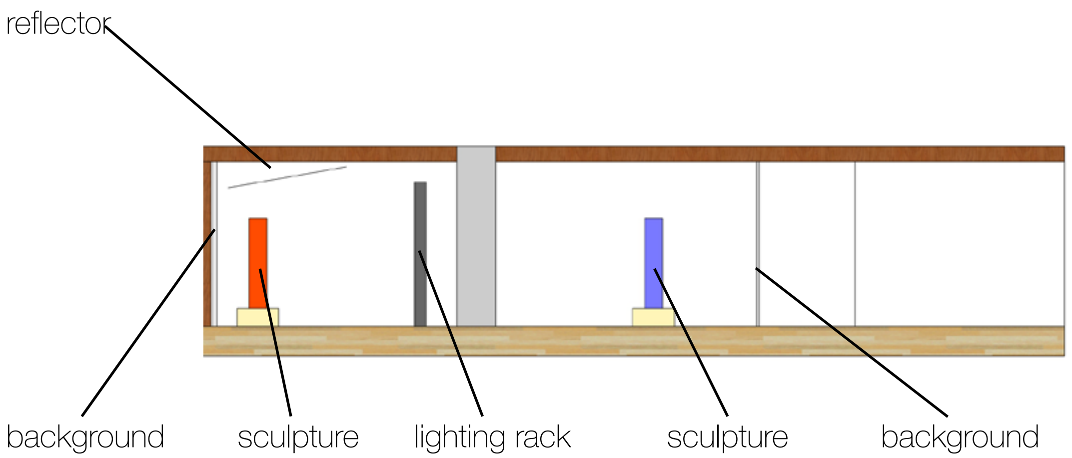


Figure 8.13. Section view of the experiment setup (Heikka & Stamidis, 2022)

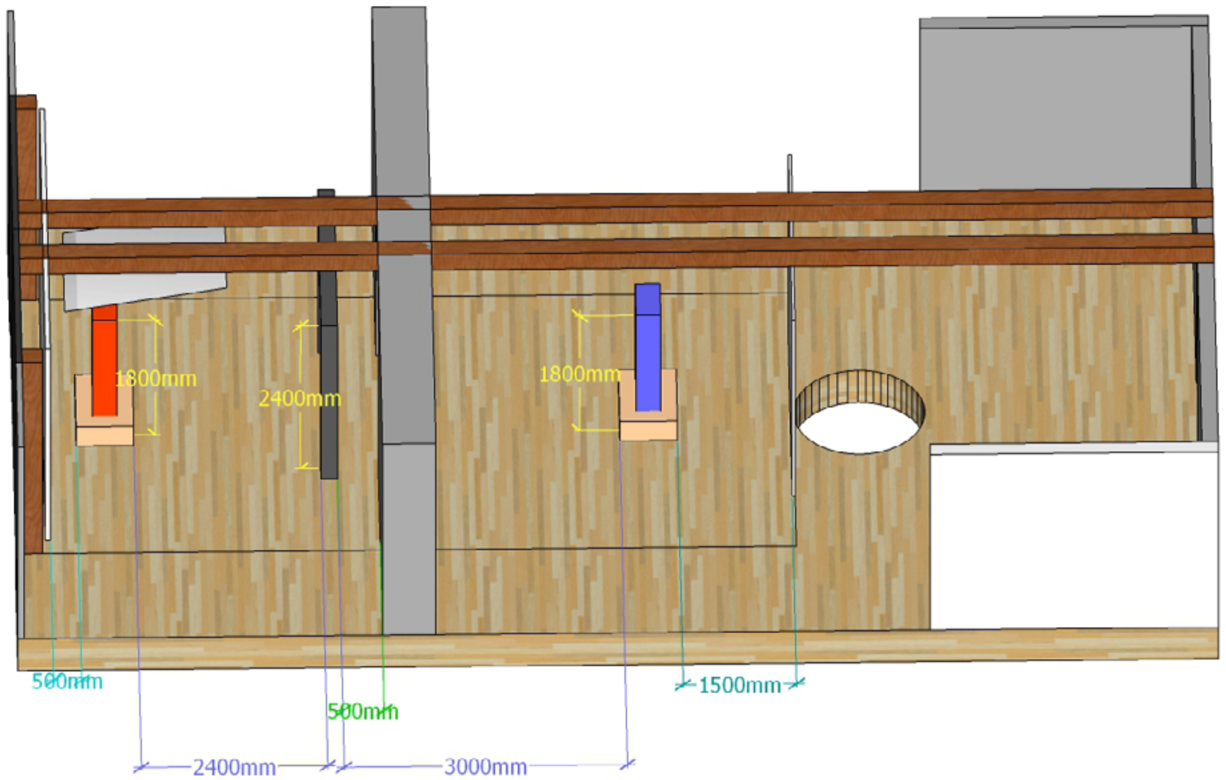


Figure 8.14. Top side view of the experiment setup with dimensions (Heikka & Stamidis, 2022)

The site of the experiment

The sculpture illuminated by the dynamic scene was placed in the space nearest the elevator, 0.6 metres from its doors. Because of spatial limitations, the illumination of the sculptures needed to be created on an independent system. For that reason, a rectangular truss system was used to attach all the lights needed to illuminate both sculptures. The lighting rack was placed on the side of the dynamic scene to get more accuracy for the several scenes. The general fluorescent lighting used in the museum was turned off for the time of the experiment so that it would not influence the lighting conditions and results. The process of creating dynamic and static lighting is further explained.

Figure 8.15. View of the static museum lighting setup from Apollon's backside (Heikka & Stamidis, 2022)

8.2.2 STATIC MUSEUM LIGHTING SETUP

The static setup was intended to correspond to current museum electric lighting standards, presented in Chapter 4.2 and Chapter 5.1. The data from Saunders (2020) indicates that the lighting should have an angle of incidence of approximately 30°, and by using at least two sources we can reduce the contrasts of shadows. However, using a second light source resulted in a power failure, which led to the use of only one source. The advantage of this is that the sculpture has only one shadow, instead of two that overlap, resulting in a more natural look.

The static scene was lit by ERCO's LED light source with a warm-neutral CCT of 3400K, CRI 85 and illuminating the statue by 110 lux on the face. The standard museum lighting angle of 30° could not be achieved due to spatial and installation limitations, which led to an angle of 70° from the centre of the sculpture, corresponding to a 20° angle of incidence of sunlight. This setup would not be typically used in a museum, as could be seen from the museum visits.

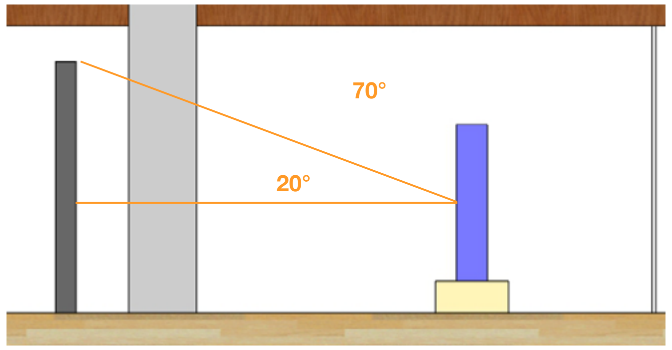
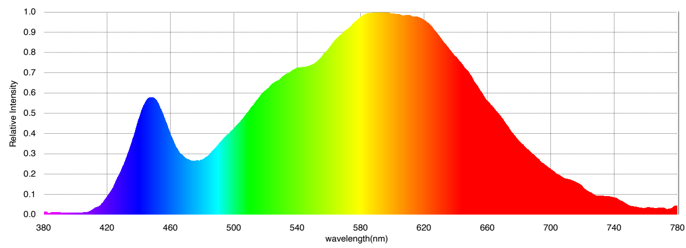
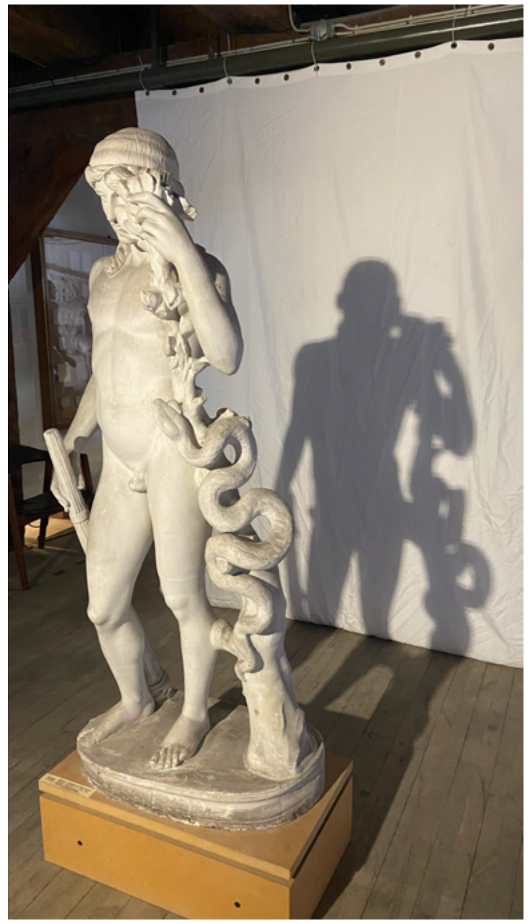


Figure 8.16. (above): Section view of the static setup with approximate angles of light.
(below): Spectrometer measurement of the light source
(around): Apollon statue from different sides in the static lighting scene
(Heikka & Stamidis, 2022)





8.2.3 EXPERIMENT DESIGN - DYNAMIC LIGHTING CONCEPT

By finding the specific space and the sculptures we could work with, we were able to implement the Design Concept presented in the previous chapter. The light sources for the dynamic concept and other equipment used for the experiment were borrowed from Aalborg University and Arthur van der Zaag. The light sources regarding skylight and electric light were attached to the same truss system as for the static lighting.

- Equipment used for the Dynamic Concept:
- 5 Halogen Fixtures, "Spotlight, mini PROFILE zoom"
- 5 RGBW LED - "Cameo" 15W DMX-controlled
- DMX-controllable dimmer (for controlling the halogen fixtures)
- DMX-sushi (from controlling the RGDW LED)
- Daslight 4: computer program - DMX controller
- Truss System 2400 mm x 2400 mm
- Reflector Fabric
- Light Filters

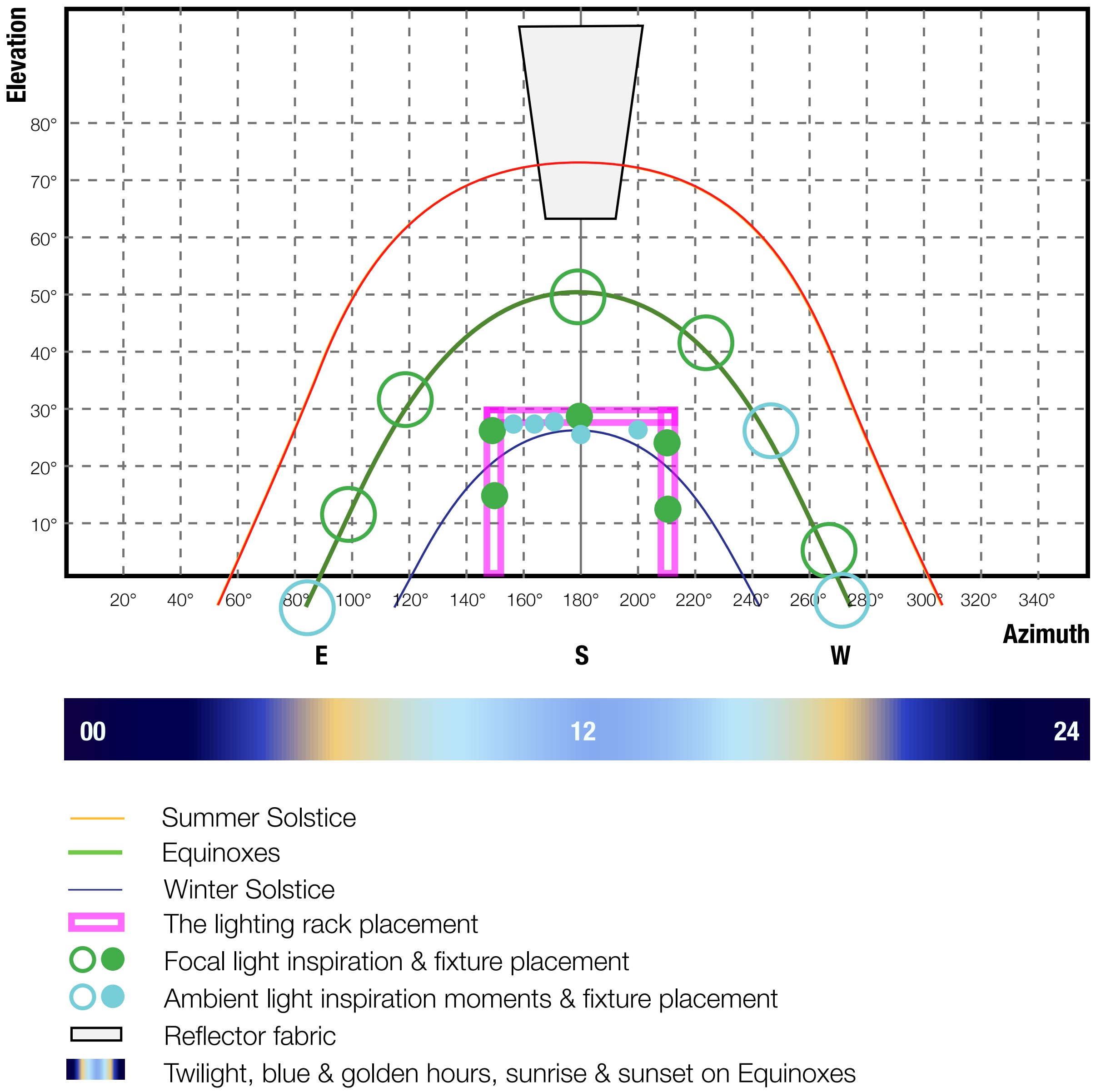


Figure 8.18. Green Circles: Focal Light | Blue Circles: Ambient Light | Reflector Fabric (Heikka & Stamidis, 2022)

◄ **Figure 8.17.** The location of the lighting rack (shown as magenta rectangles) together with the selected scenes in the sun position graph (Heikka & Stamidis, 2022)

Due to the spatial and installation limitations, the final positions of the light sources were much closer to the Winter Solstice than the equinox, as illustrated in Fig. 8.17. As shown, five different times of the day were chosen to represent direct sunlight, and the noon scene was additionally used for moonlight. The green circles are scenes that include both sunlight and skylight, while the blue circles are scenes with no direct sunlight. The scenes we chose to represent were the blue hour, golden sunrise, mid-morning sun, noon, afternoon, early evening with clouds, red sunset, twilight clouds and moonlight. They are represented individually in Chapter 8.2.3.1.

Both halogen and RGBW LED sources were DMX-controlled via Daslight 4 computer program and DMX-sushi. The halogens were connected to a DMX-controllable dimmer. That way we could achieve a cross-fade movement of the focal light and ambient light and control all fixtures from one program. First, the duration of the full cycle over these conditions was set to 14 minutes, which felt too long for the sake of the experiment, as we wanted to ensure that everyone would stay there over the entire cycle. Thus, it was shortened to 3 minutes 30 seconds. The short duration of the experiment cycle means that approximately 16 hours of a day was represented 274 times faster than the real progress of time.

FOCAL LIGHT:

Movement and angle: The movement of the sun inspired the placement of the halogen lights. However, as they are statically placed and they do not move, the sensation of movement was created by the change of where the light is coming from.

Spectrum: The halogens were used to represent the focal glow due to their excellent light qualities and resemblance to the spectrum of direct sunlight. The lamps were additionally equipped with light filters that allowed us to alter the transmitted spectrum of the white light, shifting the CCT towards the desired CCT, determined by the spectrometer measurements & the principles of atmospheric scattering.

Distribution: The halogen fixtures had movable lenses that allowed us to alter the sharpness and size of the beam. As a result, the size of the beam adjusted accordingly to scenes with or without clouds.

Quantity: Daslight4 DMX controller software was used to control the intensity of the fixtures, in order to create a balance between the focal and ambient light during the different scenes. Due to light filtering of some of the halogen sources, their intensity was decreased in accordance to how strong the filter was.

AMBIENT LIGHT:

Movement and angle: The movement of clouds and their heights and colours inspired the skylight features. The movement aspect is more apparent in the skylight than in the focal light, as several light sources that all change from scene to scene cause a sensation of movement.

Spectrum: The use of RGBW LEDs would allow us to control five sources individually but also to create colour combinations that would represent the different sky types on a cycle of the day. The fixtures were controlled by DMX-Sushi through a computer DMX software Daslight 4. The first tuning of the different sky types representation took place at Aalborg University while the fine-tuning made on the site of the experiment

Distribution: The five RGBW LED fixtures were placed on the top part of the truss system pointing to the reflector fabric. This would mimic the nature of the skylight, which is also just based on reflections.

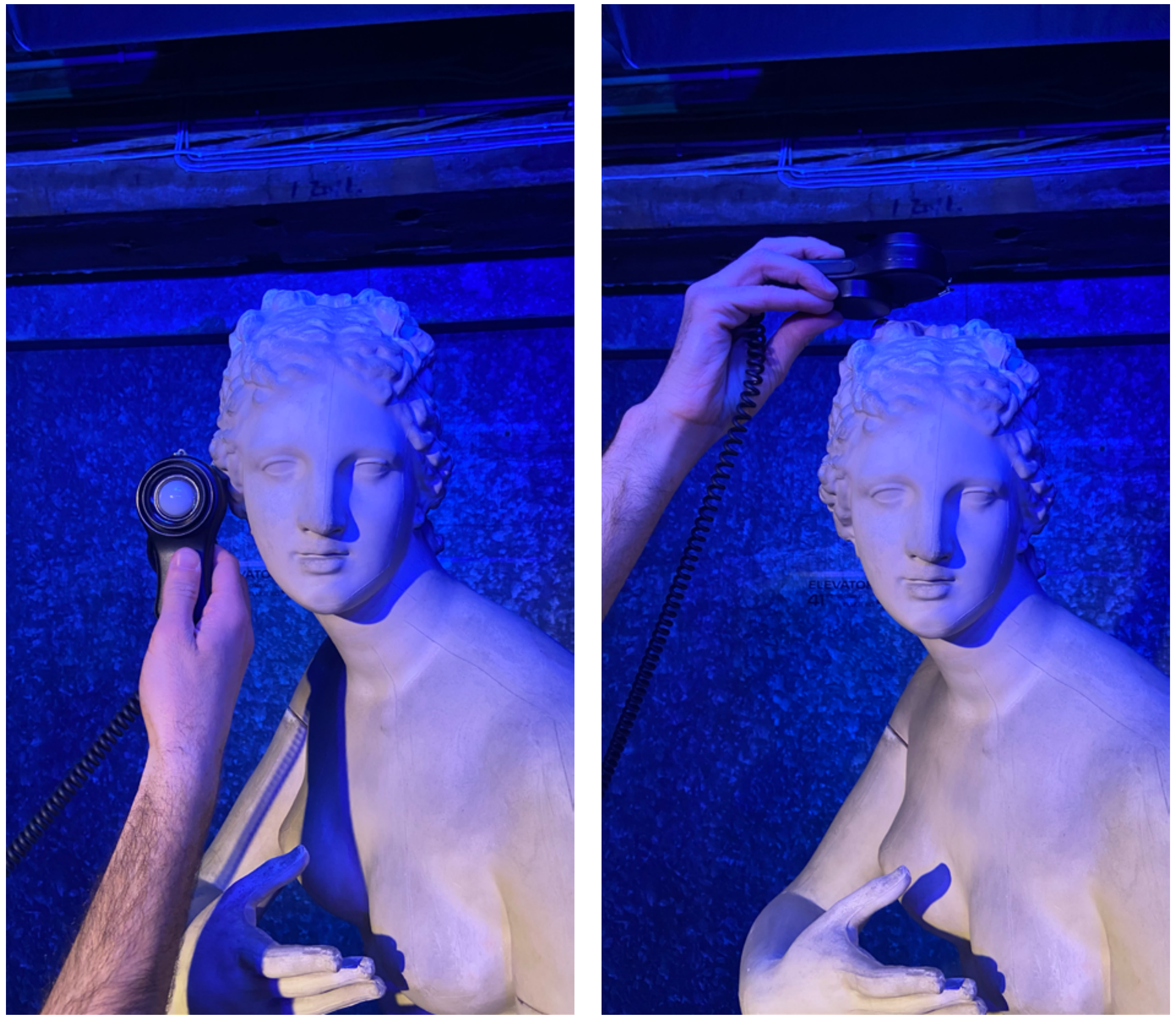
Quantity: Daslight4 DMX controller software was used to control the intensity of the fixtures, in order to try to achieve balance between the focal and ambient light during the different scenes.

8.2.3.1. SCENES

While the scenes are presented next, it must be considered that the spectrometer measurement was taken from one point only, with both focal light and only a part of the ambient light arriving on the measurement tool. Therefore the measurement does not give us the full reality, nor do the pictures taken with iPhone 11 & iPhone SE (2020) cameras. In the text below some values are presented as:

- CCT_f : Correlated colour temperature (CCT) of Focal light
- CRI_f : Colour rendering index (CRI) of Focal Light
- CCT_{af} : Correlated colour temperature (CCT) of Focal + Ambient Light
- CRI_{af} : Colour rendering index (CRI) of Focal + Ambient Light

Figure 8.19. Position of the lux meter for measuring the illuminance (lux) values (Heikka & Stamidis, 2022)



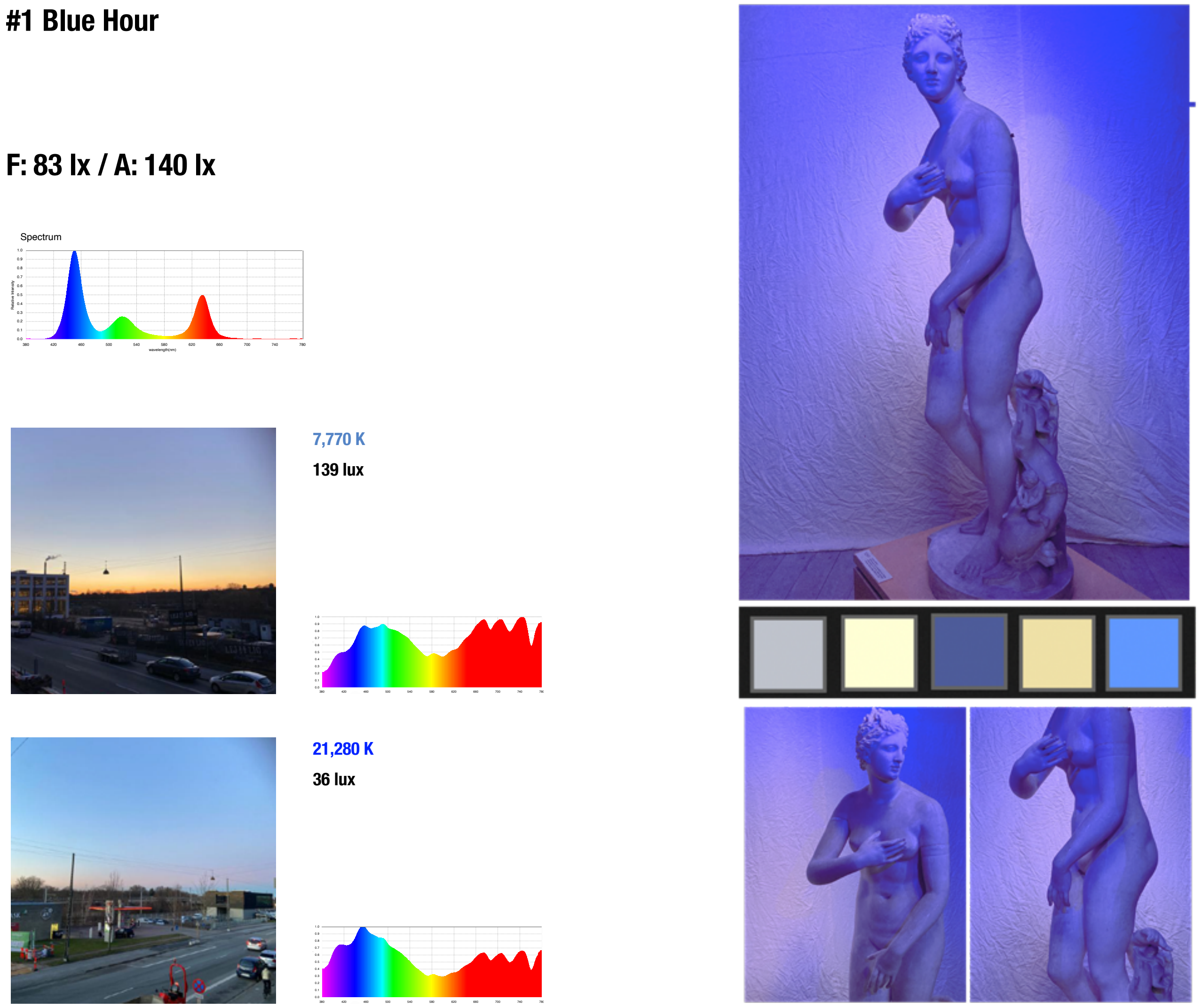


Figure 8.20. Blue Hour scene (Heikka & Stamidis, 2022)

Scene 1 – Blue Hour

The first scene was intended to represent the blue hour before the sunrise and was inspired by Fig. 8.20. The spectrometer measurements of the East and West sides after sunset show us that the CCTs are very high, with the sunset side at 7,800 K and the opposite Eastside at 21,300K. As the skylight was created by RGBW light sources, the red, green and blue wavelength peaks are clearly visible. However, their proportions correspond quite well to the spectrum of light at blue hour. Due to the discontinuous spectrum, the light was perceived as strongly blue. The vertical illuminance on the face of the sculpture is 83 lux, and the horizontal illuminance above the head 140 lux, meaning that most of the light is indeed coming from above.

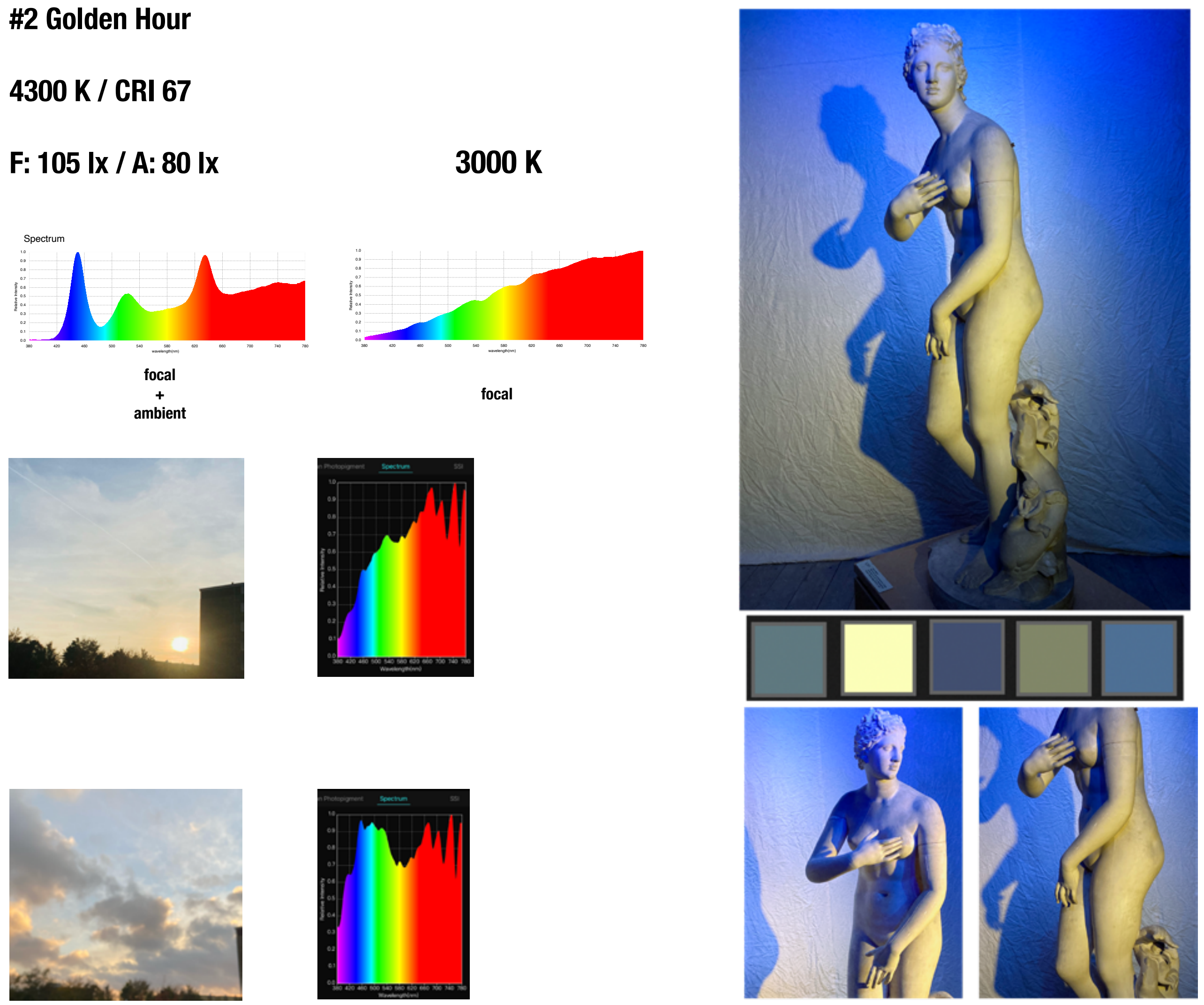


Figure 8.21. Golden Hour scene (Heikka & Stamidis, 2022)

Scene 2 – Golden Hour

The second scene was intended to represent the golden sunrise, with the focal light around 6° from the horizontal line and was inspired by the pictures of the Fig. 8.21. The spectrometer measurements of a golden sunset show similarities in the spectrum of the sun and the sky at the golden hour. The CCT of the focal and ambient light arriving on the face of the sculpture reaches the CCT_{af} of 4300K, with a CRI_{af} of 67. The low CRI is on account of the RGBW light sources. The halogen fixture was fitted with a filter that decreased the CCTf of the focal light to 3000K, achieving a more golden tone of light, with a CRI_{f} of 99. The illuminance on the face is 25 lux higher than over the head, at 105 lux.

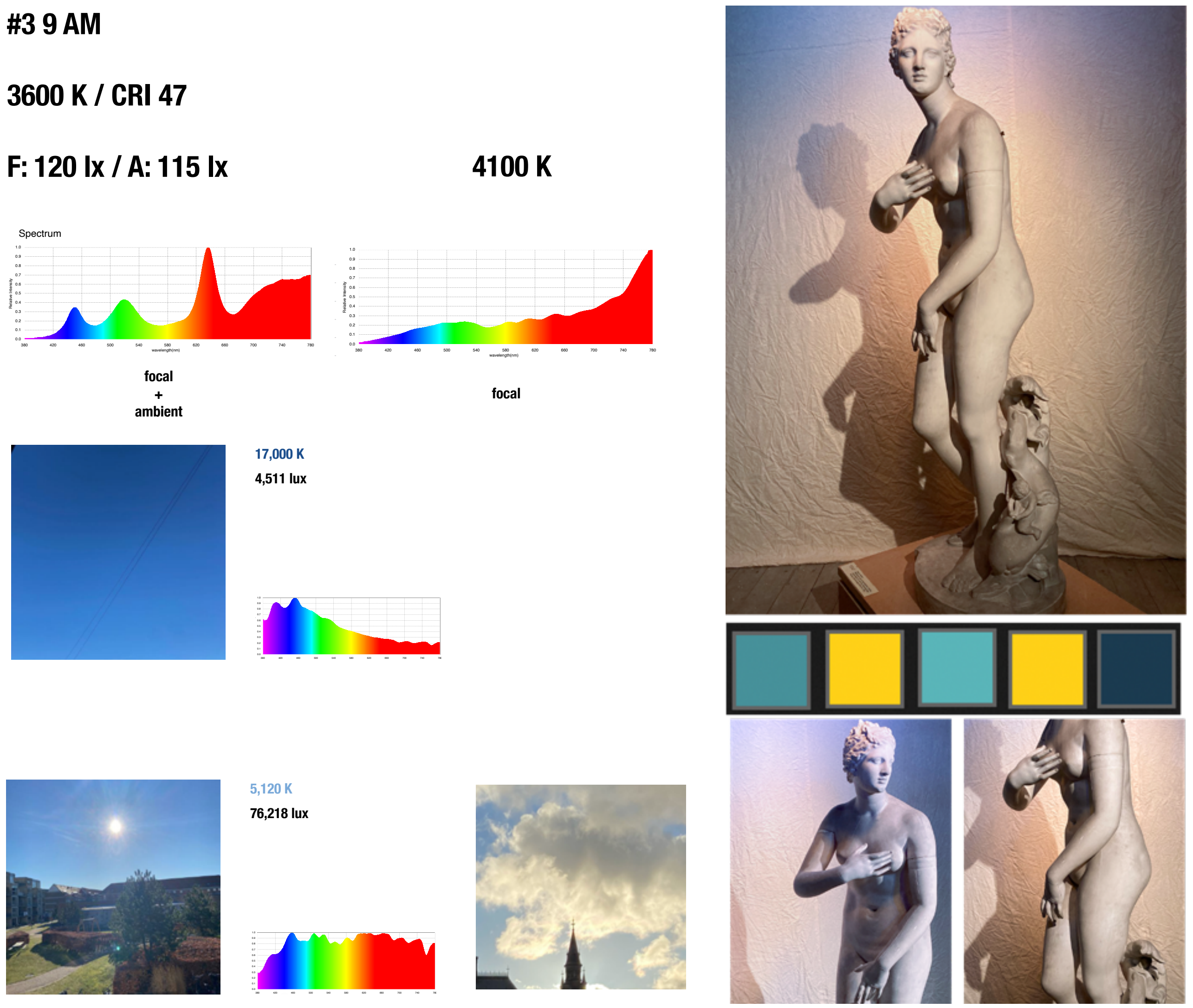


Figure 8.22. 9 AM scene (Heikka & Stamidis, 2022)

Scene 3 – 9 AM

The third scene was intended to represent the light at around 9AM, with a blue sky and some clouds, inspired by the picture of the Fig. 8.22. The spectrometer measurement of this scene does not correspond to the measurements of the skies, as there should be significantly more blue and green in the spectrum of the skylight. This also shows in the measured CCT_{af} of the focal + ambient light arriving on the face of the sculpture, as it reaches a low CCT of 3600K, with a CRI_{af} of only 47. The low CRI is on account of the RGBW light sources. The halogen fixture was fitted with a filter that increased the CCT_{f} of the focal light to neutral 4100K with a CRI_{f} of 88. The illuminance on the face is only 5 lux higher than the ambient light, while in the sky measurements the illuminance of the sky around direct sunlight is over 16 times higher than the diffused skylight.

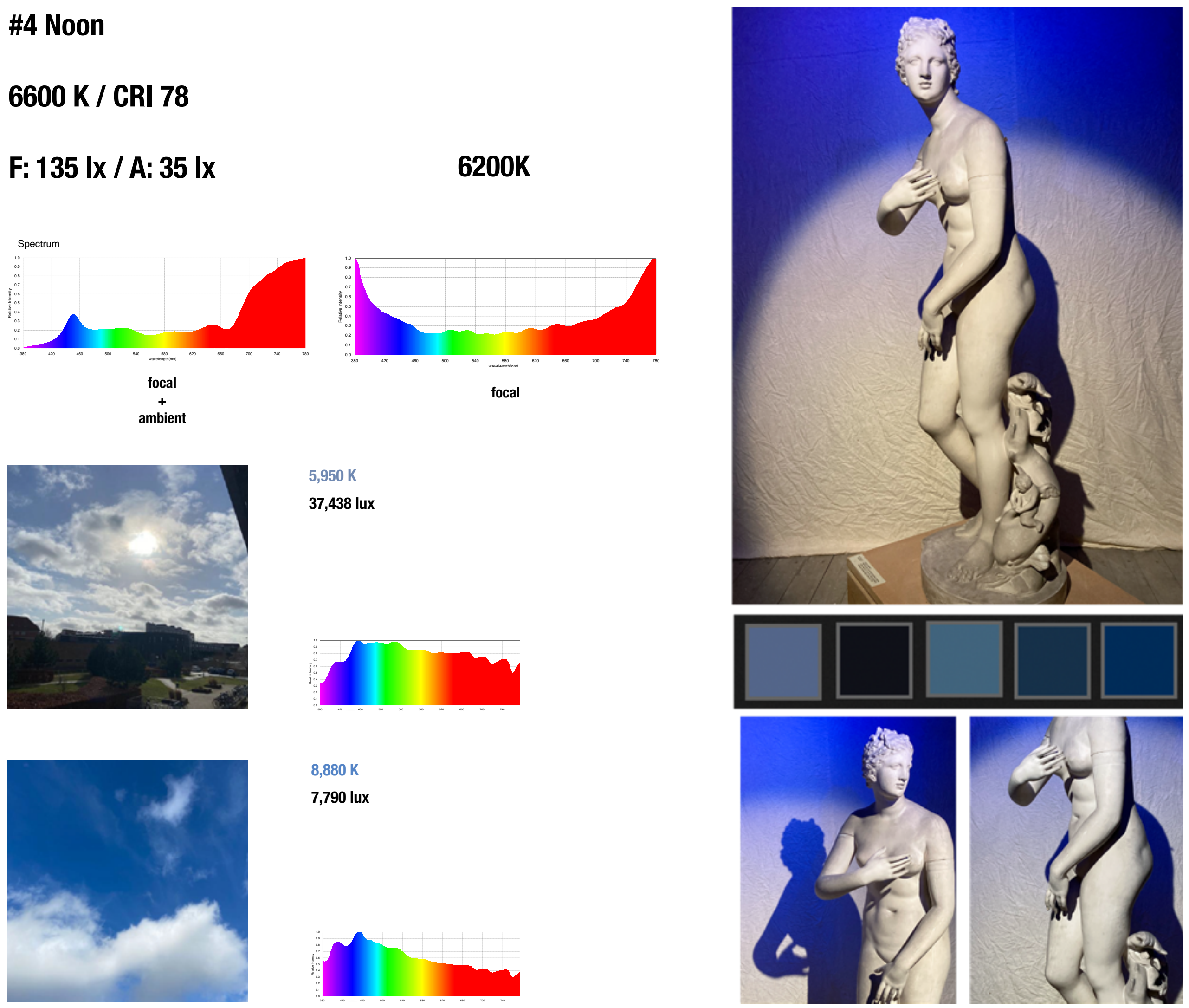


Figure 8.23. Noon scene (Heikka & Stamidis, 2022)

Scene 4 – Noon

The fourth scene was intended to represent the light at solar noon when the sun is at its highest position and when the daylight is at its coolest CCT, inspired by the pictures on Fig. 8.23. Disregarding the long wavelengths of light, the spectrometer measurement of this scene corresponds very well to the spectrometer measurements of the inspirational skies at noon. Furthermore, the combined CCT of the light sources also reaches 6600K, corresponding to the CCT of daylight at noon. Both CRI_{af} and CRI_{f} value are at 78. The halogen fixture was fitted with two blue filters that increased the CCT of the focal light to a cool-white of 6200K. The illuminance ratio is also almost correct, with significantly more light from the focal light than the ambient.

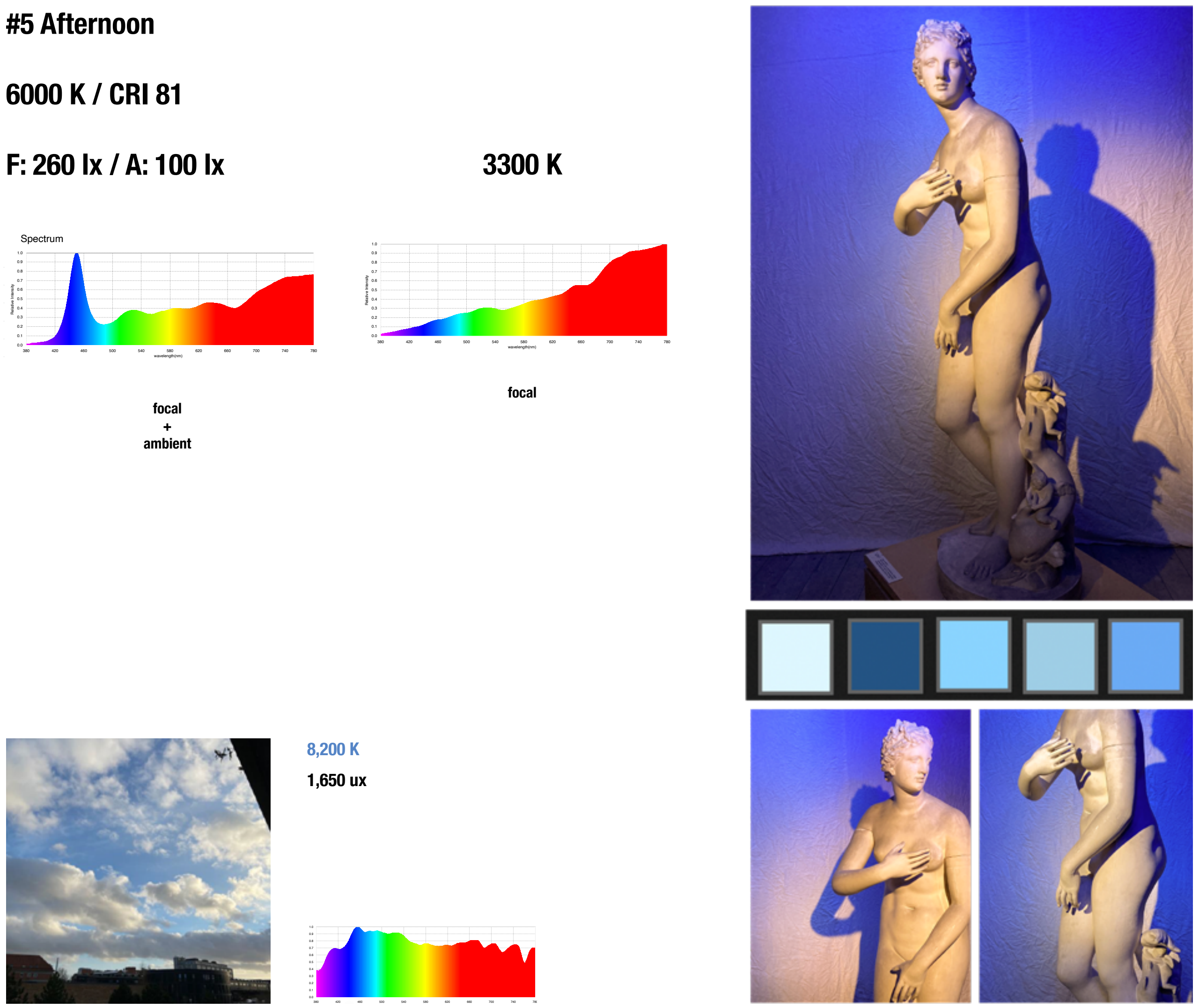


Figure 8.24. Afternoon scene (Heikka & Stamidis, 2022)

Scene 5 – Afternoon

The fifth scene was intended to represent the light in the afternoon, with sunlight shining from behind the clouds inspired by the pictures on Fig. 8.24. The spectrometer measurement of this scene does not correspond to the measurement of the sky, as there should be less blue and more green light in the spectrum of the skylight. However, the measured CCT_{af} of 6000K transmits the time of the day well, although it does not reach the high measured CCT of 8200K. The CRI_{af} is surprisingly high at 81, which is likely the result of the halogen light, which is only fitted with an achromatic diffusion filter. Its CCT_{f} is a warm-neutral 3300K with a CRI_{f} of 92. The illuminance ratios are acceptable in this scene too, with the face being illuminated by 260 lux while ambient light is measured at 100 lux.

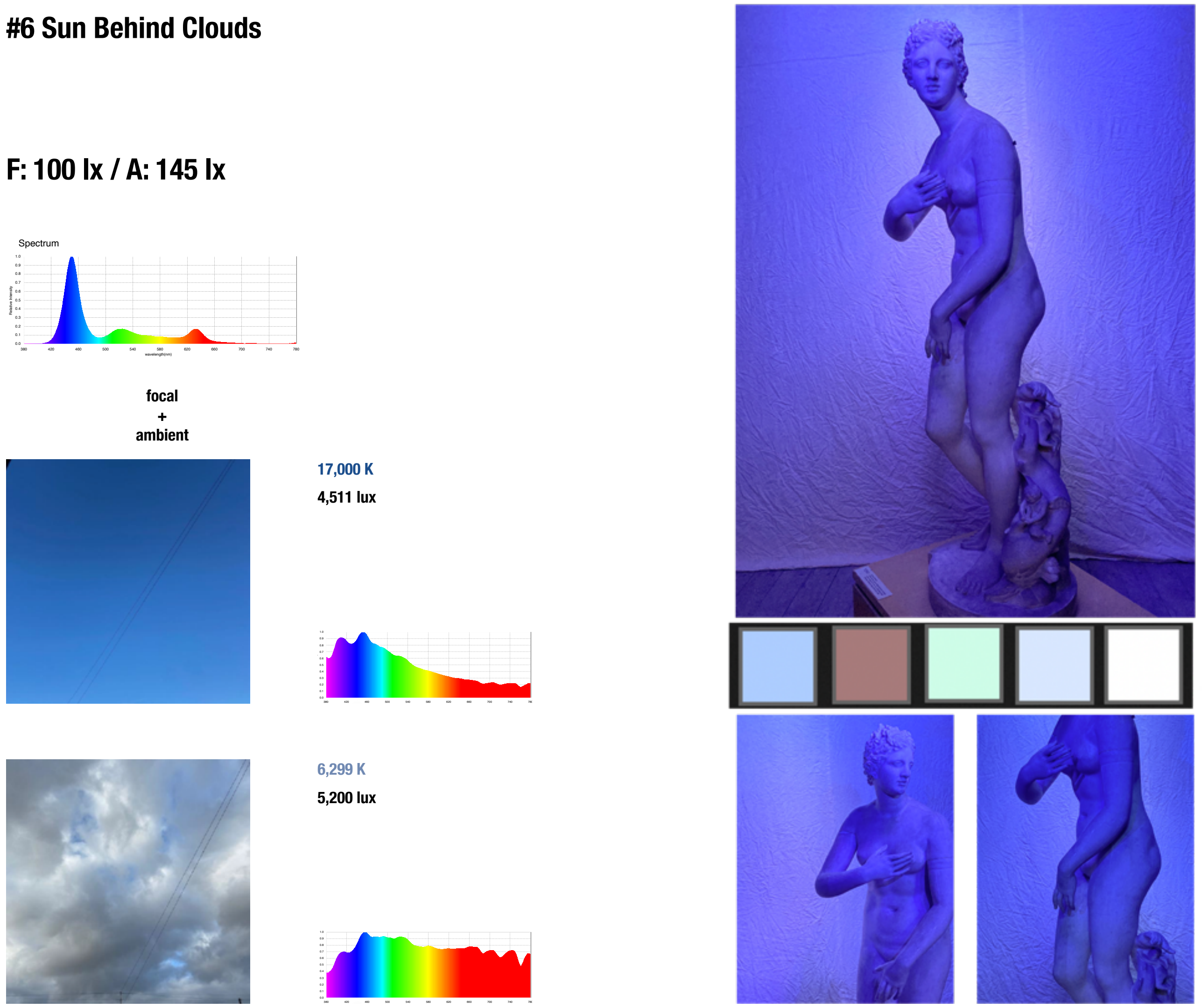


Figure 8.25. Sun Behind Clouds scene (Heikka & Stamidis, 2022)

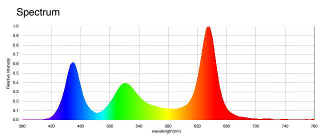
Scene 6 to 9 – Clouds

As some days are overcast, the idea was to transmit this to the viewers too. Getting closer to the sunset, more clouds begin to appear, as hinted by the previous scenes. For the cloudy scenes only the skylight was utilised, meaning that only RGB LEDs were used, leading to rather strong colours. These four scenes were also cross-fading into each other faster than the previous scenes, to communicate the movement of the clouds to the viewers. Only with two of the scenes, namely #7 & #8, a CCT value was achieved from the spectrometer measurement. With #7, the measurement indicated a warm CCT of 4500K with a CRI of 38. Scene #8 had a very high CCT of 23,400K with a CRI of 42. The scenes #7 and #9 were identical.

#7, #9 Clouds 2

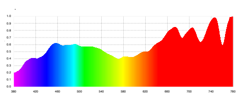
4500 K / CRI 38

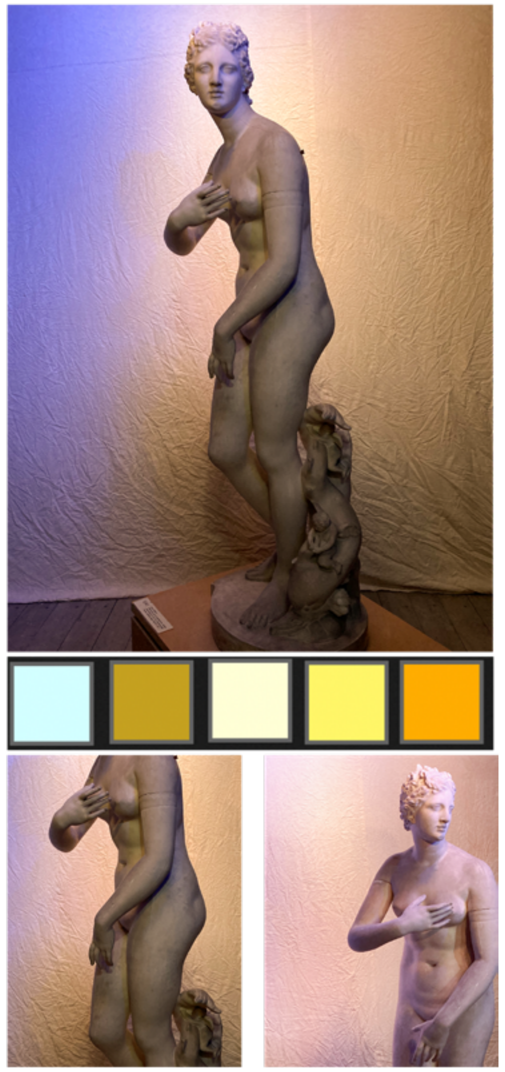
F: 110 lx / A: 160 lx

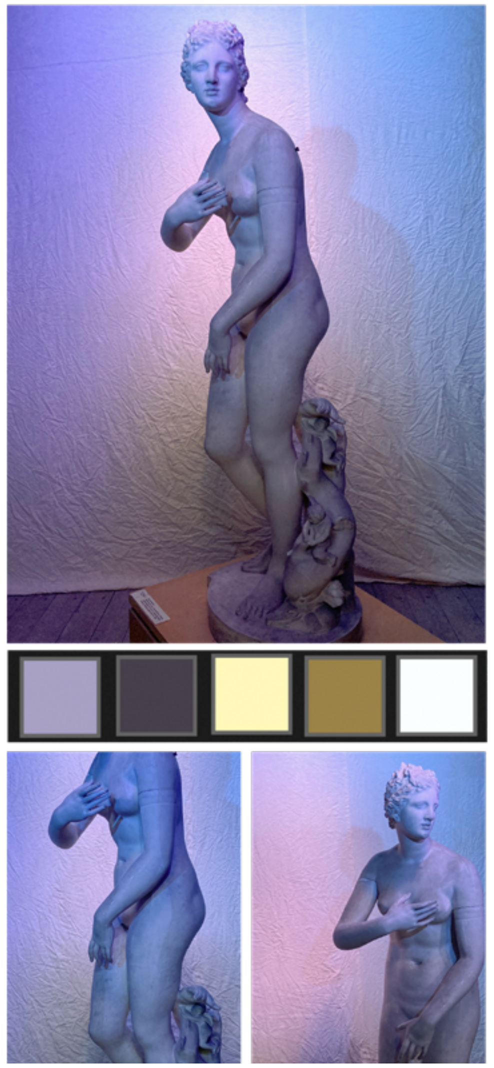


6052 K

520 lux



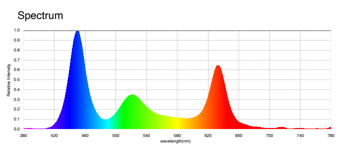




#8 Clouds 3

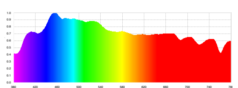
23,400 K / CRI 42

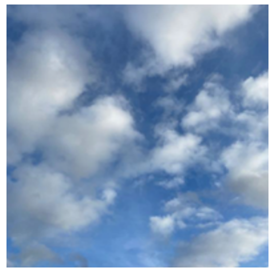
66 lx / 85 lx



6,730 K

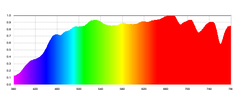
6,167 lux





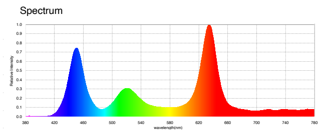
4,640 K

28,295 lux

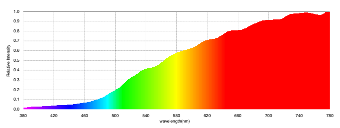


#10 Start of Red Sunset

F: 84 lx / A: 110 lx **2600 K**



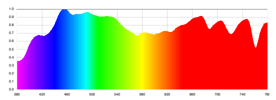
focal
+
ambient



focal

6,570 K

1,212 lux



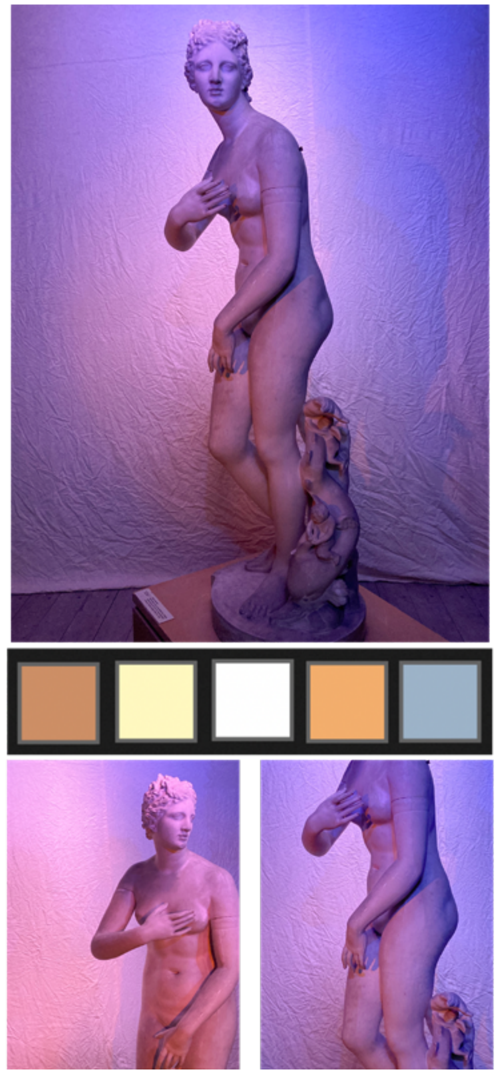


Figure 8.28. Start of Red Sunset scene (Heikka & Stamidis, 2022)

Scene 10 –Start of the Red Sunset

The tenth scene was intended to represent sun emerging from behind the passing clouds, inspired by the pictures on Fig. 8.28, with a faint warm focal glow shining on the sculpture, and with the sky covered in colourful clouds toning the sculpture as in the timelapse. The spectrometer measurement of this scene indicates that there should be less red light from the skylight. The spectrometer does not give CCT and CRI values for the combined focal + ambient light, but the focal glow is measured with a CRI_f of 91 and a warm CCT_f of 2600K due to the use of an amber filter on the light source. Due to the gentle presence of focal light, the illuminance on the face is still smaller than above the head.

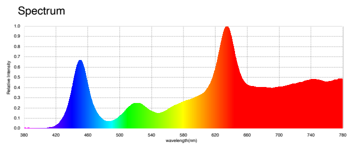
Figure 8.26. Clouds 2 scene (Heikka & Stamidis, 2022)

Figure 8.27. Clouds 3 scene (Heikka & Stamidis, 2022)

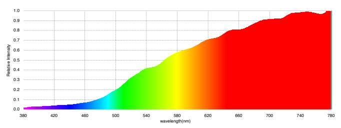
#11 Red Sunset 1

F: 145 lx / A: 135 lx

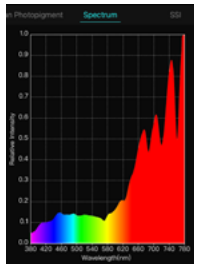
2600 K

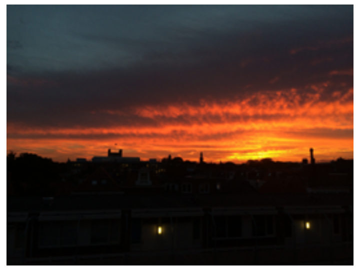


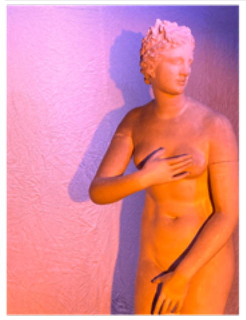
focal + ambient



focal







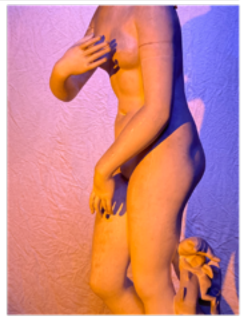


Figure 8.29. Red Sunset 1 scene (Heikka & Stamidis, 2022)

Scene 11 –Red Sunset 1

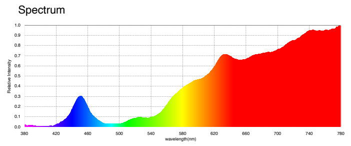
The eleventh scene was intended to represent a fully-emerged sun from behind the passing clouds, together with vividly coloured clouds as skylight, inspired by the pictures on Fig. 8.29. The spectrometer measurement of this scene shows accuracy with achieving the intention, however the RGB peaks are still too strong. The CCT and CRI values are again not given, and the focal light remains with the same values as in the previous scene. The illuminance from the focal glow has surpassed the illuminance of the ambient light, however only by 10 lux.

#12 Red Sunset 2

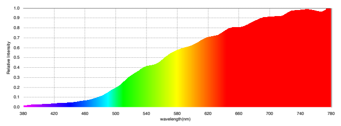
1800 K / CRI 81

F: 45 lx / A: 12 lx

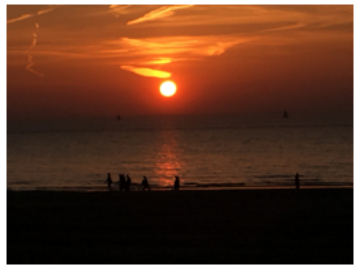
2600 K

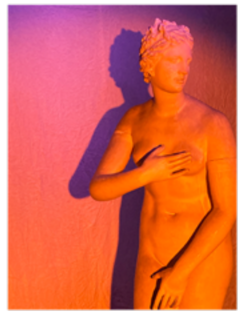


focal + ambient



focal





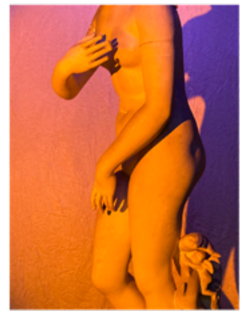


Figure 8.30. Red Sunset 2 scene (Heikka & Stamidis, 2022)

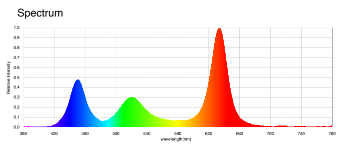
Scene 12 –Red Sunset 2

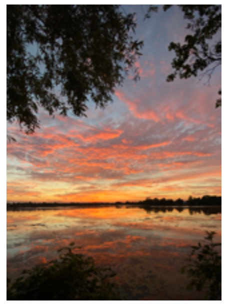
The twelfth scene was intended to represent the very moment of sun setting behind the horizon, inspired by the pictures on Fig. 8.30, with lower illuminance levels of both focal and ambient light. The warmth of the light truly transmits the feeling of a beautiful red sunset with magenta clouds toning the shadows. Here, a CCT value was given, and it corresponded to 1800K, with a CRI of 81. The illuminance from the focal glow has grown higher than in the previous scene, with 45 lux on the face and 12 lux from the ambient luminescence.

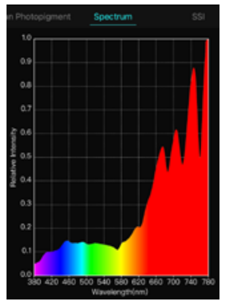
#13 Twilight Clouds

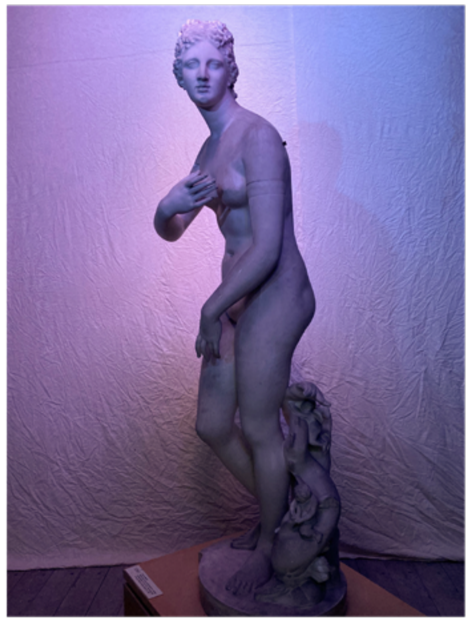
3300 K / CRI 20

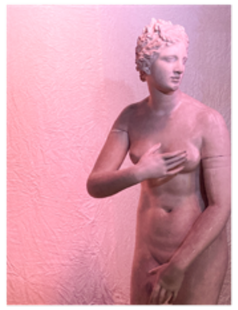
F: 75 lx / A: 53 lx











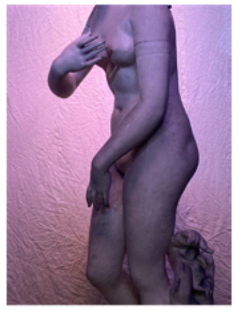


Figure 8.31. Twilight Clouds scene (Heikka & Stamidis, 2022)

Scene 13 – Twilight Clouds

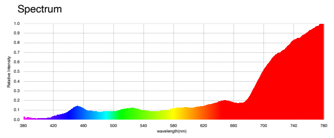
The thirteenth scene was intended to represent the twilight clouds after sunset, with no focal glow and only diffused skylight in striking colours. This was one of the scenes we achieved with a very high accuracy, based on how the sculpture looked (note: difficult to see in the photos). The spectrum of light also seems relative to the inspirational measurement. The measured CCT in this scene was 3300K, with a CRI of 20.

#14 Moonlight

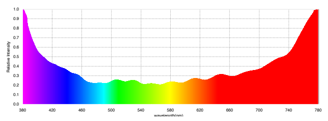
3800 K / CRI 81

F: 17 lx / A: 5 lx

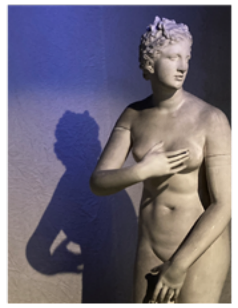
6200 K



focal + ambient



focal



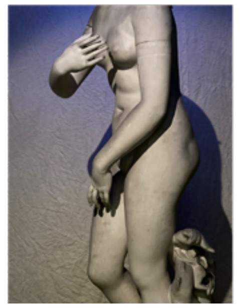


Figure 8.32. Moonlight scene (Heikka & Stamidis, 2022)

Scene 14 – Moonlight

The fourteenth scene was intended to represent moonlight, i.e. reflected sunlight, from a full moon, inspired by the pictures on Fig 8.32.The measured CCTaf was 3800 K, and CRI 81. This scene had no spectrometer measurements to compare to. The illuminance of the skylights was kept low, alike the cool white focal glow that came from the light fixture placed at the highest position (noon). The halogen fixture was fitted with a filter that increased the CCT of the focal light to a cool white of 6200K. The illuminance ratio is also almost correct, with significantly more light from the focal light than the ambient.

Figure 8.33. (Left:) Collage of all the scenes used in the experiment; (Above:) Movement of shadows (Heikka & Stamidis, 2022)

The collage shows how the course of the day is communicated by our experiment. The movement of the shadows and the changes in their sharpness and prevalence communicate the time of the day as well as the weather conditions. The sculpture and its perception are affected by these changes in quantity, spectrum, distribution, direction and movement. Different parts are highlighted throughout the scenes, and the colours reflected by the white plaster surface vary in accordance to the SPDs of the light sources. Some of the colours appear very strong and unnatural, which is related to the way we perceive colours of the light produced by an RGB light source, which produces colours through illusions (for example cyan light is not factually cyan wavelengths, but a perception created by the brain, who understands the light as colour that is missing its complementary red wavelength). This creates a feeling of an artificial environment that does not correspond to natural conditions. However, it has entertaining value. After putting the setup and scenes together, all that was left was to get feedback from visitors.

8.3 SURVEY

Once the two setups were finalised, each lighting approach was evaluated through a survey of participants, in order to get a better understanding of the dynamic lighting effects on the enhancement of the artwork and visitor experience. The procedure of the survey lasted three hours (10:00 - 13:00) and the process was the following:

- People were participating in groups of unequal numbers.
- Once they arrived at the site they were introduced to the experiment.
- To not affect people's opinions, no specific explanation was given to them before the experiment rather than to experience and observe the two setups freely, while a discussion would happen after they have filled in the questionnaires.
- The participants were asked to stay and experience the experiment as long as they wished.
- The participants were asked to write any comment according to the experiment.

In total, 22 people took part in the process with a minimum age of 22 years old and maximum of 52 years old (average age of 27 years old). The group of participants consisted of 15 females, 4 males and 3 who did not respond. The questionnaires the people had to fill in were composed of three different categories. The first two categories referred to personal preference and the last category referred to experience. In order to understand people's preferences, the questions were formulated according to a Likert type scale as it described in Chapter 3 "Methodology". The first category referred to the "Perception of the artworks" and included four questions (Fig. 8.35). The second category referred to the "Appreciation of / Engagement with the Artwork" following the same format as the previous category (Fig. 8.35). The third category included questions according to the Experience. In the Literature Review chapter 4.1.2 the term experience is explained as a "blend. It is therefore not just the physical or the emotional; it is both combined, blended" (Shaw & Ivens, 2002). As a result, analysing the emotional response of the participants would help us understand how the physical contexts - light and sculpture - affected their feelings

Figure 8.34. Photos from the experiment (Heikka & Stamidis, 2022)

and therefore how they experienced the different situations. The formula of the questions is based on the PAD as it described in Chapter 3 "Methodology". The participants were asked to fill in a five-point scale of their, at that time, emotional state referring to "Pleasant - Unpleasant", "Comfortable - Uncomfortable", Excited - Calm", "Stimulated - Aroused", "Satisfied - Dissatisfied" and "Connected - Melancholic" (Fig. 8.35).

The questionnaires were the same for both setups (one for the static lighting and one for the dynamic lighting). Moreover, by observing the participants in the process of the experiment we aimed to understand how much time they spent on which set up.

Questions about the perception of the artwork:

A To what extent does lighting enhance the general appearance (visibility) of the sculpture?

poor ○ ○ ○ ○ ○ ○ excellent

B To what extent does lighting reveals the general form/shape of the sculpture?

poor ○ ○ ○ ○ ○ ○ excellent

C To what extent does lighting enhance the texture of the sculpture?

poor ○ ○ ○ ○ ○ ○ excellent

D To what extent does lighting reveals the details (volume, shapes, expression) of the sculpture?

poor ○ ○ ○ ○ ○ ○ excellent

Questions about the appreciation/engagement of the artwork

E How suitable does the lighting seem to be for the sculpture?

poor ○ ○ ○ ○ ○ ○ excellent

F How attractive does the sculpture appear?

poor ○ ○ ○ ○ ○ ○ excellent

G How appealing does sculpture seem?

poor ○ ○ ○ ○ ○ ○ excellent

Questions about the experience – How did you feel while observing the sculpture?

Pleasant						Unpleasant
Comfortable						Uncomfortable
Excited						Calm
Stimulated						Relaxed
Satisfied						Dissatisfied
Connected						Melancholic

Figure 8.35. Questionnaire used in the experiment (Heikka & Stamidis, 2022)

8.3.1 Results

The questionnaires were analysed by computing the geometric mean and standard error of the results. The geometric mean was selected as it shows a result less affected by extreme values and with the standard error we can understand to what extent that mean represents the sample (the less the standard error value the more it represents the sample). The results are presented and analysed through charts and their tables. The tables with the questionnaire analytical results can be found in the Appendix. In addition, some of the comments of the participants are presented.

8.3.2 Results - Perception of the Artwork

The results regarding the first question, "lighting enhancing the general appearance", are equal in both setups, though dynamic lighting is slightly preferred. The second question regarding lighting revealing the general form/shape of the sculpture shows an important difference between dynamic lighting and static lighting. Similar are the results of the fourth question, regarding lighting revealing the details (volume, shapes and expression), with dynamic lighting to be generally preferred. In addition, one of the participants explained: "While bringing out the details more, the lighting also emphasises some "faults" of the sculpture". The participant seemed to enjoy the fact that with dynamic lighting more details and "mistakes" can be observed.

Regarding the question C, "to what extent does lighting enhance the texture of the sculpture", the results seem in both cases to be closer to a neutral opinion, but still with a preference for the dynamic illumination of the sculpture. This could be explained by the materiality of the sculptures, which is gypsum plaster, and both surfaces have a smooth surface.

Moreover, dynamic lighting had more positive comments regarding the sculpture's perception as participants seemed to enjoy the changes of the colour of the light but also the "movement" of the light resulting in different highlights and shadows. A participant comments: "Seems more appealing because of the changes of colours and because of that you notice more details. Some of the colours work well for her body and some others for her face" and another participant wrote: "I loved the changes of the shadows and the great colours. Great concept about daylight.". Moreover a participant wrote: "Highlights texture/details from creation process + restauration (wich is good)." The comment further continues: "all answers depend on the room and the concept dynamic would work only in a empty-ish room nor with so many other sculptures lighted the same way". While the participant enjoyed the revealing of texture and details by dynamic light, they also commented on the empty room a setup like that should be placed in. Moreover, they point out the fact that this setup might not work as the only way of illuminating an entire exhibition.

	Investigated Parameters	Dynamic Lighting Setup				Static Lighting Setup			
	Questions	A	B	C	D	A	B	C	D
Perception of Artworks	Geometrical Mean	4.45	5.06	4.13	4.95	3.67	3.44	3.20	3.32
	Standard Error	0.25	0.22	0.30	0.21	0.25	0.22	0.30	0.21
	Median	4.45	5.06	4.13	4.95	4.45	5.06	4.13	4.95

Table 2. Results of the questionnaires about Perception of Artworks (Heikka & Stamidis, 2022)

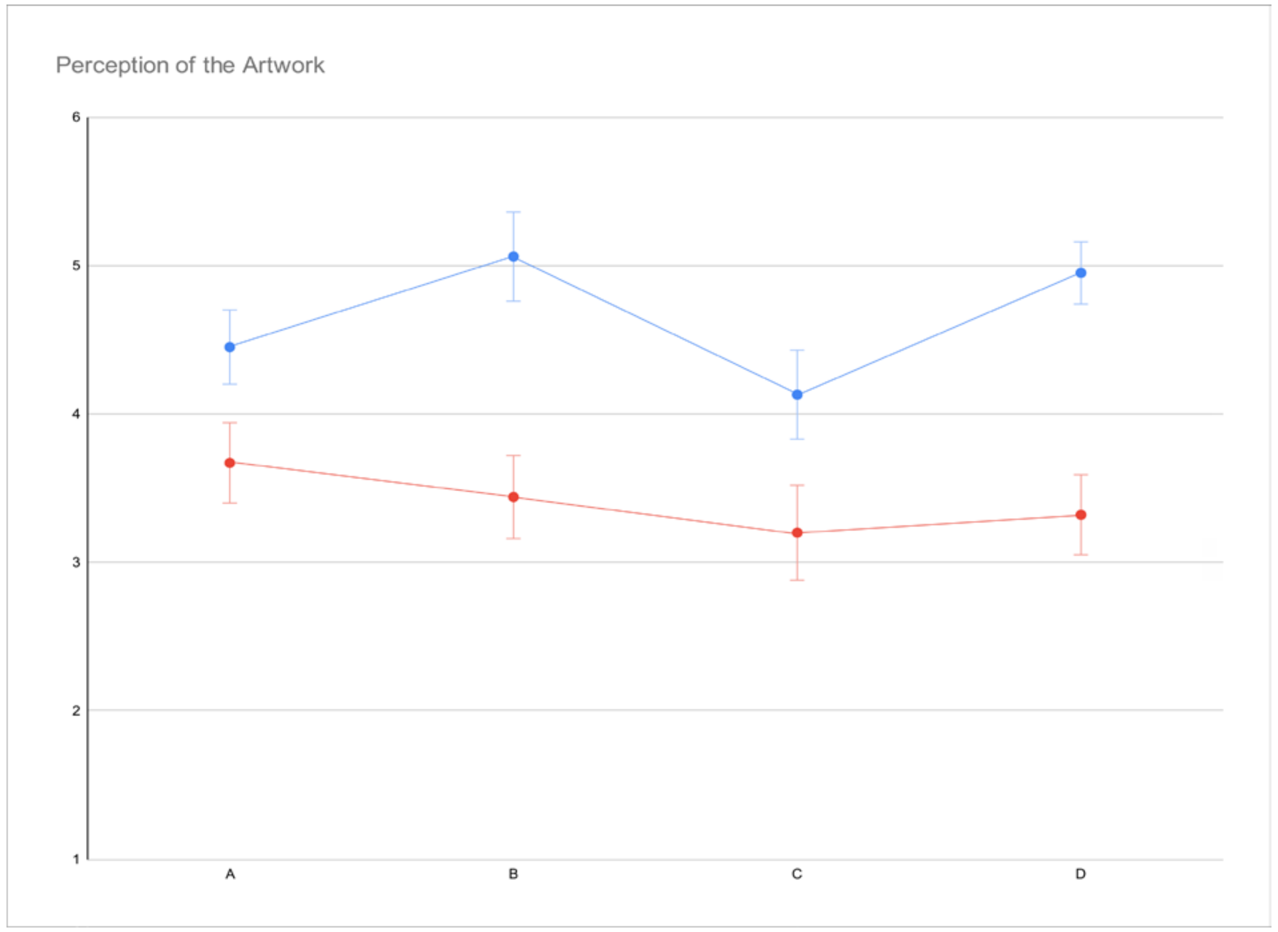


Figure 8.36. Results of Table 2 (Geometric mean and Standard Error). Combined results of the Dynamic Lighting (Blue Colour) and Static Lighting (Red Colour) (Heikka & Stamidis, 2022)

	Investigated Parameters	Dynamic Lighting Setup			Static Lighting Setup		
Appreciation of / Engagement with the Artwork	Questions	E	F	G	E	F	G
	Geometrical Mean	4.85	4.86	5.10	3.24	3.17	3.34
	Standard Error	0.23	0.26	0.22	0.30	0.29	0.24
	Median	5	5.5	6	3.5	4	3

Table 3. Results of the questionnaires about Appreciation of / Engagement with the Artwork (Heikka & Stamidis, 2022)

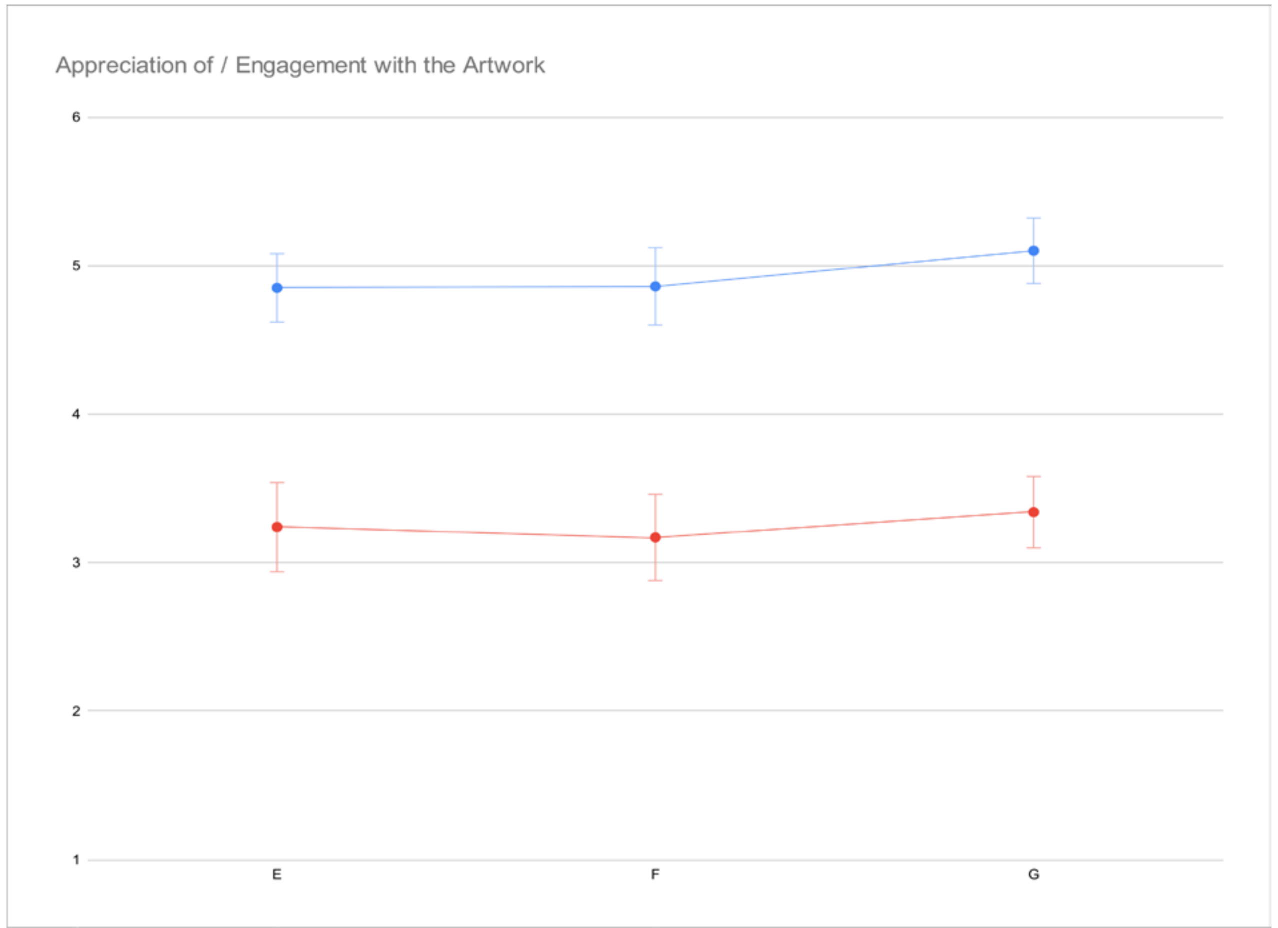


Figure 8.37. Results of Table 3 (Geometric mean and Standard Error). Combined results of the Dynamic Lighting (Blue Colour) and Static Lighting (Red Colour)(Heikka & Stamidis, 2022)

8.3.3 RESULTS - APPRECIATION OF / ENGAGEMENT WITH THE ARTWORK

The results in this category show an important difference between dynamic lighting and static lighting. In all three questions, dynamic lighting seemed to be generally preferred regarding appreciation of and engagement with the sculpture. Similar answers were given for the questions referring to "how suitable does the lighting seem to be for the sculpture" and "how attractive does the sculpture appear" where the participants preferred dynamic lighting compared to static lighting. The higher value for this category was given to dynamic lighting on the third question regarding "how appealing does the sculpture seem" where most participants found that dynamic lighting makes the sculpture look more appealing in comparison to static lighting.

The preference for dynamic lighting can be also seen from the comments of the participants. A participant wrote about dynamic lighting; "The colour affected her personality - Red warm colours make her more elegant as a 'mother figure'. Makes the experience much more interesting". The participant found dynamic lighting interesting as the changes of the colour of the light could change the personality of the sculpture - "elegant and mother figure". As a result, the participant created a personal explanation of how light affects the sculpture resulting in a personal experience of appreciating the sculpture. Regarding the static illumination, another participant also wrote: "Harsh shadows (contrast) + no diffuse light = distracting". As it is mentioned in the previous chapter, because of the space and equipment limitations of this experiment, the lighting conditions were not perfectly achieved for both sculptures. As a result, only using one fixture in a 60° angle for the static illumination created a distracting experience.

8.3.4 RESULTS - EXPERIENCE

In the last category referring to the Experience of the participants, people were asked to state their emotional response while observing the two different setups. As can be seen in Fig. 8.38, dynamic lighting made them feel pleasant and comfortable. Correspondingly, static lighting did not cause a strong emotional response regarding pleasant/unpleasant (inclining towards pleasant) but it made them feel comfortable while observing the sculpture. Regarding the emotions of stimulated/relaxed, participants felt more stimulated while observing the sculpture with dynamic illumination, but also they felt more relaxed observing the static lightning setup. On the other hand, participants observing the static setup did not show an important emotional response regarding satisfaction/dissatisfaction and connected/melancholic as their responses are more neutral. Nevertheless, in the case of dynamic lighting, people felt more satisfied while observing the sculpture and slightly more connected.

Lastly, the participants had neutral responses regarding excitement/calm for both lighting setups. In addition to that question, a participant wrote: "I feel calm but also excited/stimulated because of the changes - I don't know what to expect next and it's something new though some colours feel a bit artificial/unnatural sometimes". Excited and calm are two opposite emotions, but as we can see from the participant's comment, someone can experience both emotions in the same situation but for different reasons. For the participant, it was exciting to observe the dynamic lighting as being a new experience for them, but at the same time, the subtle changes in lighting and the sculpture's appearances made them feel calm, though they perceived some of the colours as too artificial. Comments regarding static lighting focused more on the dull atmosphere the lighting created and the discomfort of observing the sculpture for a long time: "No personality or connection to the statue. Much more boring and flat", while another participant commented: "Uncomfortable and flat because of very bright light and coming from the front".

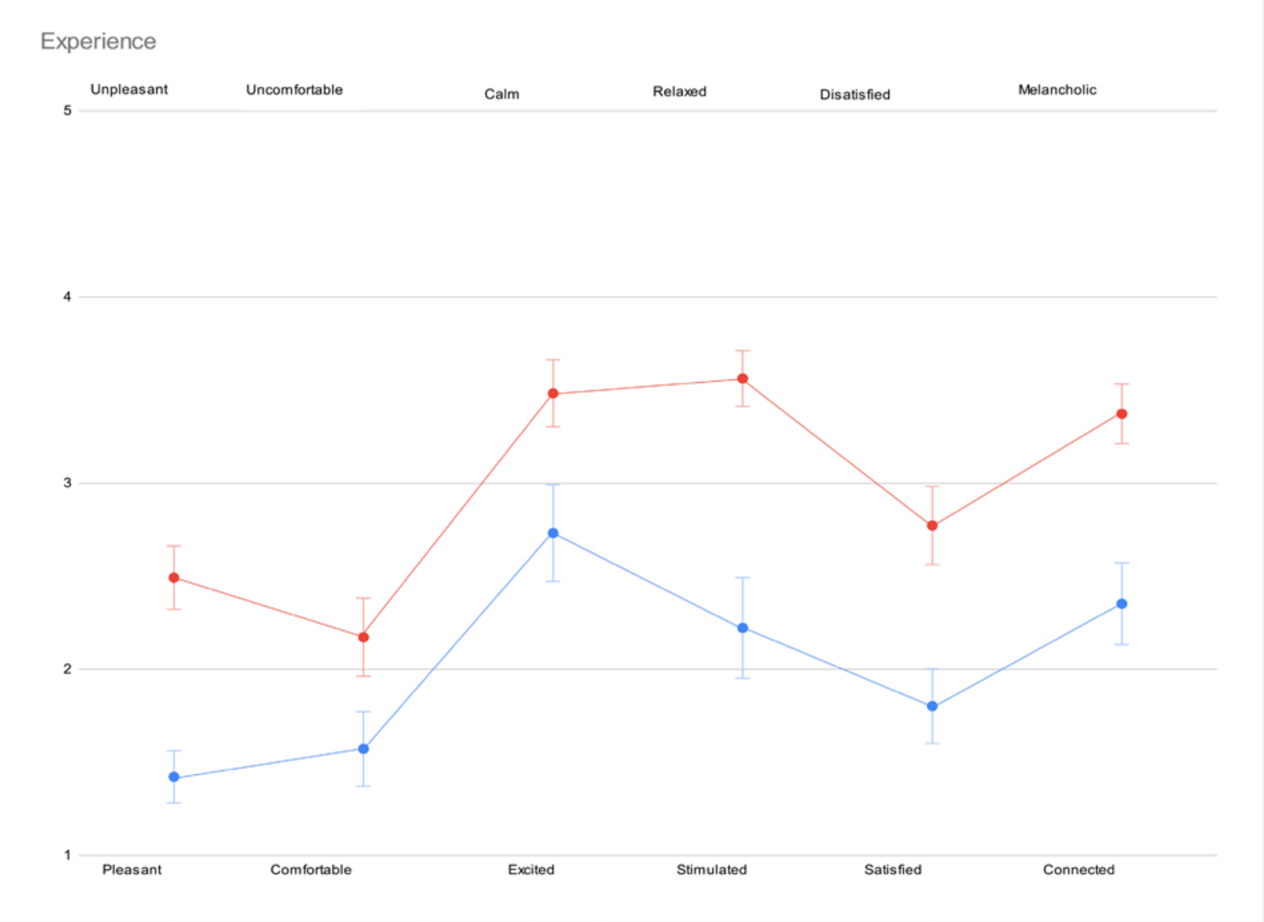


Figure 8.38. Results of Experience (Geometric mean and Standard Error).
1 = One side of the emotion || 5 = the opposite emotion 1.
Combined results of the Dynamic Lighting (Blue Colour) and Static Lighting (Red Colour) (Heikka & Stamidis, 2022)

8.3.5 RESULTS - SUMMARY

In conclusion, it can be stated that dynamic lighting was generally preferred in most of the questionnaire categories. The dynamic illumination was preferred for the "Perception" of the sculpture while the lighting seemed to have excellent results in revealing the form/shape and details (volume, shapes, expression). Regarding the second category of "Appreciation/Engagement", dynamic lighting seemed to be almost excellent in all of the three questions regarding suitability, attractiveness and appeal in comparison to static setup responses inclined toward neutral-poor. Moreover, dynamic lighting seemed able to evoke stronger emotional responses for the participants in comparison to the static setup that had neutral responses. As a result, dynamic lighting was more affective and effective in creating an influential experience. According to the participants' comments, dynamic lighting inspired people to write positive comments while referring to the perception of their own experiences. While there was one negative comment referring to the unnatural representation of light colours regarding the dynamic lighting, the static scene had only negative comments, where people were expressing the flat appearance and the uninteresting illumination of the sculpture. Lastly, observing participants in the process of the experiment, it was noticeable that they tend to spend more time observing the sculpture with the dynamic lighting while most of them were observing the sculpture with the static lighting only to fill in the questionnaires.

9. DISCUSSION

This thesis project aimed to answer the research question

> "How can the museum visitor experience and presentation of sculptures be enhanced by electric lighting, inspired by the dynamics of daylight?"

In order to answer the research question, a design concept was developed and tested through the experiment. The purpose of the experiment was to understand how the design concept can fulfil the three criteria formulated through extensive literature and analysis.

CRITERION 1: LIGHTING SHOULD BE DYNAMIC

The straightforward criterion for natural sciences was fulfilled successfully, though according to the literature review and results of the experiment, different aspects could be improved. The concept of natural light-inspired illumination was transmitted to the viewers without prior explanation, and the lighting was dynamic with changes primarily in the angle of incidence, spectrum, quantity and distribution. Due to spatial limitations, moving heads on moving track light systems could not be used in the experiment, leading to the quality of movement not being so strongly represented. While the movement was deficient, the incident angle of focal light noticeably changed from scene to scene offering a dynamic lighting experience inspired by natural light. Moreover, The use of only RGBW fixtures for the ambient light resulted in strong unnatural colours, also noted by the experiment participants. Another problematic aspect of the experiment was the use of a reflector fabric that caused more specular than diffuse reflections, resulting in the casting of distinct shadows in some scenes where only a skylight was used. As a result, further research and experiments would need to be done in order to achieve a better representation of the ambient "skylight" on the sculpture. In addition, as the timelapse in Chapter 5.3 shows, sunlight's dynamic changes influence the artwork, adding colour to the sculpture around sunrise and sunset and brilliance at noon when the light intensity is at its highest. While these qualities were quite accurately achieved by the dynamic concept, the illuminance ratios of direct:ambient light could not be tuned in accordance with natural conditions.

CRITERION 2: LIGHTING SHOULD ENHANCE THE VISITOR EXPERIENCE

The visitor experience seemed to be enhanced by the dynamic setting. The visitor experience is a complex topic influenced by several aspects such as the visitor's background and emotional state, communication of exhibits, museum atmosphere and the variety between exhibits. The results from the experiment's participants showed that, compared to the static scene, the dynamic scene caused stronger emotional responses and in general more desirable feelings of pleasure, comfort, satisfaction and connection. Some participants mentioned that they felt both excited - calm and stimulated -relaxed in the dynamic lighting setting, as it was something new and interesting but at the same time very calming and relaxing to look at. It stopped all the participants, and they spent significantly longer in the space with the dynamic setting.

The questionnaire results showed that the dynamic scene made the visitors engage more with the sculpture and fostered their interest and attraction towards the exhibit; evoking these feelings can be considered as an improvement of the visitor experience. Furthermore, the dynamism of the light was capable of causing different representations and perceptions of what the sculpture represents and what their personality is like. This forceful communicative, thought-provoking and emotionalising power of dynamic light can be treated as something that further improves the visitor's experience of the exhibition and likely leaves them with strong memories. In fact, further research could focus on determining whether the visitors really have memorised the artwork due to the lighting used to illuminate it and if this is their primary memory from the entire museum visit. The comments regarding the atmosphere were not all positive, however. Strong, "artificial" colours seemed to be experienced as negative, which may be related to the kitschy environment Schielke warned about in his 2020 article, adversely affecting the experience of particularly art aficionados.

LIGHTING SHOULD ENHANCE THE ARTWORK

In museums, it is important that the works of art are highlighted and represented in a way that enhances their appearance and appreciation. The dynamic setting, again, achieved this to a greater extent than the static illumination, particularly for revealing the form, shape and details (volumes, shapes & expression) of the sculpture. Smaller differences were detected by the enhancement of general appearance and enhancement of texture, though the dynamic setting scored higher in both of these too.

As the literature suggests, shadows cast from and within the object are key to revealing form and texture, influencing the perception and representations of sculptures. The experiment successfully emphasised these qualities of the artwork, though the material of the sculptures used in the experiment was a rather smooth gypsum plaster instead of the ancient sculpting materials marble (slightly translucent) or limestone (rougher texture). This may explain the similar neutral responses for the static and dynamic settings in accordance to the revelation of texture, as the material was smooth instead of rough, and the most visible textural details were the lines that indicated where the plaster casts were placed. However, one of the participants commented that it was nice to see the restoration faults in the gypsum copy, suggesting that for gypsum copies this design concept promotes the educational aspect. Moreover, the experiment strongly emphasised the picturesque moments related to sunset, the golden and blue hour, which were recommended for sculptures' illumination throughout history until the widespread use of electric lighting, and the colours used strongly emotionalised the artwork. On the other hand, in some scenes of the dynamic setup the colour combinations of light created an artificial illusion that had a considerable influence and might have stolen the attention from the sculpture itself. Therefore, more experiments would help to define the balance between light's influence on the sculpture in such a concept.

In reference to the static setting, there were installation limitations as well. We could not use the standard museum lighting angle of 30°, which in turn affected the glariness of the statue. This was commented on by some respondents and might have an influence on how participants evaluated the appearance of the Apollon sculpture. Moreover, museum lighting requests high-quality fixtures. While the halogen fixtures used in the experiment for the dynamic scene were high in CRI, they consume a considerable amount of energy. On the other hand, the RGB LED fixtures were extremely low in CRI if they even gave a value for it, but high-CRI white LED lighting technology is widely used in museums. As a result, further research and experiments should be done in order to find balance in the lighting quality of the design concept.

While the criteria were fulfilled to a good extent, several topics were left undiscussed by the report, for example, the ideal length of the dynamic cycle, background colour and integration with scenography, and the setup's influence on experienced glare. Analysis and literature have shown that those aspects play a key role both in sculptures' presentation and appreciation, and further affect the visitor experience. Thus those topics need to be further explored in order to get a better understanding of how a dynamic lighting concept affects artworks' presentation and visitors' experiences. Another interesting aspect future research could seek an answer to would be the "instagrammability" of the dynamic concept and its influence on visitor interest in the exhibit and exhibition.

Finally, as the museum visitor spectrum is very broad, future research should be conducted at a real museum with a more representative sample of visitors over a longer period of time. This would give more universal and applicable results, particularly for visitor experience, and give a more specific answer to whether the visitors spend more time engaging with the artwork and inspecting its qualities. In future studies, observations of participants could be also recorded systematically, measuring the time the participants spend in the space, their movement in the space, what exactly they look at and if these are affected by the different positions of the light source. Moreover, future research could seek an answer to whether this influences museum fatigue positively or negatively.

10. CONCLUSION

In conclusion, the purpose of the project was to create a new concept for museums to present their artwork. Through extended literature review, analysis and interviews with museum professionals, while inspired by the dynamics of daylight, a design concept was developed and tested through a physical experiment. Results from the experiment show us that natural light-inspired dynamic lighting achieves to create an interesting concept that enhances the visitor experience and the presentation of the artwork. Museum lighting is a complicated field that has to serve multiple purposes of functionality and proper artwork illumination. As during the last years the concept of entertainment has increasingly become a part of the museum experience, this report suggests a lighting concept that goes beyond the traditional static illumination of artworks, aiming to intrigue people's interest in artworks. This proposal is an exhibition concept or tool that museum curators, scenographers and of course lighting designers can get inspired by and use for improving the illumination on ancient sculptures while enhancing the visitor experience and interest towards the exhibition. Museum lighting aims for perfection and as a result, more research and experiments are needed to improve such a dynamic lighting concept so that it can be integrated in a museum environment. Finally, the authors conclude that this exhibition concept can be applied to any three dimensional object, particularly to those that were placed outdoors (to increase communicative aspect) and that have white or light surfaces that benefit from the striking moments of sunset that graciously tone the objects.

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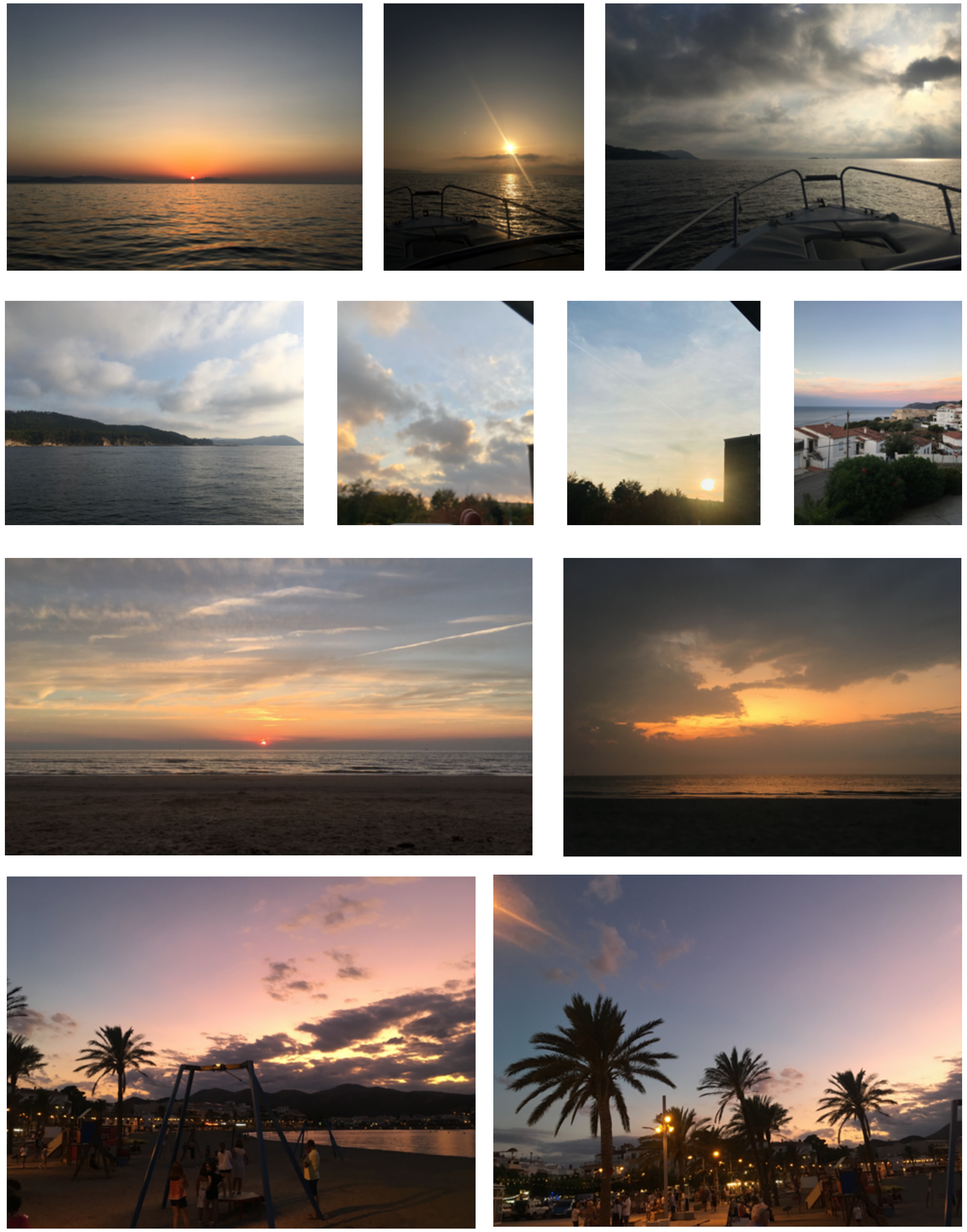
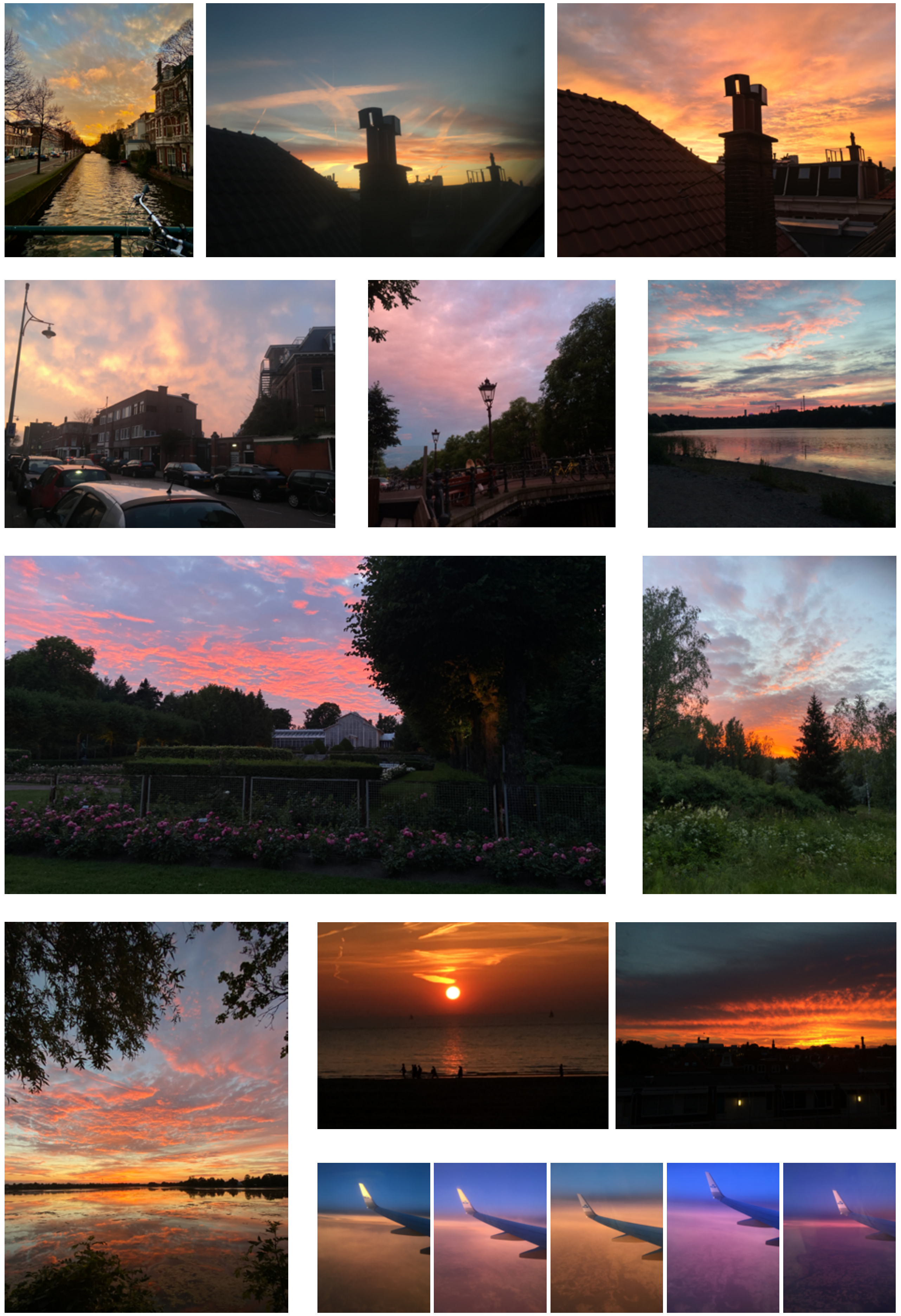
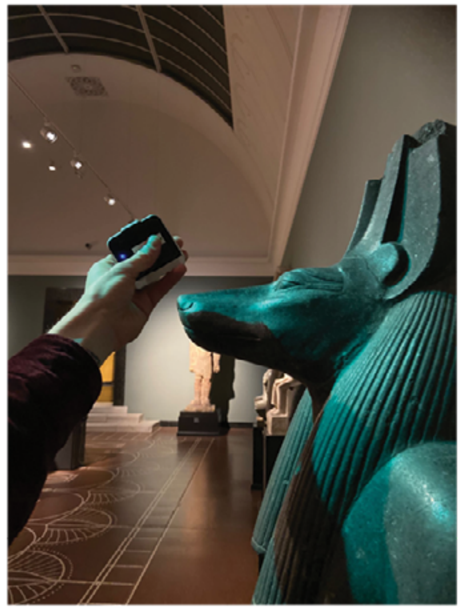
APPENDIX

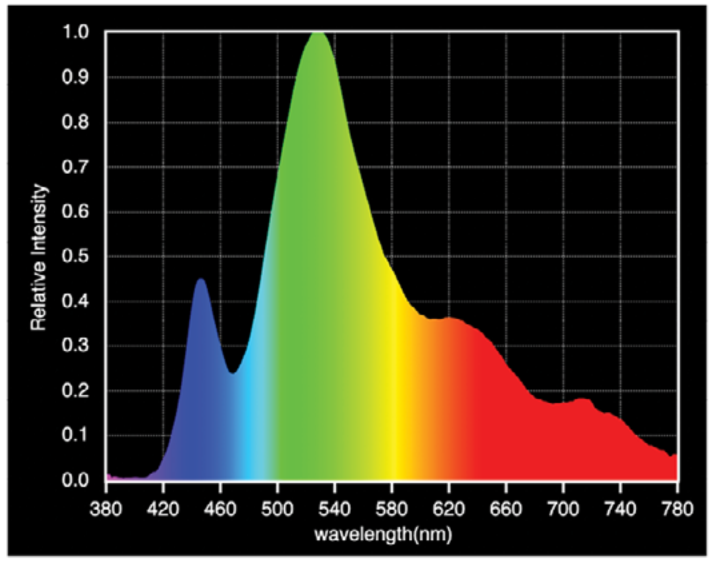
A1. PHOTOS OF SKIES / SUNSET. © A.V.V. HEIKKA



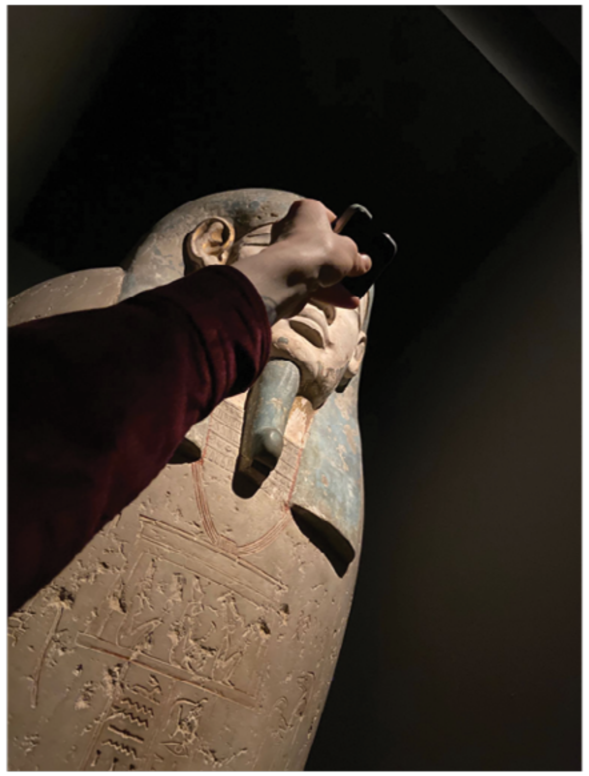


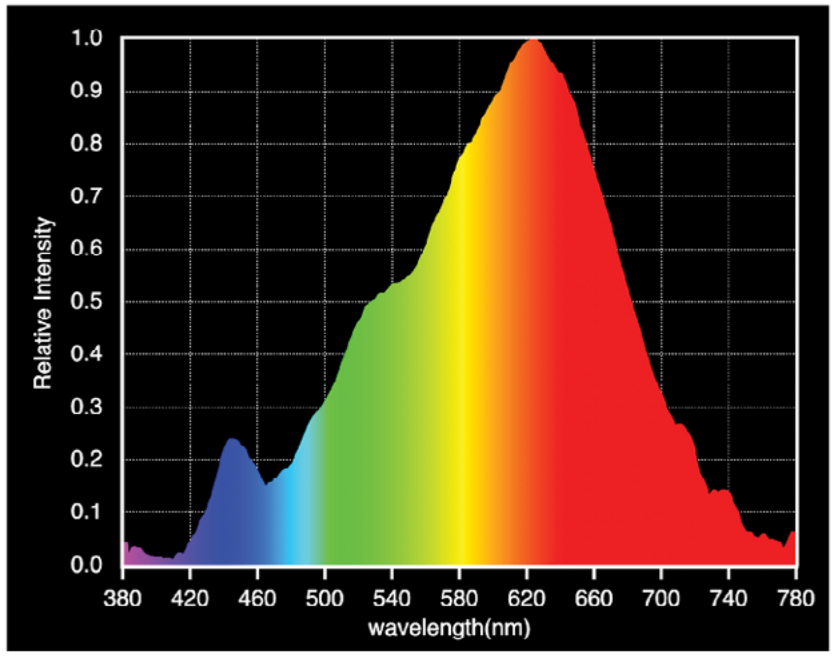
GLYPTOTEKET





2022-02-17 18:22:20
CCT
Illuminance 88 lux
CRI (Ra)(R1~R8)
CRI (Re) (R1-R15)
TM-30-20 Rf
TM-30-20 Rg
Flicker Percentage 29
Flicker Index 0.08
Flicker Frequency 100
λp 527 nm
λD 545 nm





2022-02-17 16:15:57
CCT 2749 K
Illuminance 54 lux
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CRI (Re) (R1-R15) 90
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TM-30-20 Rg 98
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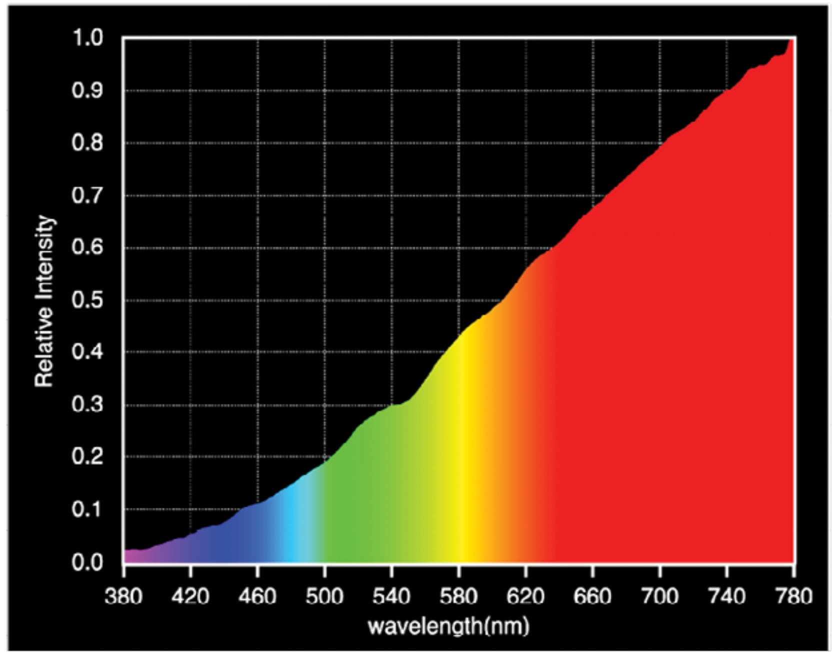
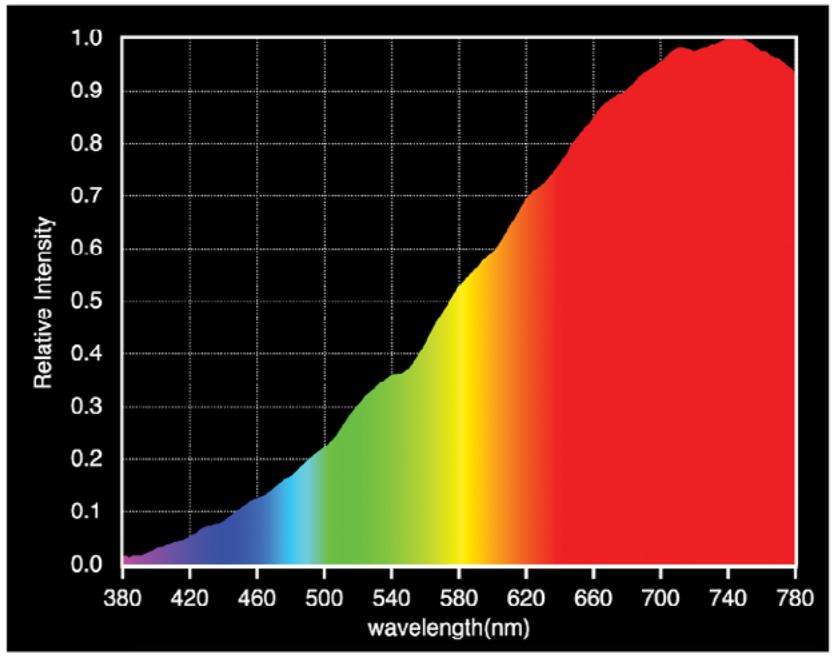
Flicker Index 0.02
Flicker Frequency 128
λp 624 nm
λD 583 nm



2022-02-17 16:28:47
CCT 2640 K
Illuminance 312 lux
CRI (Ra)(R1~R8) 100
CRI (Re) (R1-R15) 99
TM-30-20 Rf 99
TM-30-20 Rg 100
Flicker Percentage 6
Flicker Index 0.01
Flicker Frequency 100
λp 780 nm
λD 584 nm



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CCT 2572 K
Illuminance 254 lux
CRI (Ra)(R1~R8) 99
CRI (Re) (R1-R15) 99
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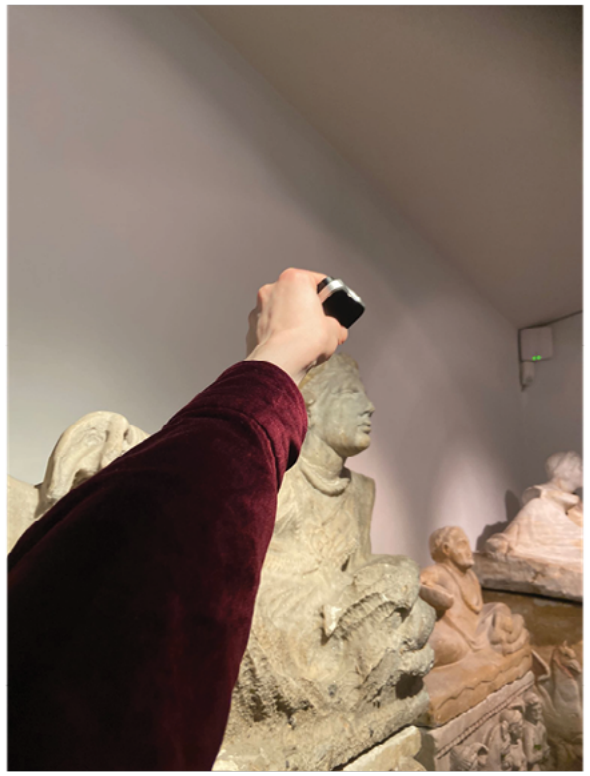
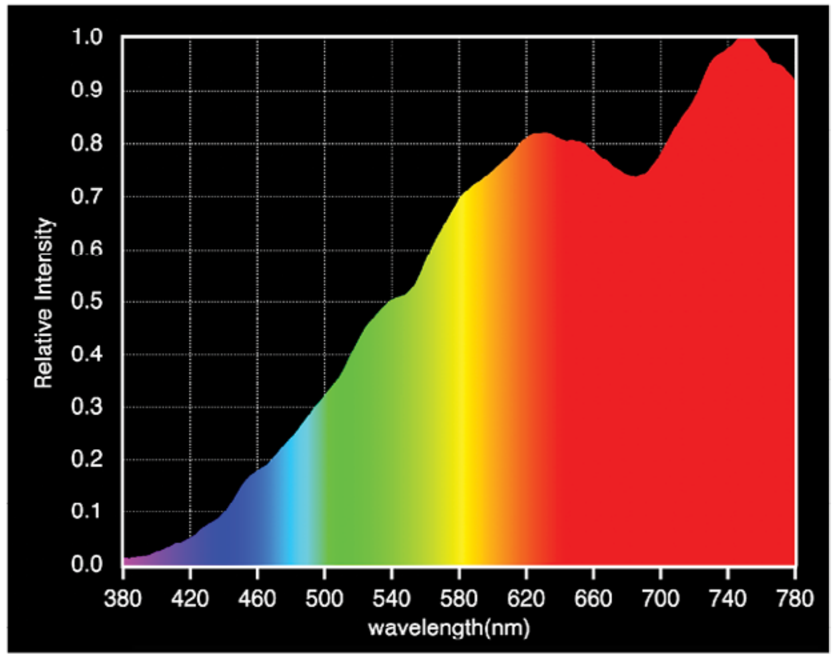
TM-30-20 Rg 99
Flicker Percentage 8
Flicker Index 0.02
Flicker Frequency 100
λp 742 nm
λD 585 nm





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CCT 2894 K
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CRI (Re) (R1-R15) 91
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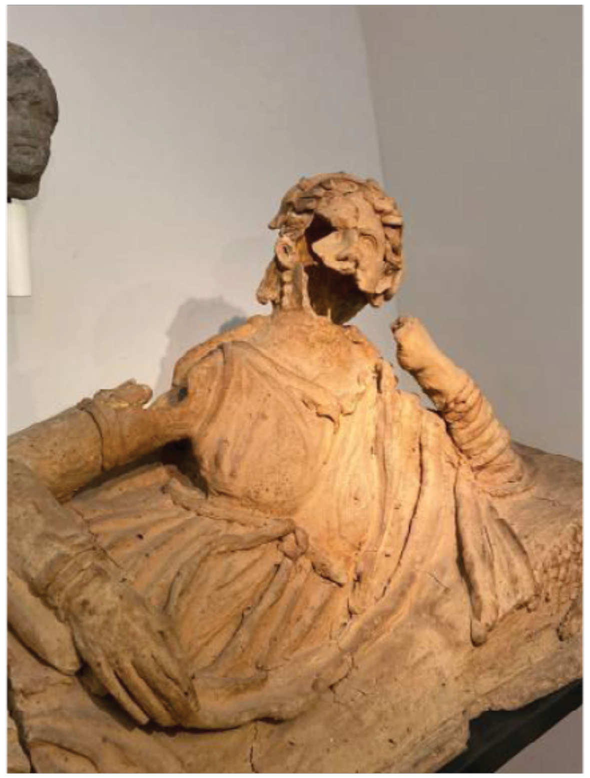
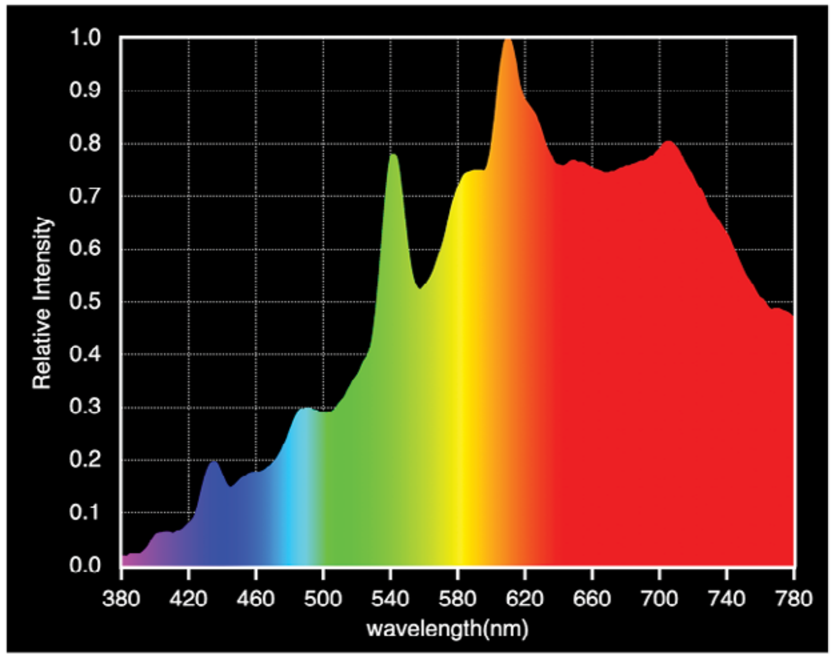
TM-30-20 Rg 93
Flicker Percentage 5
Flicker Index 0.01
Flicker Frequency 100
λp 751 nm
λD 581 nm





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CCT 2882 K
Illuminance 252 lux
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CRI (Re) (R1-R15) 89
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TM-30-20 Rg 97
Flicker Percentage 7
Flicker Index 0.01
Flicker Frequency 100
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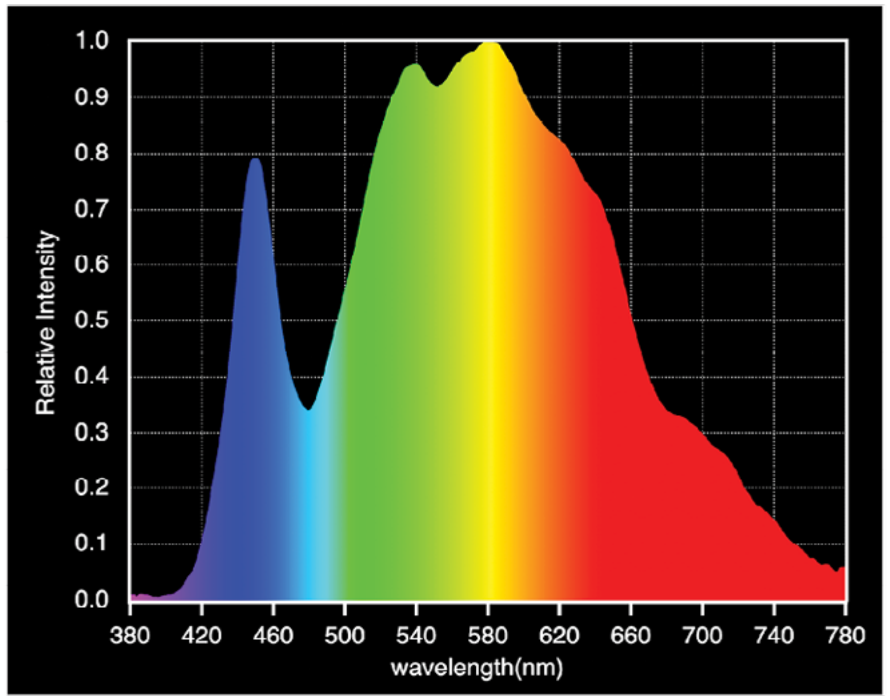
λD 582 nm



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CCT 4345 K
Illuminance 178 lux
CRI (Ra)(R1~R8) 82
CRI (Re) (R1-R15) 74
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TM-30-20 Rg 95
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Flicker Index 0.04
Flicker Frequency 100
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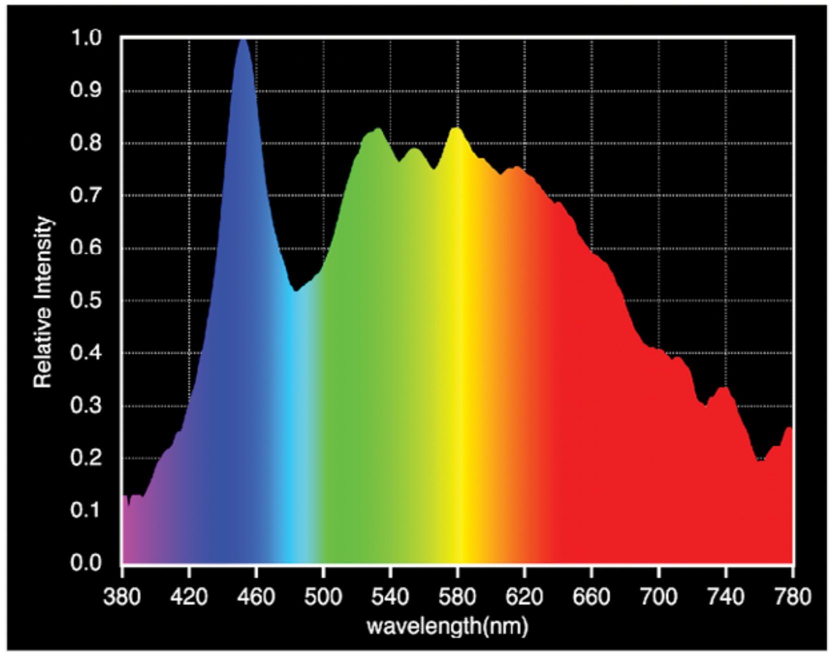
λD 572 nm



2022-02-17 16:41:35
CCT 5144 K
Illuminance 68 lux
CRI (Ra)(R1~R8) 94
CRI (Re) (R1-R15) 91
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TM-30-20 Rg 101
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Flicker Index 0.05
Flicker Frequency 1
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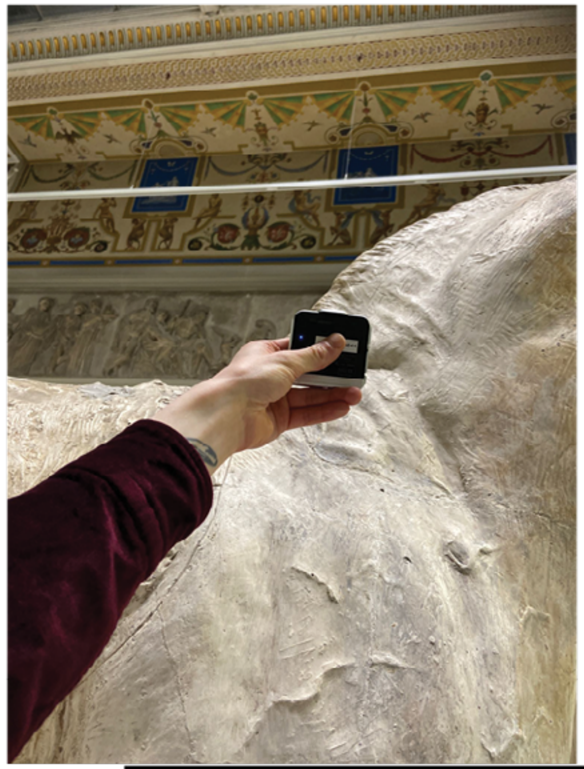
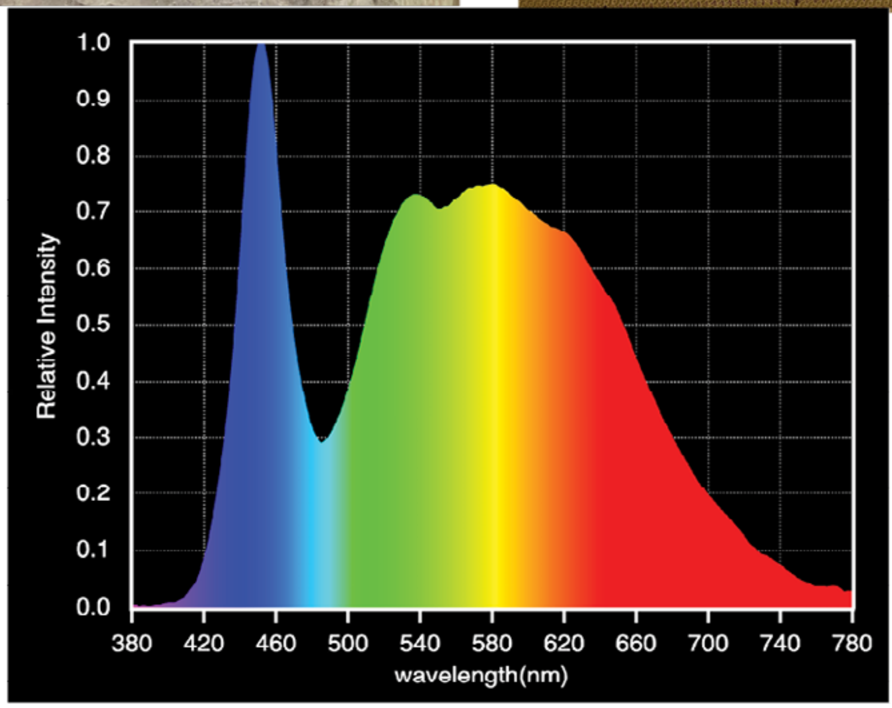
λD 570 nm





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CCT 4787 K
Illuminance 345 lux
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CRI (Re) (R1-R15) 81
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TM-30-20 Rg 100
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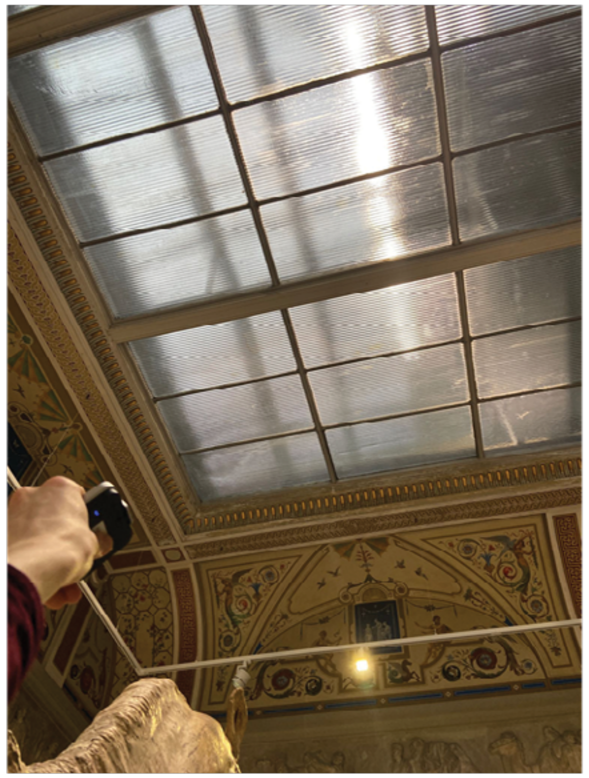
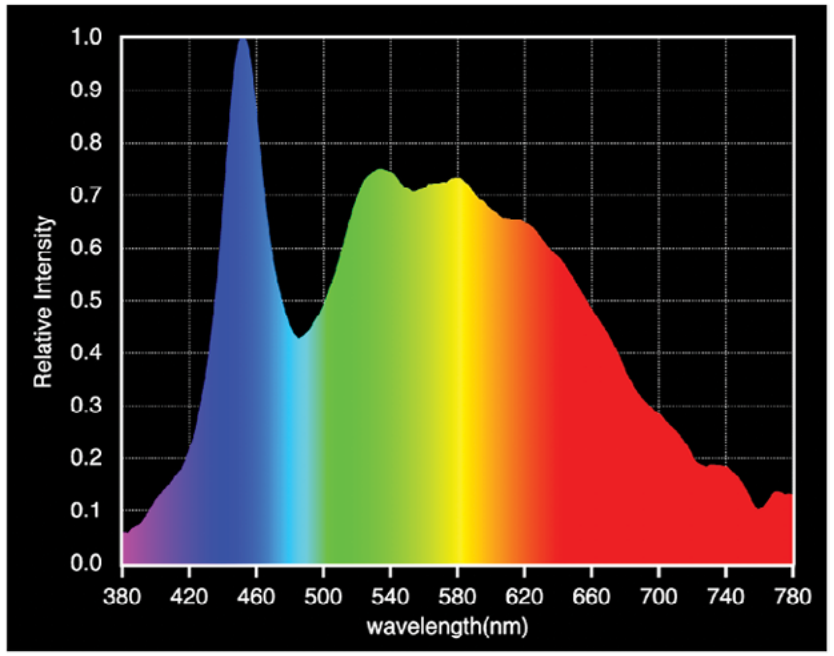
Flicker Index 0.02
Flicker Frequency 45
λp 450 nm
λD 575 nm





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CRI (Re) (R1-R15) 88
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TM-30-20 Rg 100
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Flicker Index 0.02
Flicker Frequency 45
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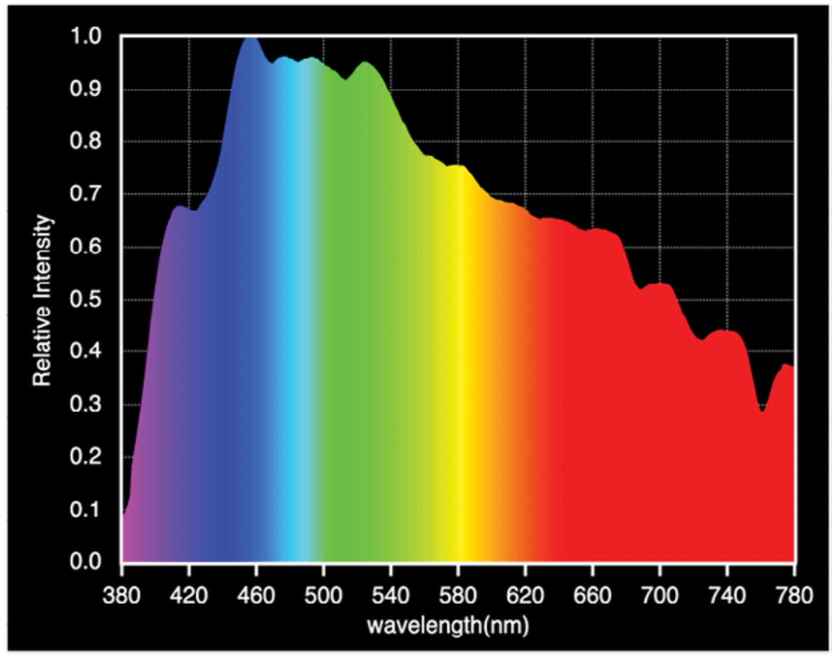
λD 565 nm



2022-02-17 15:44:34
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CRI (Re) (R1-R15) 98
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Flicker Index 0.00
Flicker Frequency 1
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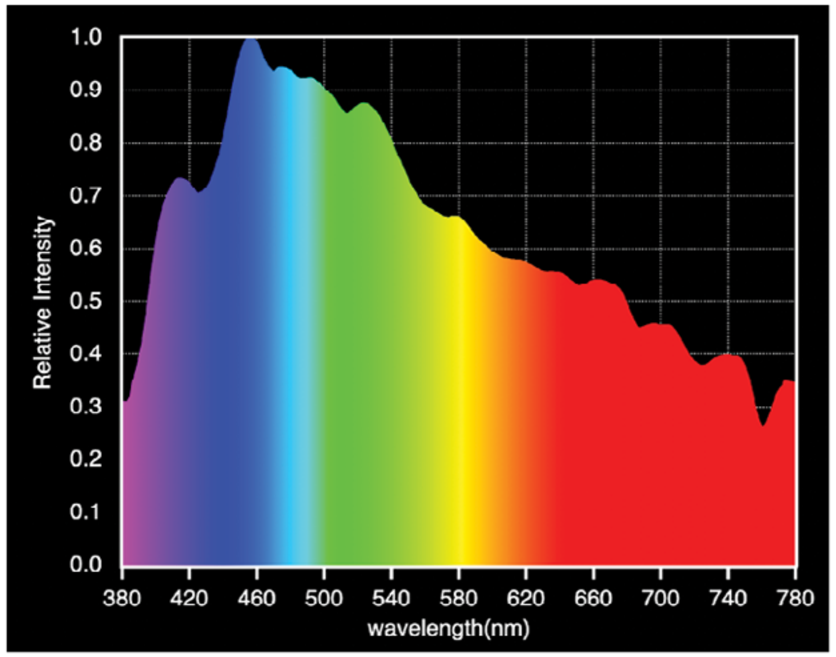
λD 491 nm



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7833 K
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CRI (Re) (R1-R15) 98
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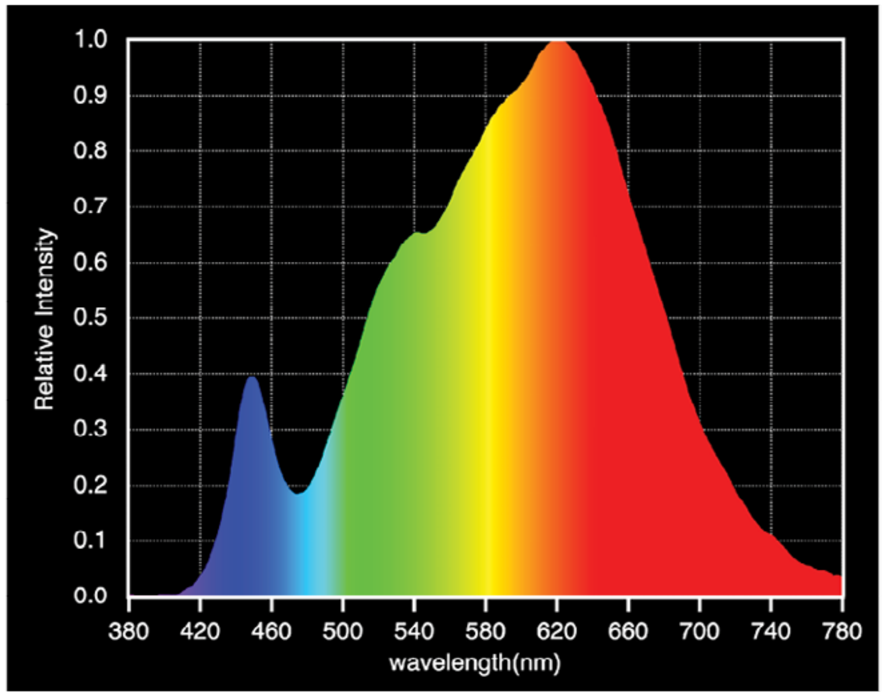
TM-30-20 Rg 93
Flicker Percentage 2
Flicker Index 0.01
Flicker Frequency 1
λp 454 nm
λD 487 nm



2022-02-17 18:20:35
CCT 3048 K
Illuminance 235 lux
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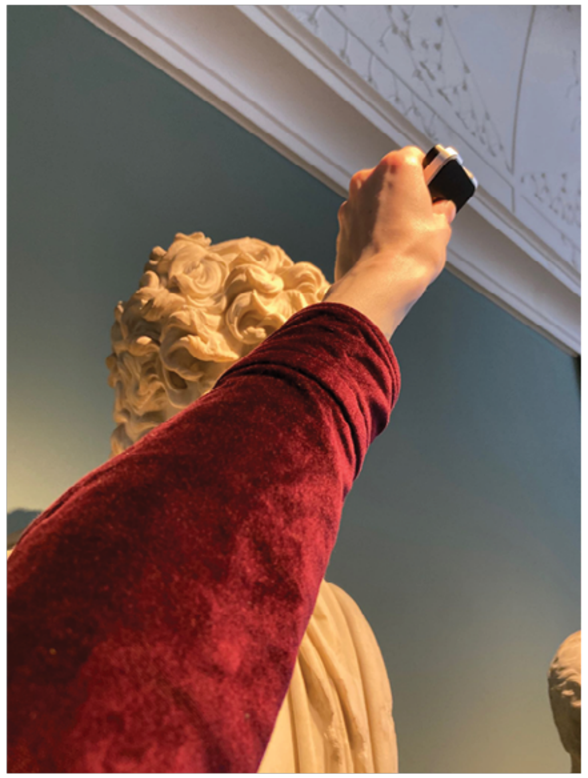
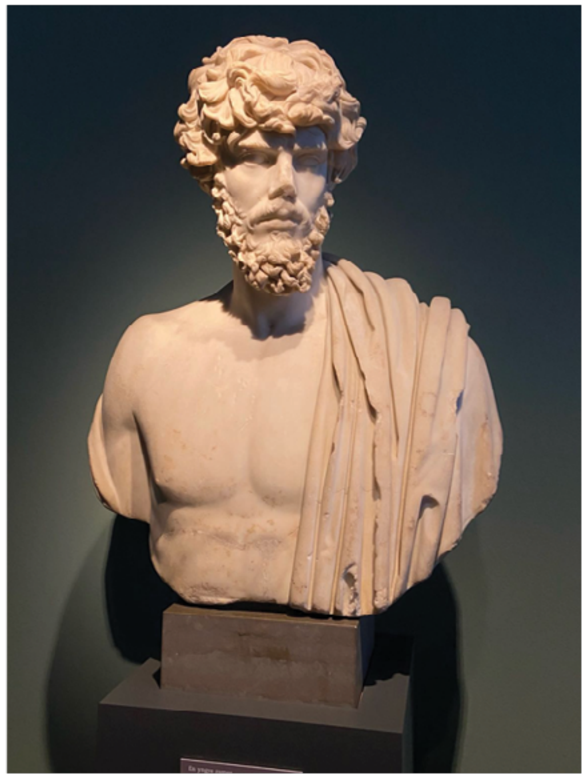
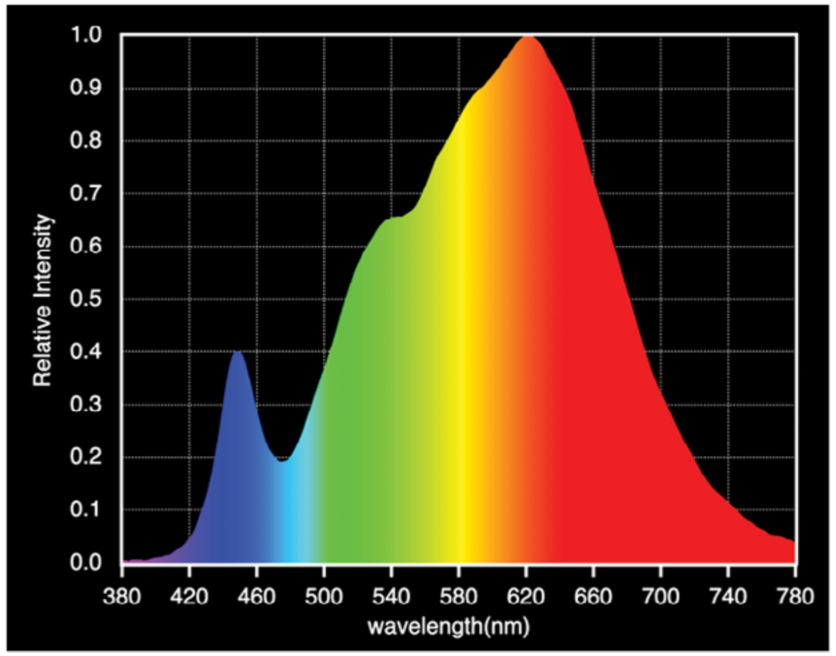
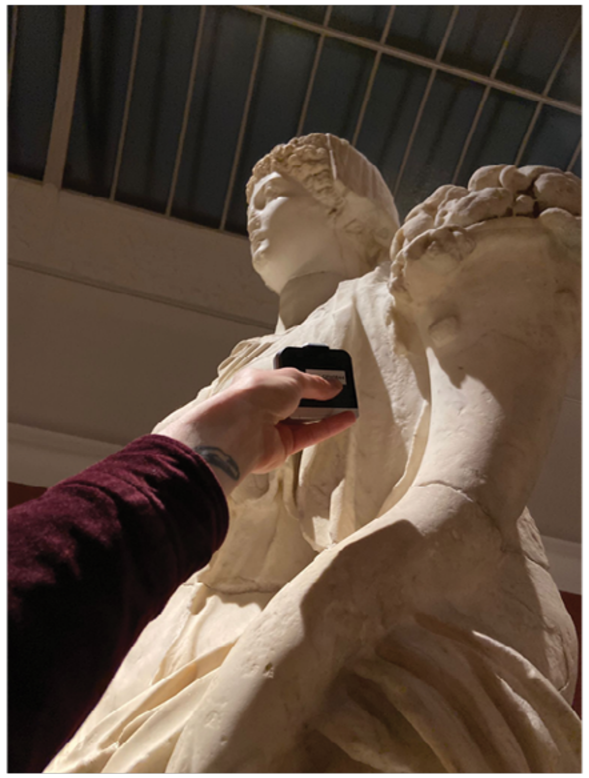
CRI (Re) (R1-R15) 86
TM-30-20 Rf 92
TM-30-20 Rg 99
Flicker Percentage 28
Flicker Index 0.08
Flicker Frequency 100
λp 620 nm
λD 581 nm

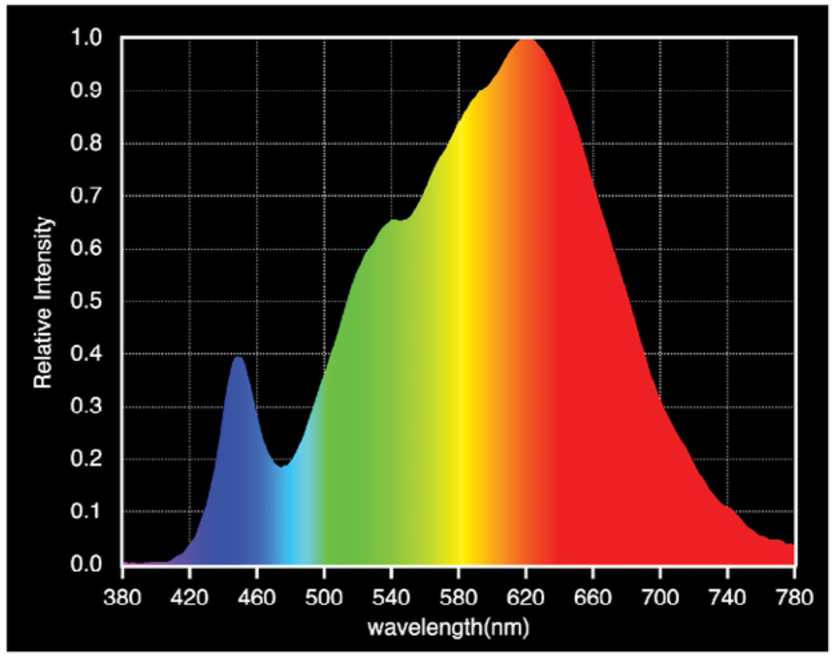




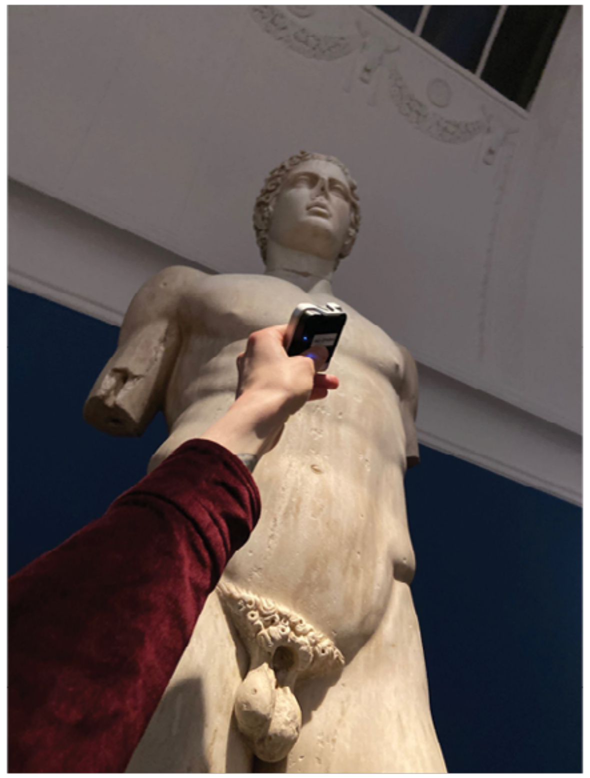


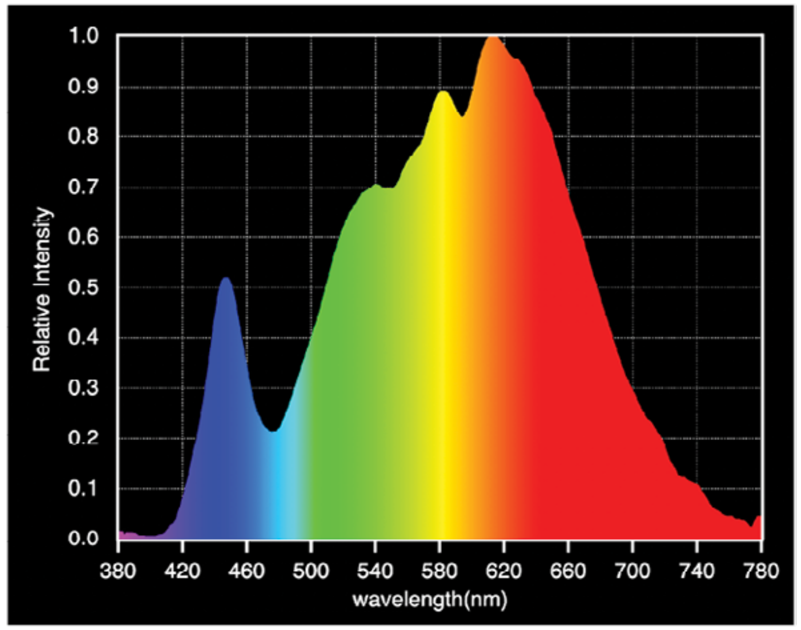
2022-02-17 16:01:33
CCT 3074 K
Illuminance 713 lux
CRI (Ra)(R1~R8) 90
CRI (Re) (R1-R15) 87
TM-30-20 Rf 92
TM-30-20 Rg 99
Flicker Percentage 32
Flicker Index 0.08
Flicker Frequency 100
λp 622 nm
λD 581 nm



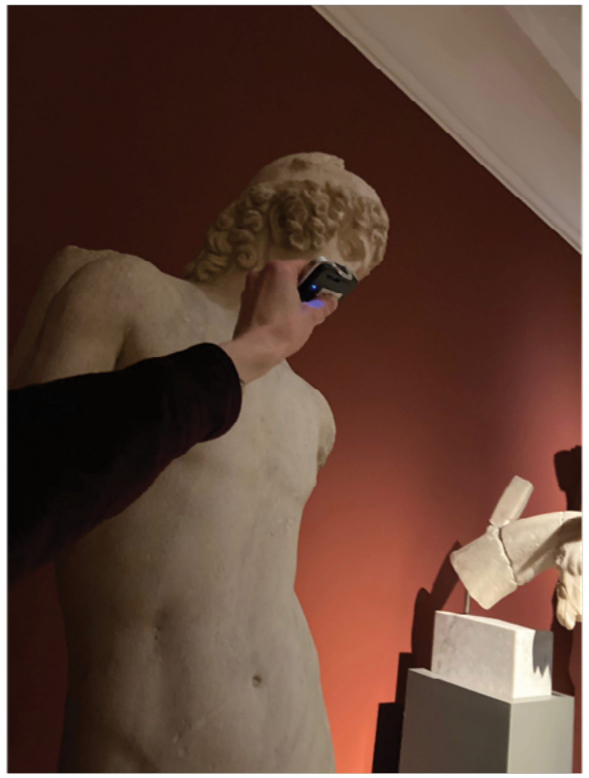


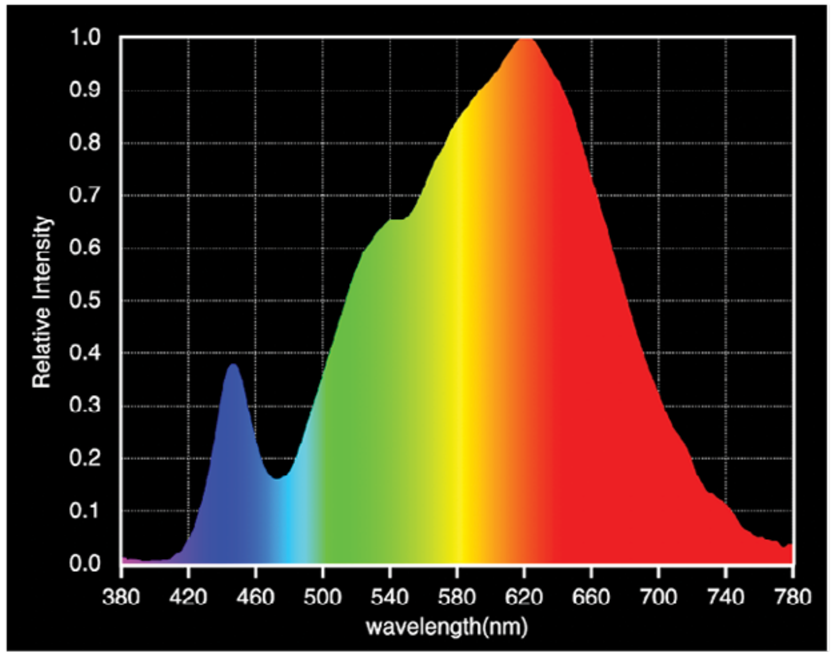
2022-02-17 18:22:20
CCT 3321 K
Illuminance 71 lux
CRI (Ra)(R1~R8) 90
CRI (Re) (R1-R15) 87
TM-30-20 Rf 90
TM-30-20 Rg 101
Flicker Percentage 37
Flicker Index 0.11
Flicker Frequency 100
λp 613 nm
λD 581 nm



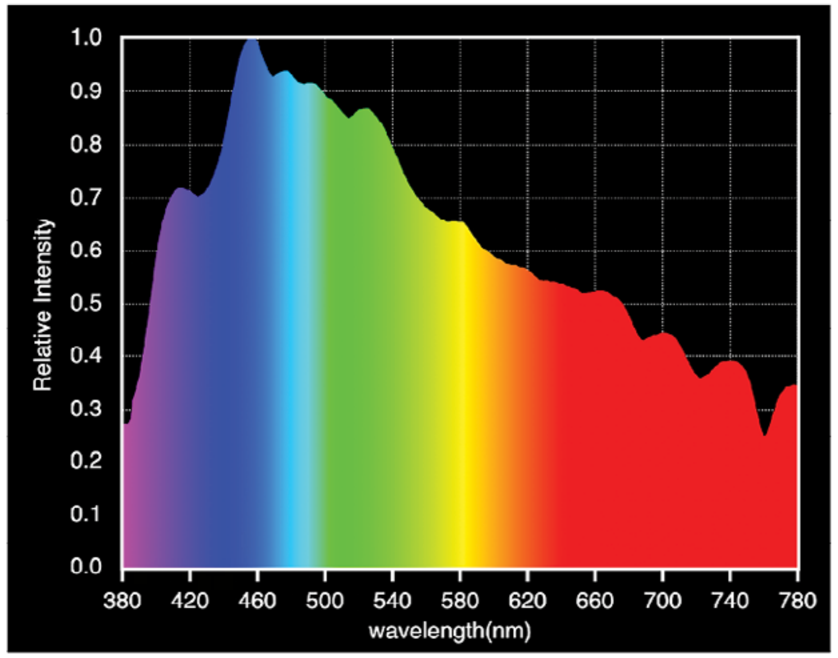


2022-02-17 18:22:20
CCT 3030 K
Illuminance 75 lux
CRI (Ra)(R1~R8) 90
CRI (Re) (R1-R15) 86
TM-30-20 Rf 91
TM-30-20 Rg 99
Flicker Percentage 100
Flicker Index 0.14
Flicker Frequency 100
λp 621 nm
λD 581 nm

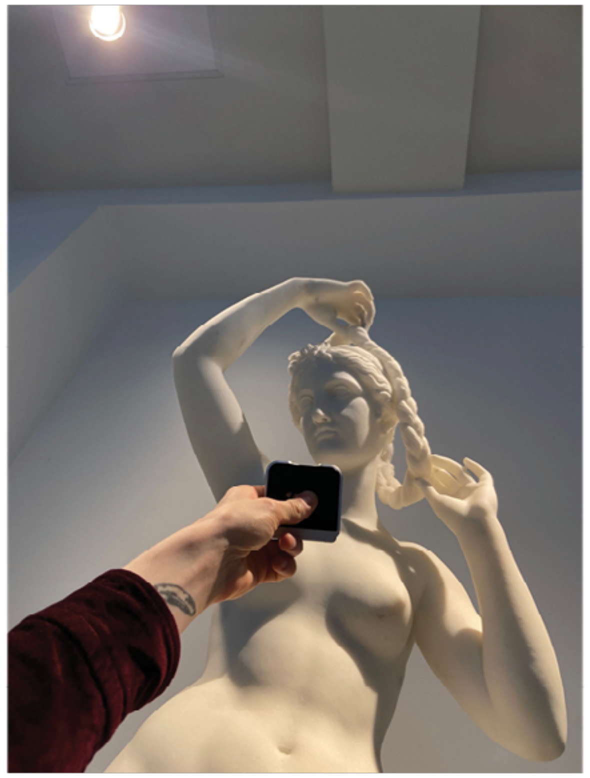


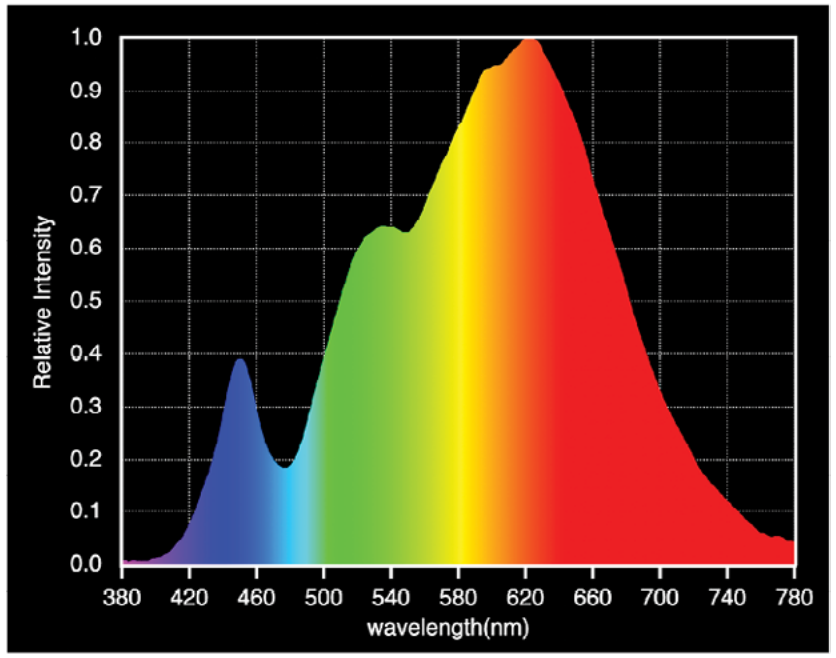


2022-02-17 18:10:56
CCT 2970 K
Illuminance 8 lux
CRI (Ra)(R1~R8) 90
CRI (Re) (R1-R15) 87
TM-30-20 Rf 92
TM-30-20 Rg 98
Flicker Percentage 100
Flicker Index 0.31
Flicker Frequency 100
λp 624 nm
λD 582 nm

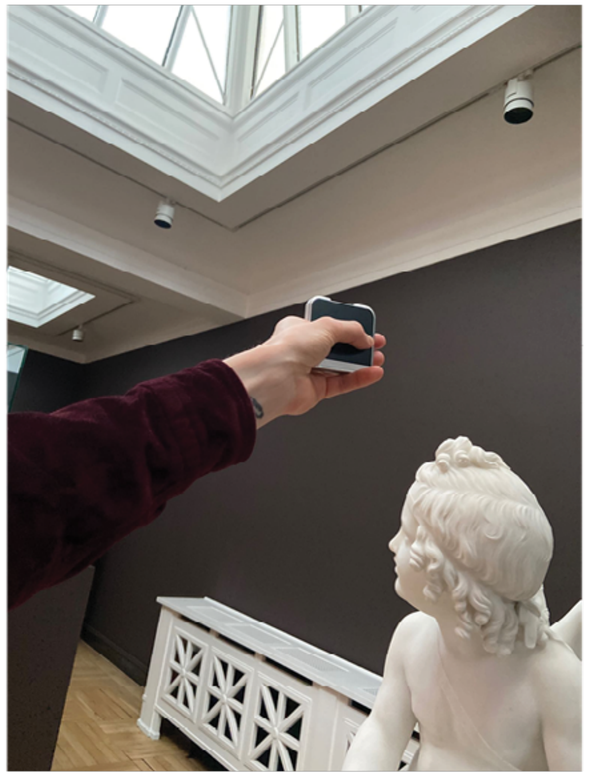


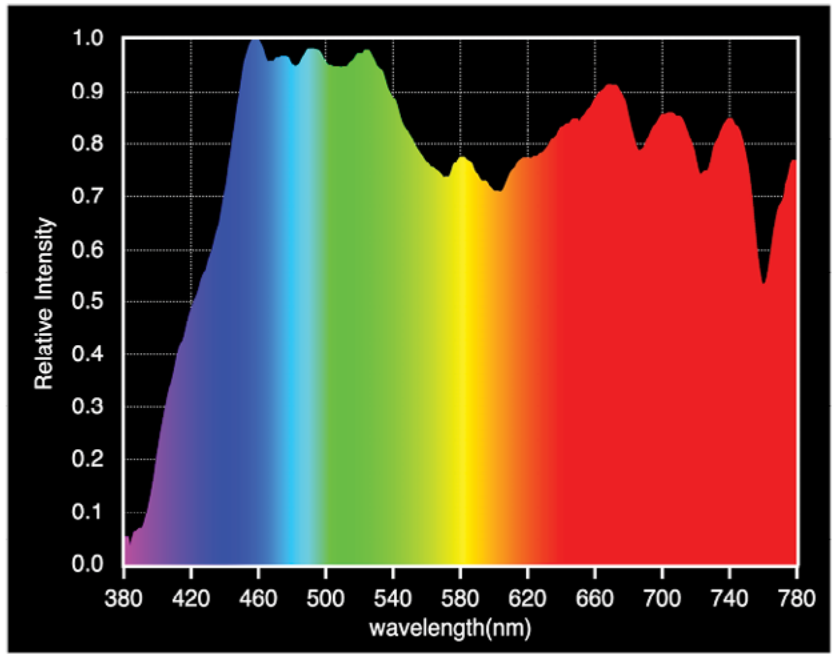
2022-02-17 15:46:28
CCT 7901 K
Illuminance 396 lux
CRI (Ra)(R1~R8) 98
CRI (Re) (R1-R15) 97
TM-30-20 Rf 97
TM-30-20 Rg 98
Flicker Percentage 1
Flicker Index 0.00
Flicker Frequency 1
λp 456 nm
λD 487 nm





2022-02-17 16:27:57
CCT 3074 K
Illuminance 372 lux
CRI (Ra)(R1~R8) 92
CRI (Re) (R1-R15) 89
TM-30-20 Rf 93
TM-30-20 Rg 100
Flicker Percentage 71
Flicker Index 0.24
Flicker Frequency 100
λp 622 nm
λD 581 nm





2022-02-17 16:53:44
CCT 6072 K
Illuminance 66 lux
CRI (Ra)(R1~R8) 94
CRI (Re) (R1-R15) 91
TM-30-20 Rf 94
TM-30-20 Rg 101
Flicker Percentage 8
Flicker Index 0.02
Flicker Frequency 1
λp 457 nm
λD 498 nm

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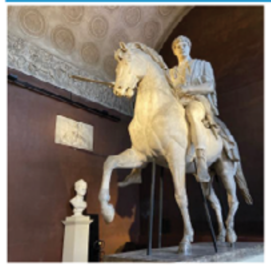
Lighting Parameter Analysis Report



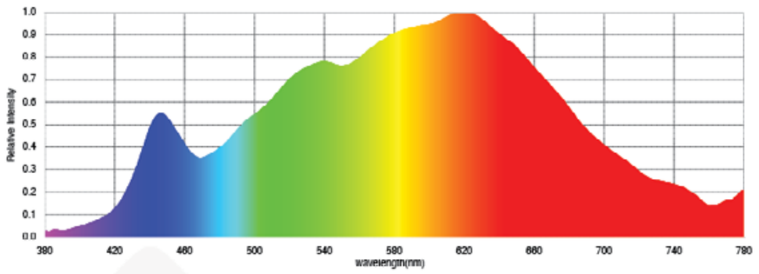
Product information and test conditions

Name		
Time	2022-02-17 10:42:49(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4023
CIE_y	0.3968
CIE_u'	0.2313
CIE_v'	0.5133
CCT	3615 K
Duv	0.0034
CRI (Ra)(R1~R8)	94
CRI (Re) (R1-R15)	91
CQS	95
TLCI(Qa)	94
GAI	67
TM-30-20 Rf	95
TM-30-20 Rg	99
Illuminance	133 lux
Foot Candle	12.4 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 94 Re = 91

:/MWbGXHvWki/m/0LJyXCbOSc/e/2

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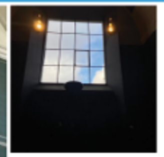
Lighting Parameter Analysis Report



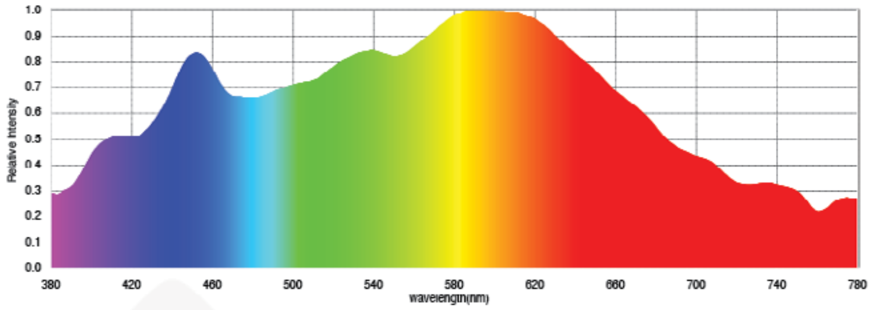
Product information and test conditions

Name		
Time	2022-02-17 11:10:10(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.3609
CIE_y	0.3553
CIE_u'	0.2207
CIE_v'	0.4888
CCT	4446 K
Duv	-0.0041
CRI (Ra)(R1~R8)	95
CRI (Re) (R1-R15)	94
CQS	94
TLCI(Qa)	92
GAI	88
TM-30-20 Rf	94
TM-30-20 Rg	100
Illuminance	753 lux
Foot Candle	69.9 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 95 Re = 94

r/Xe5CPBVemL/m/6cxnk6iQpm/e/2

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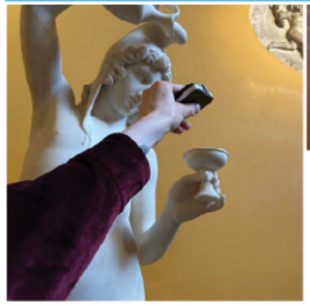
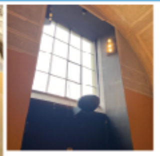
Lighting Parameter Analysis Report





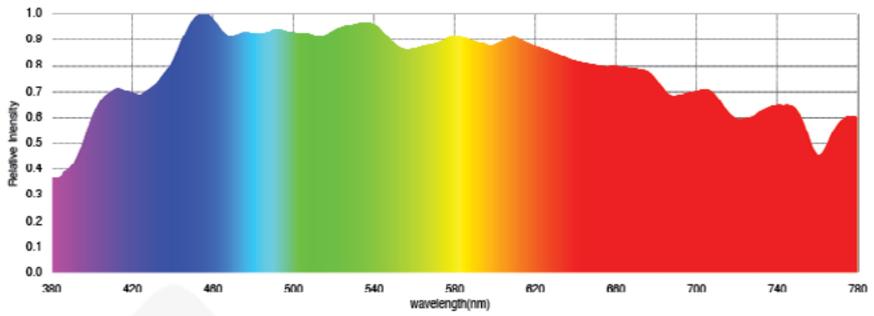
Product information and test conditions

Name	
Time	2022-02-17 10:45:08(Time-zone GMT+8)
Manufacturer	
User	Antti (heikka.antti@gmail.com)
Temperature(°C) Humidity(%)	**Distance(m)**

Parameters

CIE_x	0.3299
CIE_y	0.3397
CIE_u'	0.2057
CIE_v'	0.4765
CCT	5614 K
Duv	0.0005
CRI (Ra)(R1~R8)	98
CRI (Re) (R1-R15)	98
CQS	99
TLCI(Qa)	100
GAI	96
TM-30-20 Rf	99
TM-30-20 Rg	101
Illuminance	480 lux
Foot Candle	44.6 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 98 Re = 98

/r/kTBwr2FnEk/m/AnZaXnLQdf/e/2

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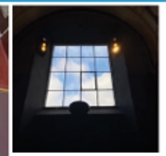
Lighting Parameter Analysis Report



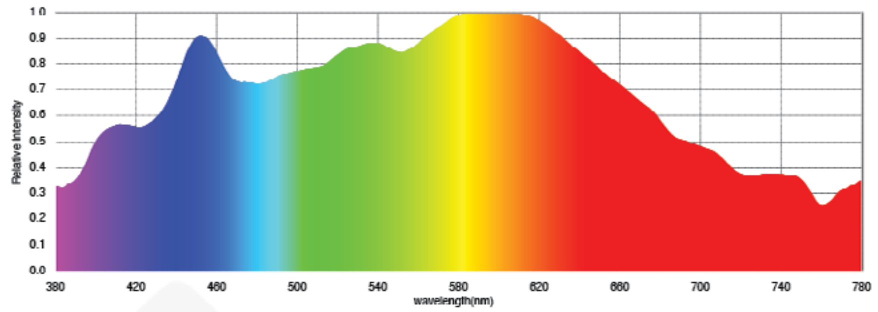
Product information and test conditions

Name	
Time	2022-02-17 10:54:57(Time-zone GMT+8)
Manufacturer	
User	Antti (heikka.antti@gmail.com)
Temperature(°C) Humidity(%)	**Distance(m)**

Parameters

CIE_x	0.3540
CIE_y	0.3516
CIE_u'	0.2175
CIE_v'	0.4860
CCT	4668 K
Duv	-0.0034
CRI (Ra)(R1~R8)	96
CRI (Re) (R1-R15)	95
CQS	95
TLCI(Qa)	94
GAI	90
TM-30-20 Rf	95
TM-30-20 Rg	101
Illuminance	920 lux
Foot Candle	85.4 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 96 Re = 95

/r/WzVA9Efsfc/m/V5uqhEe8ED/e/2

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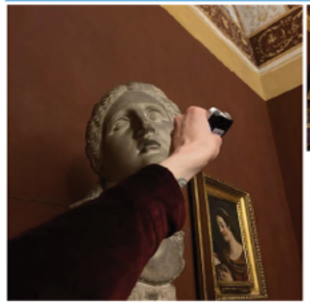
Lighting Parameter Analysis Report



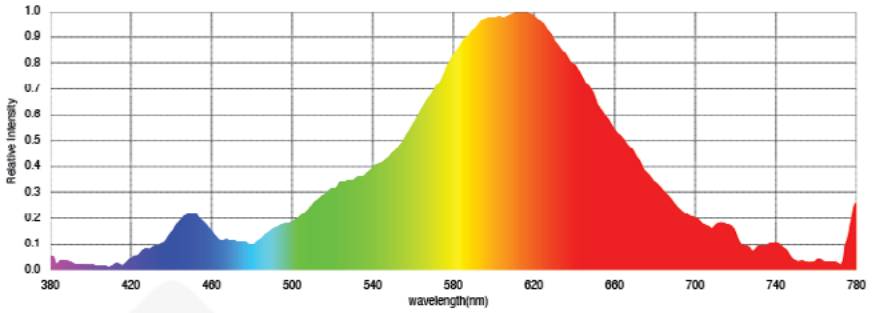

Product information and test conditions

Name			
Time	2022-02-17 12:14:06(Time-zone GMT+8)		
Manufacturer			
User	Antti (heikka.antti@gmail.com)		
Temperature(°C)	**Humidity(%)**	**Distance(m)**	

Parameters

CIE_x	0.4864
CIE_y	0.4150
CIE_u'	0.2776
CIE_v'	0.5330
CCT	2409 K
Duv	0.0003
CRI (Ra)(R1~R8)	78
CRI (Re) (R1-R15)	73
CQS	81
TLCI(Qa)	60
GAI	36
TM-30-20 Rf	82
TM-30-20 Rg	96
Illuminance	30 lux
Foot Candle	2.8 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 78 Re = 73

'r/zijCFMoWqQ/m/2BaVIURAUB/e/2

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Lighting Parameter Analysis Report

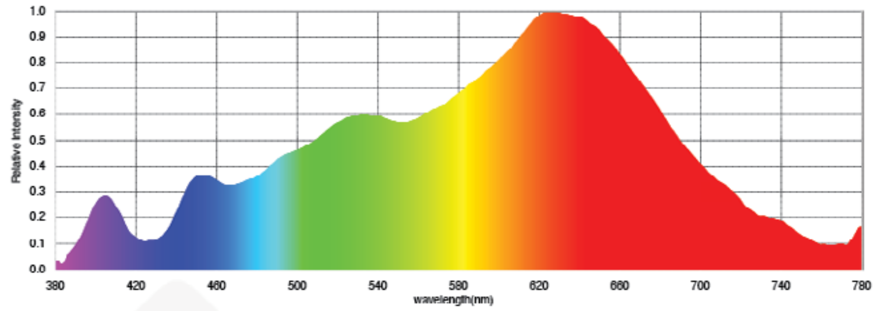
Product information and test conditions

Name			
Time	2022-02-17 11:20:37(Time-zone GMT+8)		
Manufacturer			
User	Antti (heikka.antti@gmail.com)		
Temperature(°C)	**Humidity(%)**	**Distance(m)**	

Parameters

CIE_x	0.4238
CIE_y	0.3969
CIE_u'	0.2452
CIE_v'	0.5166
CCT	3174 K
Duv	-0.0009
CRI (Ra)(R1~R8)	95
CRI (Re) (R1-R15)	94
CQS	96
TLCI(Qa)	97
GAI	65
TM-30-20 Rf	95
TM-30-20 Rg	101
Illuminance	107 lux
Foot Candle	10.0 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 95 Re = 94

n/r/i424ug1Qsn/m/Tg6wagtt6S/e/2

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Spectrum Genius

Lighting Parameter Analysis Report

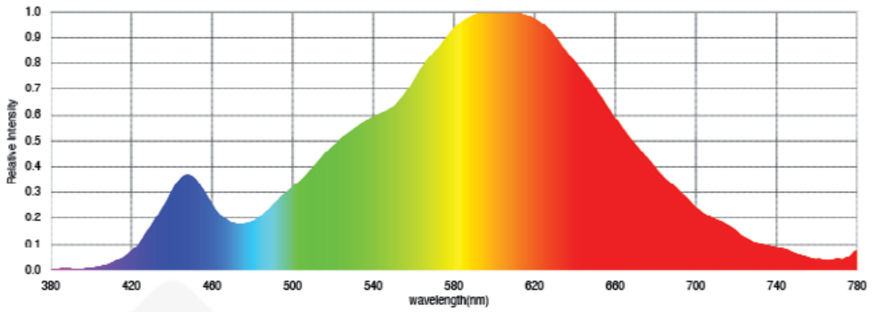

Product information and test conditions

Name		
Time	2022-02-17 11:15:12(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4439
CIE_y	0.4124
CIE_u'	0.2515
CIE_v'	0.5257
CCT	2953 K
Duv	0.0024
CRI (Ra)(R1~R8)	83
CRI (Re) (R1-R15)	77
CQS	84
TLCI(Qa)	71
GAI	49
TM-30-20 Rf	86
TM-30-20 Rg	96
Illuminance	230 lux
Foot Candle	21.3 fc

Spectrum



CRI (Re) (R1-R15)

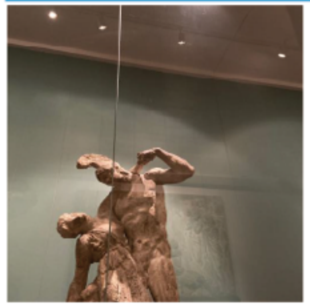
Ra = 83 Re = 77

r/cQizNoAbkb/m/D4krHoulsh/e/2

2022/02/17

Spectrum Genius

Lighting Parameter Analysis Report



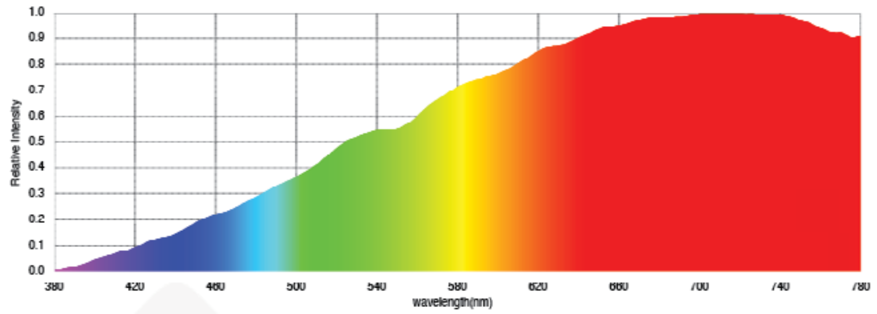
Product information and test conditions

Name		
Time	2022-02-17 11:47:58(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4453
CIE_y	0.4169
CIE_u'	0.2505
CIE_v'	0.5276
CCT	2966 K
Duv	0.0039
CRI (Ra)(R1~R8)	98
CRI (Re) (R1-R15)	97
CQS	95
TLCI(Qa)	99
GAI	49
TM-30-20 Rf	96
TM-30-20 Rg	97
Illuminance	227 lux
Foot Candle	21.1 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 98 Re = 97

r/BVENsp46Xx/m/V5t35RQRaL/e/2

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Spectrum Genius

Lighting Parameter Analysis Report

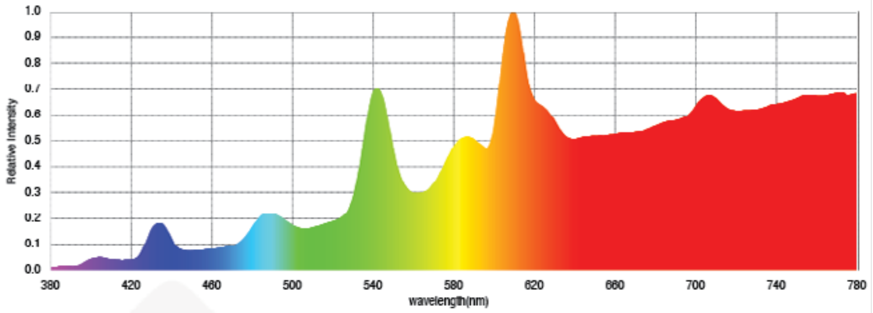
Product information and test conditions

Name			
Time	2022-02-17 11:50:02(Time-zone GMT+8)		
Manufacturer			
User	Antti (heikka.antti@gmail.com)		
Temperature(°C)	**Humidity(%)**	**Distance(m)**	

Parameters

CIE_x	0.4682
CIE_y	0.4212
CIE_u'	0.2631
CIE_v'	0.5326
CCT	2668 K
Duv	0.0032
CRI (Ra)(R1~R8)	93
CRI (Re) (R1-R15)	89
CQS	93
TLCI(Qa)	91
GAI	42
TM-30-20 Rf	93
TM-30-20 Rg	99
Illuminance	616 lux
Foot Candle	57.2 fc

Spectrum



CRI (Re) (R1-R15)

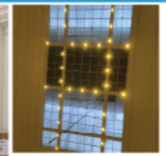
Ra = 93 Re = 89

/XoeGNG9Ilg/m/yDjmP7BBnP/e/2

2022/02/16

Spectrum Genius

Lighting Parameter Analysis Report



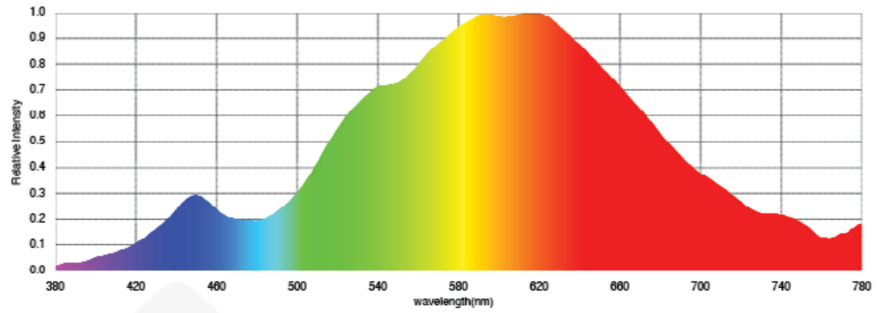
Product information and test conditions

Name			
Time	2022-02-16 10:53:15(Time-zone GMT+8)		
Manufacturer			
User	Antti (heikka.antti@gmail.com)		
Temperature(°C)	**Humidity(%)**	**Distance(m)**	

Parameters

CIE_x	0.4450
CIE_y	0.4271
CIE_u'	0.2460
CIE_v'	0.5313
CCT	3049 K
Duv	0.0078
CRI (Ra)(R1~R8)	83
CRI (Re) (R1-R15)	77
CQS	86
TLCI(Qa)	82
GAI	43
TM-30-20 Rf	88
TM-30-20 Rg	95
Illuminance	120 lux
Foot Candle	11.1 fc

Spectrum



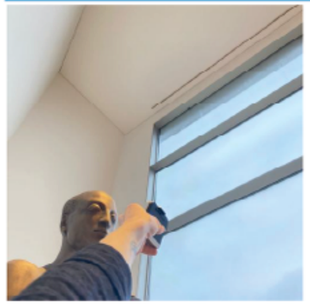
CRI (Re) (R1-R15)

Ra = 83 Re = 77

r/KHDGxbFHru/m/CsQGlStsUh/e/2

2022/02/16

Lighting Parameter Analysis Report



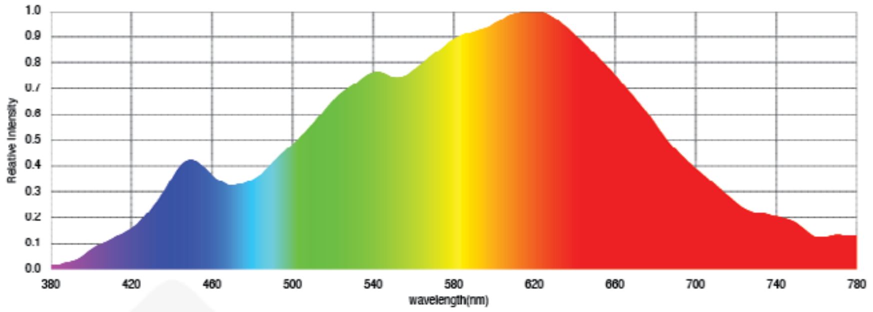
Product information and test conditions

Name		
Time	2022-02-16 11:23:02(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4150
CIE_y	0.4058
CIE_u'	0.2358
CIE_v'	0.5188
CCT	3419 K
Duv	0.0045
CRI (Ra)(R1~R8)	92
CRI (Re) (R1-R15)	89
CQS	94
TLCI(Qa)	94
GAI	60
TM-30-20 Rf	94
TM-30-20 Rg	98
Illuminance	1,064 lux
Foot Candle	98.9 fc

Spectrum



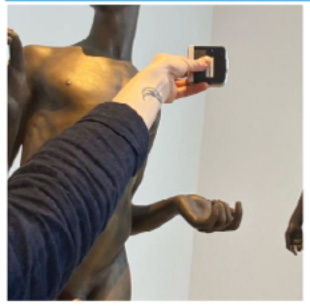
CRI (Re) (R1-R15)

Ra = 92 Re = 89

r/3YecJa8d04/m/hGIKRHCyAW/e/2

2022/02/16

Lighting Parameter Analysis Report



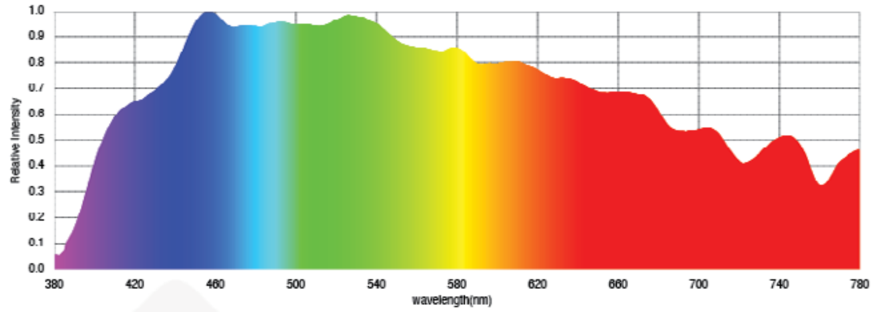
Product information and test conditions

Name		
Time	2022-02-16 11:23:33(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.3186
CIE_y	0.3417
CIE_u'	0.1972
CIE_v'	0.4758
CCT	6134 K
Duv	0.0068
CRI (Ra)(R1~R8)	98
CRI (Re) (R1-R15)	97
CQS	98
TLCI(Qa)	100
GAI	93
TM-30-20 Rf	98
TM-30-20 Rg	99
Illuminance	337 lux
Foot Candle	31.3 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 98 Re = 97

r/VXyjB6ccNp/m/J5RBeuhIV4/e/2

2022/02/16

Lighting Parameter Analysis Report

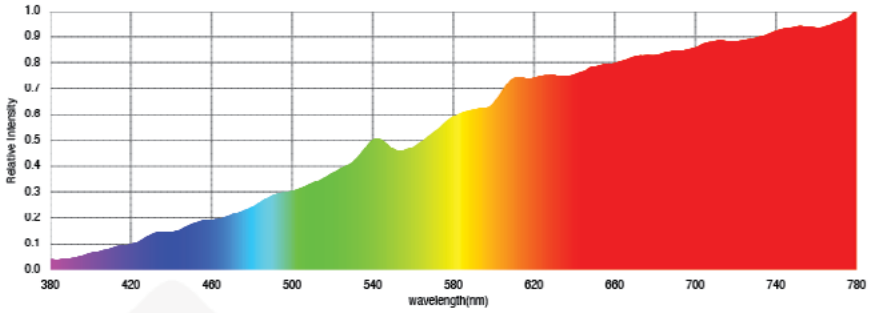
Product information and test conditions

Name			
Time	2022-02-16 11:41:34(Time-zone GMT+8)		
Manufacturer			
User	Antti (heikka.antti@gmail.com)		
Temperature(°C)	**Humidity(%)**	**Distance(m)**	

Parameters

CIE_x	0.4444
CIE_y	0.4087
CIE_u'	0.2534
CIE_v'	0.5243
CCT	2915 K
Duv	0.0009
CRI (Ra)(R1~R8)	99
CRI (Re) (R1-R15)	99
CQS	99
TLCI(Qa)	100
GAI	54
TM-30-20 Rf	99
TM-30-20 Rg	100
Illuminance	227 lux
Foot Candle	21.1 fc

Spectrum



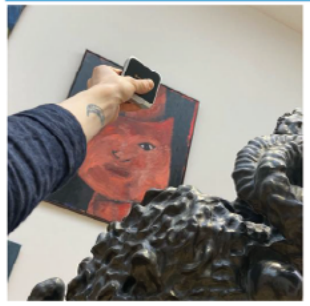
CRI (Re) (R1-R15)

Ra = 99 Re = 99

r/btradE7LMN/m/XMGV1TOhww/e/2

2022/02/16

Lighting Parameter Analysis Report



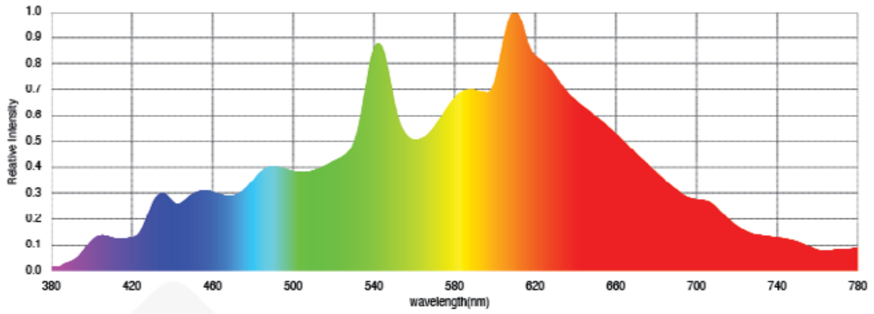
Product information and test conditions

Name			
Time	2022-02-16 11:43:44(Time-zone GMT+8)		
Manufacturer			
User	Antti (heikka.antti@gmail.com)		
Temperature(°C)	**Humidity(%)**	**Distance(m)**	

Parameters

CIE_x	0.4122
CIE_y	0.3998
CIE_u'	0.2364
CIE_v'	0.5160
CCT	3428 K
Duv	0.0025
CRI (Ra)(R1~R8)	95
CRI (Re) (R1-R15)	92
CQS	95
TLCI(Qa)	93
GAI	64
TM-30-20 Rf	95
TM-30-20 Rg	99
Illuminance	1,055 lux
Foot Candle	98.0 fc

Spectrum



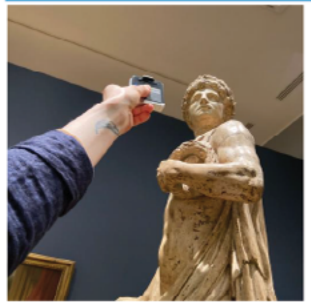
CRI (Re) (R1-R15)

Ra = 95 Re = 92

r/UALENgUvuj/m/hXJ26MTvV6/e/2

2022/02/16

Lighting Parameter Analysis Report



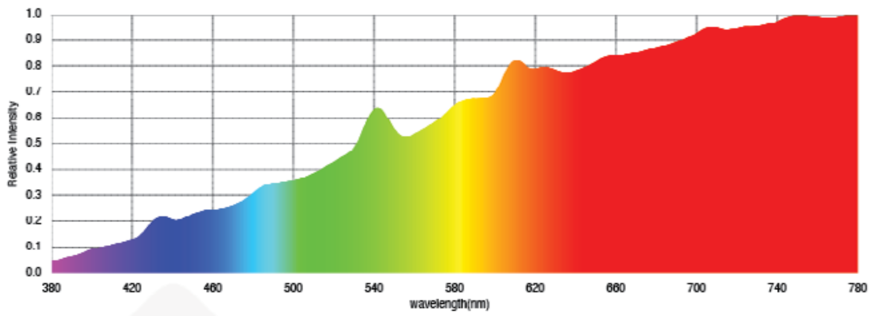
Product information and test conditions

Name		
Time	2022-02-16 12:21:26(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4291
CIE_y	0.4044
CIE_u'	0.2454
CIE_v'	0.5203
CCT	3138 K
Duv	0.0013
CRI (Ra)(R1~R8)	99
CRI (Re) (R1-R15)	98
CQS	99
TLCI(Qa)	100
GAI	60
TM-30-20 Rf	99
TM-30-20 Rg	100
Illuminance	876 lux
Foot Candle	81.4 fc

Spectrum



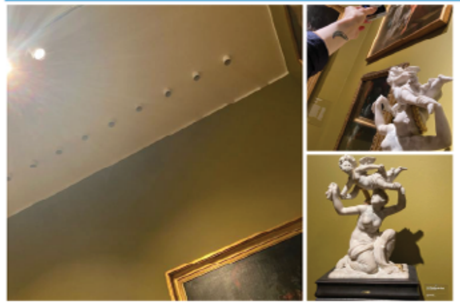
CRI (Re) (R1-R15)

Ra = 99 Re = 98

r/z6vsQUcTGC/m/yKSV5TvWse/e/2

2022/02/16

Lighting Parameter Analysis Report



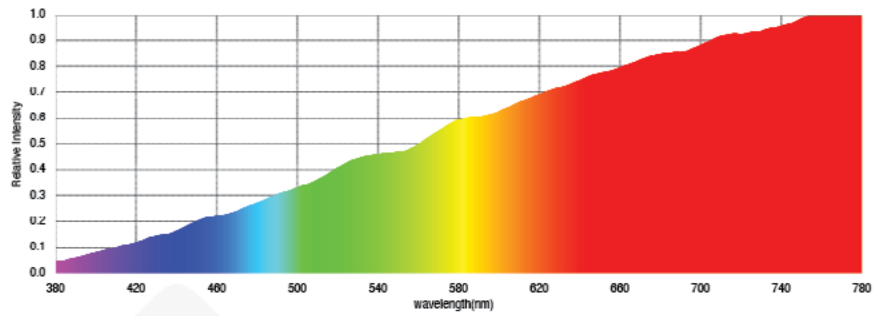
Product information and test conditions

Name		
Time	2022-02-16 12:02:10(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4317
CIE_y	0.4049
CIE_u'	0.2468
CIE_v'	0.5209
CCT	3097 K
Duv	0.0011
CRI (Ra)(R1~R8)	100
CRI (Re) (R1-R15)	99
CQS	99
TLCI(Qa)	100
GAI	58
TM-30-20 Rf	99
TM-30-20 Rg	100
Illuminance	475 lux
Foot Candle	44.1 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 100 Re = 99

r/CDzVAGKHSi/m/pkmIAseF5B/e/2

2022/02/16

Lighting Parameter Analysis Report

Product information and test conditions

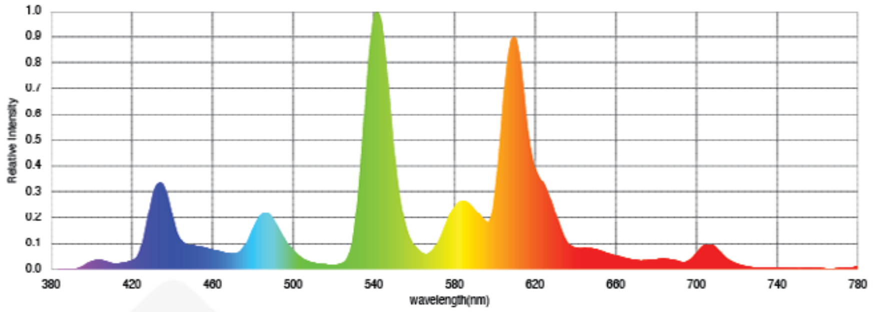
Name	
Time	2022-02-16 12:06:40(Time-zone GMT+8)
Manufacturer	
User	Antti (heikka.antti@gmail.com)

Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4086
CIE_y	0.4067
CIE_u'	0.2314
CIE_v'	0.5182
CCT	3554 K
Duv	0.0062
CRI (Ra)(R1~R8)	82
CRI (Re) (R1-R15)	73
CQS	83
TLCI(Qa)	52
GAI	67
TM-30-20 Rf	80
TM-30-20 Rg	101
Illuminance	482 lux
Foot Candle	44.8 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 82 Re = 73

r/rOty6CDVE2/m/RCeH6baZDE/e/2

2022/02/16

Lighting Parameter Analysis Report

Product information and test conditions

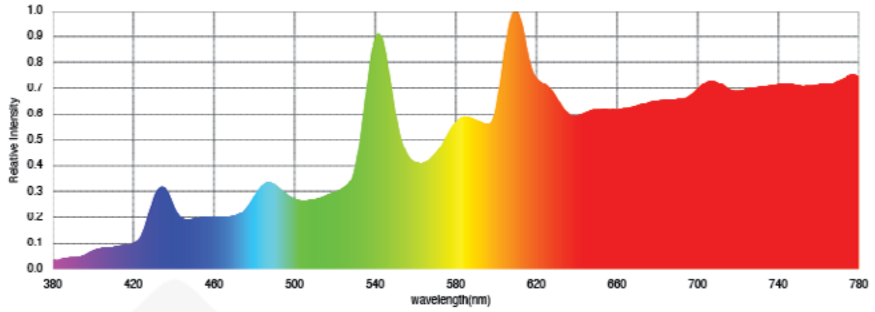
Name	
Time	2022-02-16 11:56:06(Time-zone GMT+8)
Manufacturer	
User	Antti (heikka.antti@gmail.com)

Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4269
CIE_y	0.4043
CIE_u'	0.2440
CIE_v'	0.5200
CCT	3178 K
Duv	0.0016
CRI (Ra)(R1~R8)	95
CRI (Re) (R1-R15)	92
CQS	95
TLCI(Qa)	95
GAI	62
TM-30-20 Rf	94
TM-30-20 Rg	101
Illuminance	377 lux
Foot Candle	35.0 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 95 Re = 92

r/4wnoBOrHmL/m/Wc0sgBxkLx/e/2

2022/02/16

Lighting Parameter Analysis Report

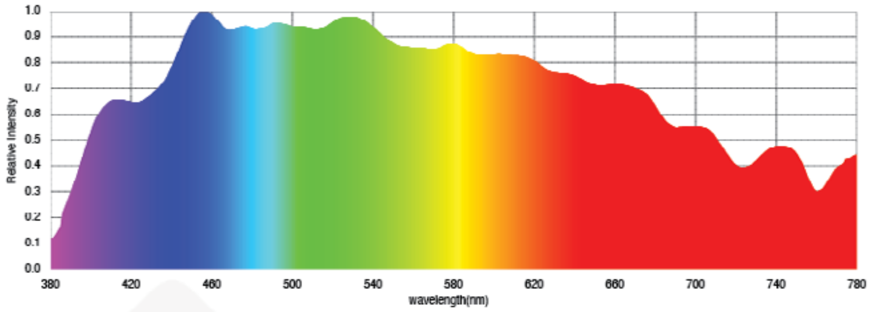
Product information and test conditions

Name		
Time	2022-02-16 10:57:54(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.3226
CIE_y	0.3417
CIE_u'	0.1999
CIE_v'	0.4764
CCT	5944 K
Duv	0.0048
CRI (Ra)(R1~R8)	99
CRI (Re) (R1-R15)	98
CQS	99
TLCI(Qa)	100
GAI	93
TM-30-20 Rf	99
TM-30-20 Rg	99
Illuminance	381 lux
Foot Candle	35.4 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 99 Re = 98

r/Gg8Vzz7sYv/m/2pcWpZUn4q/e/2

2022/02/16

Lighting Parameter Analysis Report

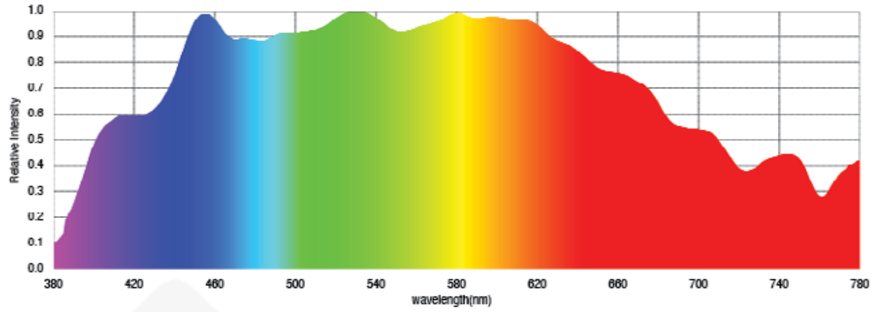
Product information and test conditions

Name		
Time	2022-02-16 10:59:08(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.3395
CIE_y	0.3516
CIE_u'	0.2076
CIE_v'	0.4838
CCT	5220 K
Duv	0.0024
CRI (Ra)(R1~R8)	98
CRI (Re) (R1-R15)	97
CQS	97
TLCI(Qa)	98
GAI	90
TM-30-20 Rf	98
TM-30-20 Rg	99
Illuminance	456 lux
Foot Candle	42.4 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 98 Re = 97

r/44J1eyaFAy/m/xW8N3svrb0/e/2

2022/02/16

Lighting Parameter Analysis Report

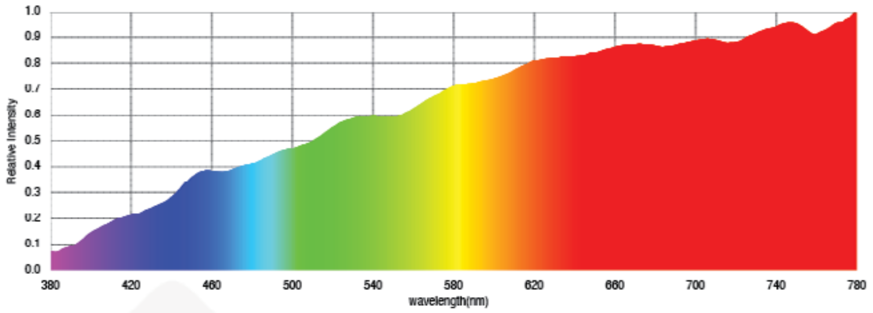
Product information and test conditions

Name		
Time	2022-02-16 11:02:27(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4033
CIE_y	0.3888
CIE_u'	0.2352
CIE_v'	0.5102
CCT	3530 K
Duv	-0.0004
CRI (Ra)(R1~R8)	99
CRI (Re) (R1-R15)	99
CQS	100
TLCI(Qa)	100
GAI	71
TM-30-20 Rf	99
TM-30-20 Rg	100
Illuminance	278 lux
Foot Candle	25.9 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 99 Re = 99

r/VRFdwX6opB/m/rEkZN3ESv7/e/2

2022/02/16

Lighting Parameter Analysis Report

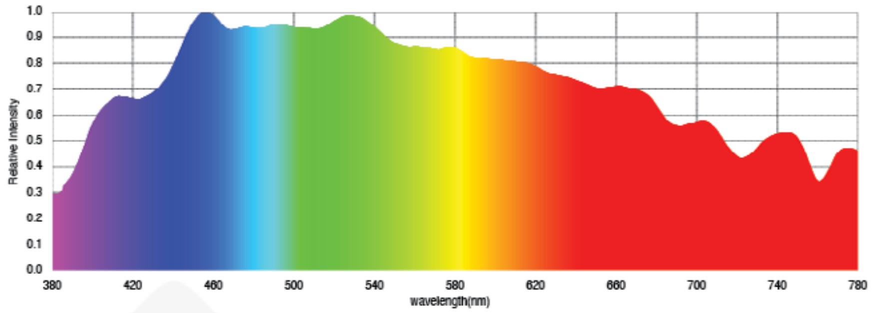
Product information and test conditions

Name		
Time	2022-02-16 11:03:28(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.3204
CIE_y	0.3411
CIE_u'	0.1986
CIE_v'	0.4758
CCT	6050 K
Duv	0.0056
CRI (Ra)(R1~R8)	99
CRI (Re) (R1-R15)	98
CQS	99
TLCI(Qa)	100
GAI	93
TM-30-20 Rf	99
TM-30-20 Rg	99
Illuminance	471 lux
Foot Candle	43.8 fc

Spectrum



CRI (Re) (R1-R15)

Ra = 99 Re = 98

r/09Mv6pCpyv/m/4gqxFkl58t/e/2

2022/02/16

Lighting Parameter Analysis Report

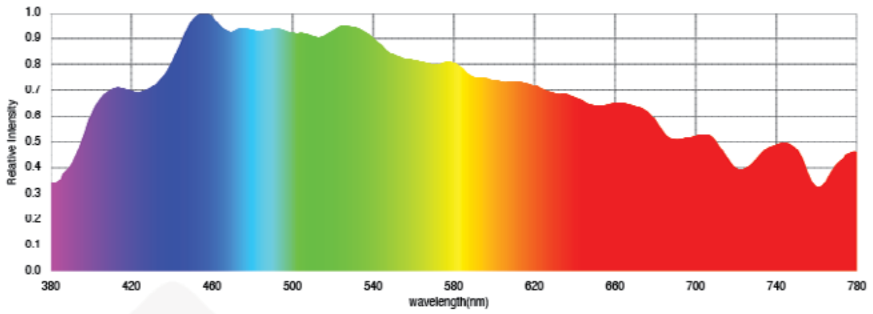
Product information and test conditions

Name		
Time	2022-02-16 11:06:11(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.3121
CIE_y	0.3342
CIE_u'	0.1955
CIE_v'	0.4710
CCT	6501 K
Duv	0.0062
CRI (Ra)(R1~R8)	98
CRI (Re) (R1-R15)	98
CQS	98
TLCI(Qa)	100
GAI	95
TM-30-20 Rf	99
TM-30-20 Rg	99
Illuminance	491 lux
Foot Candle	45.6 fc

Spectrum



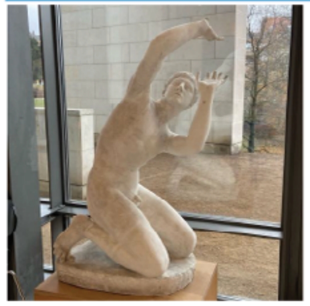
CRI (Re) (R1-R15)

Ra = 98 Re = 98

r/TjiPBEgWbE/m/DEVdhFGJvg/e/2

2022/02/16

Lighting Parameter Analysis Report



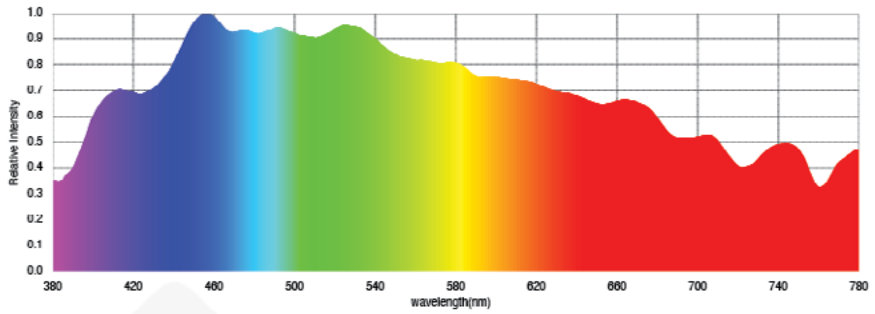
Product information and test conditions

Name		
Time	2022-02-16 11:07:32(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.3132
CIE_y	0.3347
CIE_u'	0.1961
CIE_v'	0.4714
CCT	6438 K
Duv	0.0059
CRI (Ra)(R1~R8)	99
CRI (Re) (R1-R15)	98
CQS	99
TLCI(Qa)	100
GAI	95
TM-30-20 Rf	99
TM-30-20 Rg	99
Illuminance	115 lux
Foot Candle	10.7 fc

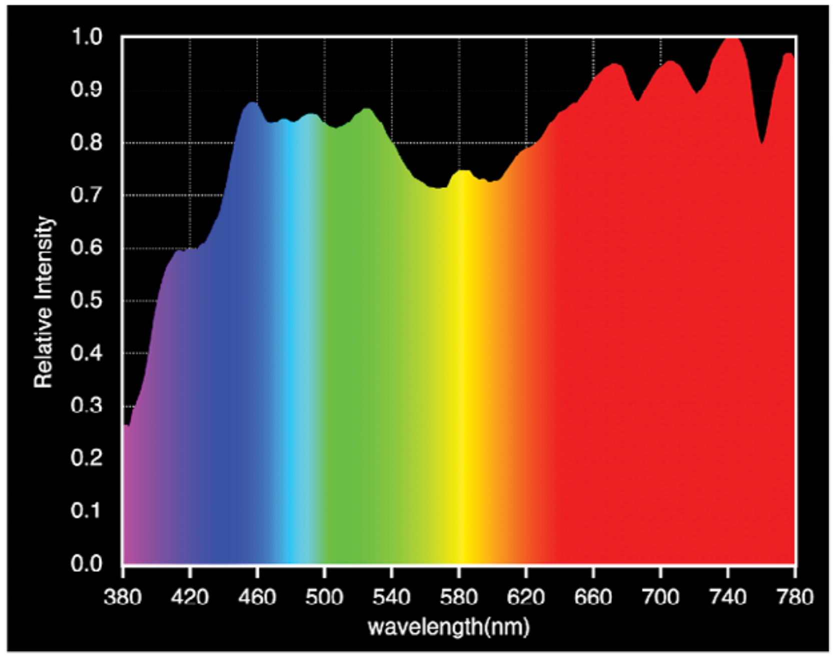
Spectrum



CRI (Re) (R1-R15)

Ra = 99 Re = 98

r/6E9kHw4a0W/m/JwP2tywDe2/e/2

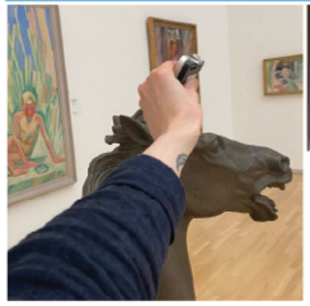


2022-02-17 16:46:18
CCT 5581 K
Illuminance 165 lux
CRI (Ra)(R1~R8) 91
CRI (Re) (R1-R15) 88
TM-30-20 Rf 94
TM-30-20 Rg 104
Flicker Percentage 3
Flicker Index 0.01
Flicker Frequency 100
λp 742 nm
λD 504 nm

2022/02/16

Spectrum Genius

Lighting Parameter Analysis Report



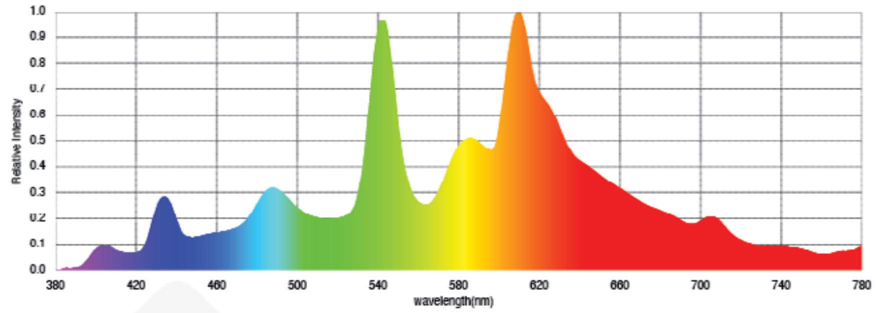
Product information and test conditions

Name			
Time	2022-02-16 11:15:20(Time-zone GMT+8)		
Manufacturer			
User	Antti (heikka.antti@gmail.com)		
Temperature(°C)	**Humidity(%)**	**Distance(m)**	

Parameters

CIE_x	0.4286
CIE_y	0.4100
CIE_u'	0.2428
CIE_v'	0.5225
CCT	3193 K
Duv	0.0037
CRI (Ra)(R1~R8)	93
CRI (Re) (R1-R15)	89
CQS	93
TLCI(Qa)	85
GAI	58
TM-30-20 Rf	93
TM-30-20 Rg	99
Illuminance	416 lux
Foot Candle	38.7 fc

Spectrum



CRI (Re) (R1-R15)

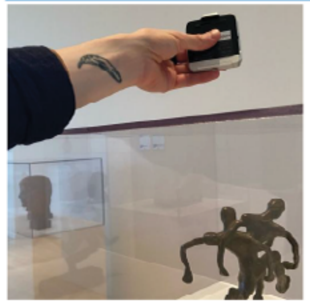
Ra = 93 Re = 89

r/yl46SLMp6L/m/S5JXiu49Wt/e/2

2022/02/16

Lighting Parameter Analysis Report

Spectrum Genius



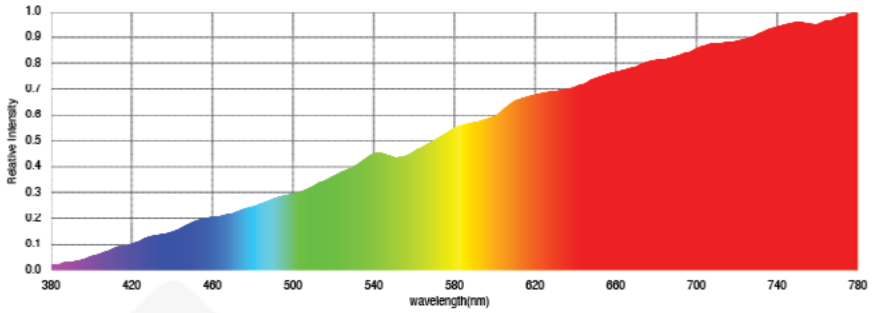
Product information and test conditions

Name		
Time	2022-02-16 11:19:07(Time-zone GMT+8)	
Manufacturer		
User	Antti (heikka.antti@gmail.com)	
Temperature(°C)	**Humidity(%)**	**Distance(m)**

Parameters

CIE_x	0.4371
CIE_y	0.4044
CIE_u'	0.2506
CIE_v'	0.5215
CCT	2999 K
Duv	0.0001
CRI (Ra)(R1~R8)	99
CRI (Re) (R1-R15)	99
CQS	100
TLCI(Qa)	100
GAI	58
TM-30-20 Rf	99
TM-30-20 Rg	100
Illuminance	240 lux
Foot Candle	22.3 fc

Spectrum



CRI (Re) (R1-R15)

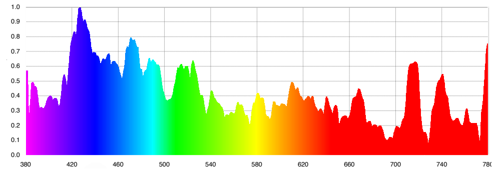
Ra = 99 Re = 99

r/wJ57QV48PP/m/BeHG3LV1nT/e/2

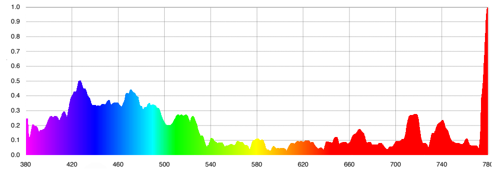
A3. SPECTROMETER MEASUREMENTS WITH CCT & CRI VALUES

18.2.22. 16:48
13080 K
1 lux

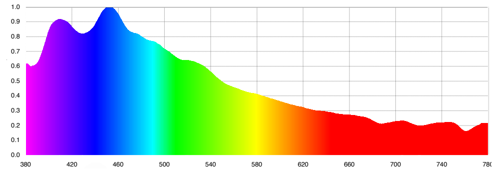
BLUE HOUR



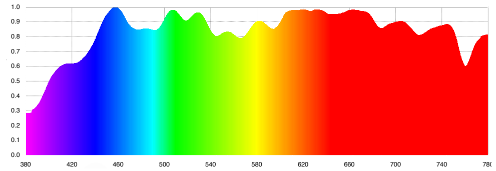
20.2.22. 5:41
– K
1 lux



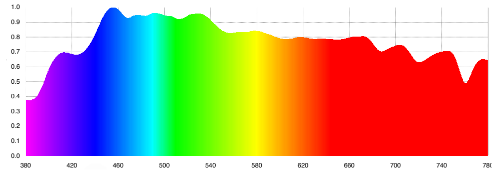
26.2.22. 9:14
17,000 K
4,511 lux



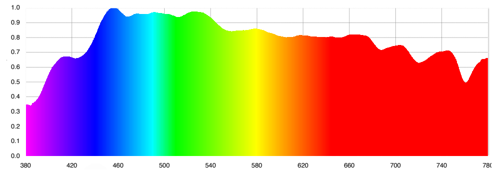
26.2.22. 9:14
5,120 K
76,218 lux



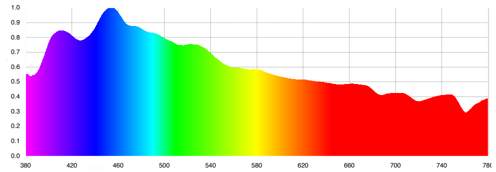
25.2.22. 12:19
6,034 K
21,063 lux



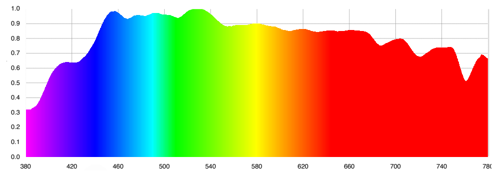
25.2.22. 12:20
5,950 K
37,438 lux



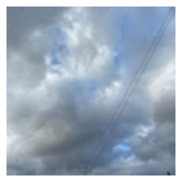
23.2.22. 13:01
8,880 K
7,790 lux

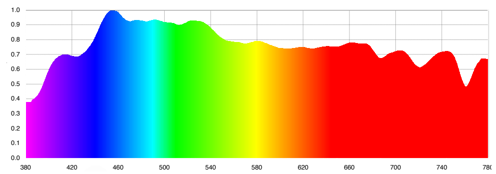


23.2.22. 13:02
5,640 K
30,781 lux

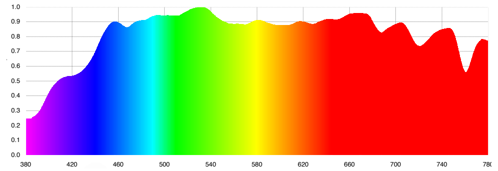


23.2.22. 14:52
6,299 K
5,200 lux

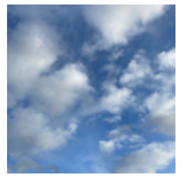


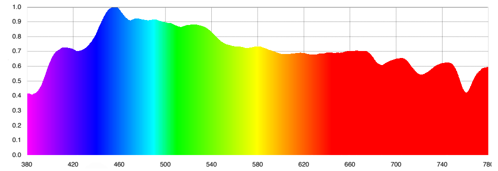


23.2.22. 14:52
5,232 K
9,776 lux

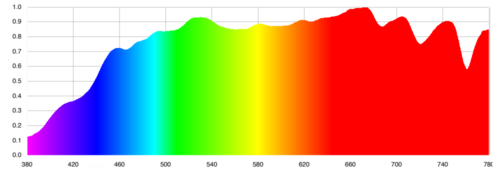


23.2.22. 14:51
6,730 K
6,167 lux

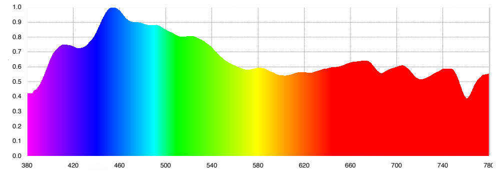




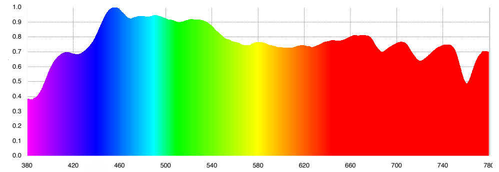
23.2.22. 14:56
4,640 K
28,295 lux



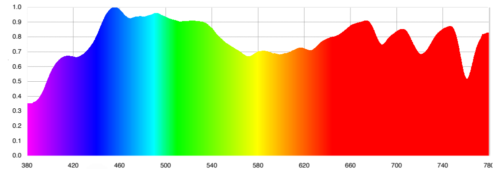
23.2.22. 15:26
6,380 K
3,380 ux



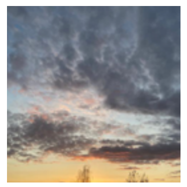
23.2.22. 15:52
8,210 K
1,650 ux

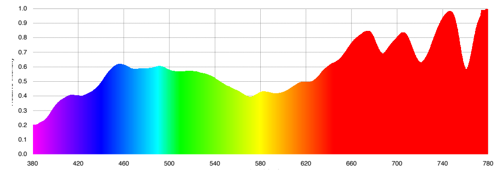


27.2.22. 16:12
6,570 K
1,212 lux

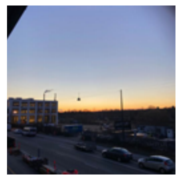


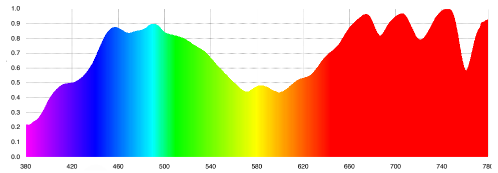
23.4.22. 18:28
6,052 K
520 lux



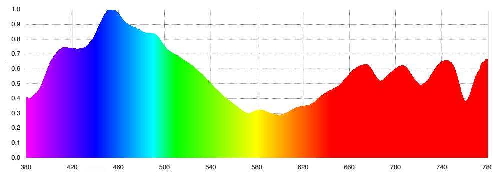


26.2.22. 16:51
7,770 K
139 lux





26.2.22. 16:52
21,280 K
36 lux



A4. EXPERIMENT RESPONSES

DYNAMIC SETUP

Timestamp	Age	Gender	To what extent does lighti	To what extent does lighti	To what extent does lighti	To what extent does lighti	How suitable seems to be	How attractive appears to	How appealing seems to	Pleasant Unpleasant	Comfortable Uncomfortab	Excited Calm	Stimulated Relaxed	Satisfied Dissatisfied	Connected Melancholic
4/25/2022 12:39:55	22	female	5	6	5	5	6	5	5	1	2	4	4	3	2
4/25/2022 12:40:49	24	female	4	3	4	3	5	6	6	1	2	2	3	2	3
4/25/2022 12:42:23	29	female	6	6	4	5	6	6	6	1	1	1	1	1	1
4/25/2022 12:43:34	31	female	6	6	5	5	6	6	6	1	1	2	1	1	2
4/25/2022 12:44:48	25	female	5	5	4	5	5	6	6	2	1	1	2	2	1
4/25/2022 12:45:42	-	-	4	5	6	6	5	6	6	1	1	5	5	2	3
4/25/2022 12:47:03	24	female	2	3	2	5	5	6	6	2	2	3	1	2	2
4/25/2022 12:48:17	29	female	5	6	4	6	5	6	6	1	1	4	1	1	3
4/25/2022 12:49:34	24	male	5	6	4	5	6	6	6	1	1	2	3	1	3
4/25/2022 12:51:19	26	female	4	6	5	6	6	6	6	1	1	3	3	1	3
4/25/2022 12:52:45	25	male	4	5	5	5	4	5	5	2	2	2	1	2	3
4/25/2022 12:53:32	26	male	5	6	6	6	6	4	6	1	1	3	3	1	1
4/25/2022 12:54:31	24	male	5	6	2	6	4	3	4	2	3	2	3	3	3
4/25/2022 12:55:32	52	female	6	6	6	5	6	4	3	1	1	5	2	1	2
4/25/2022 12:56:10	23	female	5	5	4	5	5	4	5	2	2	2	2	3	4
4/25/2022 12:57:19	27	female	3	3	1	3	2	3	3	3	3	3	3	3	3
4/25/2022 12:57:56	20	female	4	5	6	4	4	5	4	2	3	4	2	2	5
4/25/2022 12:58:53	27	female	6	5	6	6	6	5	6	1	1	5	3	1	3
4/25/2022 13:00:12	22	female	6	6	5	6	5	6	6	2	1	4	5	2	3
4/25/2022 13:01:10	-	-	4	4	3	3	3	5	4	2	3	4	4	3	4
4/25/2022 13:02:12	-	-	2	5	5	5	4	2	4	3	4	3	3	4	1
4/25/2022 13:02:53	30	female	6	6	6	6	6	6	6	1	2	2	1	3	2
Dynamic Setup	**Dynamic Setup**														

STATIC SETUP

Timestamp	Age	Gender	To what extent does lighti	To what extent does lighti	To what extent does lighti	To what extent does lighti	How suitable seems to be	How attractive appears to	How appealing seems to	Pleasant Unpleasant	Comfortable Uncomfortab	Excited Calm	Stimulated Relaxed	Satisfied Dissatisfied	Connected Melancholic
4/25/2022 12:40:16	22	Female	4	3	5	5	4	5	4	3	3	4	4	3	3
4/25/2022 12:41:52	27	Female	2	2	1	1	2	3	2	4	3	3	3	4	3
4/25/2022 12:43:02	20	Female	3	5	5	4	4	6	6	2	2	2	4	2	4
4/25/2022 12:44:21	27	Female	6	5	4	4	6	4	4	3	3	3	3	3	3
4/25/2022 12:45:08	23	Female	4	5	2	4	4	4	3	3	3	3	2	2	4
4/25/2022 12:45:55	52	Female	3	6	4	2	3	3	3	1	1	5	4	4	3
4/25/2022 12:47:36	24	Male	2	3	2	2	3	2	3	3	4	4	4	3	4
4/25/2022 12:48:42	26	Male	6	5	5	4	5	5	4	1	1	3	3	2	3
4/25/2022 12:51:17	25	Male	4	4	5	4	4	3	3	3	3	3	3	4	4
4/25/2022 12:52:09	30	Female	2	1	3	3	2	3	3	3	3	4	3	4	5
4/25/2022 12:53:10			5	4	2	5	6	6	4	2	2	2	4	1	3
4/25/2022 12:53:41			5	4	4	4	4	5	5	2	2	3	3	3	3
4/25/2022 12:54:34	26	Female	5	4	6	6	5	4	6	3	2	4	4	2	4
4/25/2022 12:55:36	24	Female	2	2	2	3	2	2	3	4	3	5	5	4	3
4/25/2022 12:56:17	29	Female	5	2	2	3	2	1	3	3	4	4	3	3	3
4/25/2022 12:57:27	24	Female	5	4	4	5	5	4	4	2	1	4	4	2	4
4/25/2022 12:58:00			4	5	6	2	2	3	3	2	2	5	5	2	2
4/25/2022 12:58:42	25	Female	4	3	3	3	3	4	4	3	1	4	4	2	4
4/25/2022 12:59:56	31	Female	4	2	5	2	3	4	3	3	1	4	4	3	2
4/25/2022 13:00:57	29	Female	2	4	2	3	1	1	1	3	4	3	3	5	4
4/25/2022 13:01:34	24	Female	5	5	4	5	5	4	4	2	2	4	4	3	4
4/25/2022 13:02:12	22	Female	4	4	2	5	3	4	3	3	3	3	4	4	4
Static Setup	**Static Setup**														