USER LIGHTING PREFERENCES IN MUSEUMS AND GALLERIES: VIRTUAL MODELS AND A SURVEY FOR MULTIPLE EXHIBITION AND LIGHTING CONDITIONS

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ABSTRACT

USER LIGHTING PREFERENCES IN MUSEUMS AND GALLERIES: VIRTUAL MODELS AND A SURVEY FOR MULTIPLE EXHIBITION AND LIGHTING CONDITIONS

Just as any other interior, lighting quality of exhibition spaces need to be examined to enhance visual quality and comfort. Exhibition lighting is already a chaotic process with many quantitative and qualitative parameters, their relation with each other and concerns of multi-disciplines. Consequently, the impacts and the potentials of subjective appreciation, daylight, user perception and behavior, new developments and the relation between the parameters are often disregarded.

In this thesis, a comprehensive study is conducted to understand the impact of lighting type, color temperature, room and exhibition parameters on navigation and impressions. A set of three exhibition spaces with various room and lighting conditions were modelled virtually, to be evaluated in a three-part questionnaire. A total of 90 participants are selected equally from three profession groups which are architects, visitors and artists. Their movement through the exhibition, preferences and impressions are analyzed with various statistical analysis methods.

Results show that there are some distinctive preferences between occupation groups. In the first part, it can be seen that navigation choices changes with the lighting type as the movement towards daylight increases in transition areas and the end. Generally, daylight is preferred for sculpture while artificial light is preferred for paintings. In the second and third part, it was found out that lighting type is the major factor against color temperature in preference and impressions. The best setting is picked as single spotlight with neutral color temperature. Warm ambient lighting is not received well. Ultimately, lighting preferences and perception change with different room and exhibition conditions.

ÖZET

MÜZE VE GALERİLERDE KULLANICI AYDINLATMA TERCİHLERİ: BİRÇOK SERGİ VE AYDINLATMA KOŞULU İÇİN SANAL MODELLER VE BİR ANKET

Diğer bütün iç mekanlar gibi, sergi alanlarının aydınlatma kalitesi görsel konfor ve kalitenin iyileştirilmesi için incelenmelidir. Sergi aydınlatması halihazırda birçok nitel ve nitel değişken, bu değişkenlerin arasındaki ilişki ve farklı disiplinlerin görüşleri ile kaotik bir süreçtir. Bunun sonucunda, sübjektif değerlendirme, doğal aydınlatma, kullanıcı algısı ve tercihleri, yeni gelişmeler ve parametrelerin arasındaki bağlantı çoğunlukla göz ardı edilmektedir.

Bu tezde, aydınlatma türü, renk sıcaklığı, oda ve sergi parametrelerinin yönelim ve izlenimler üzerindeki etkisi kapsayıcı bir çalışmada ele alınmıştır. Çeşitli oda ve aydınlatma parametrelerinde üç farklı modelden oluşan sergi mekanı serisi üç aşamalı bir ankette değerlendirilmek üzere sanal olarak modellenmiştir. Mimarlar, ziyaretçiler ve sanatçılar eşit olacak şekilde, üç ana meslek grubundan toplam 90 kişi ankete katılmıştır. Katılımcıların sergide yönelimi, tercihleri ve izlenimleri çeşitli istatistik analiz yöntemleri ile incelenmiştir.

Elde edilen sonuçlarda, meslek grupları arasında dikkate değer tercih farkları vardır. Anketin ilk kısmında, geçiş mekanlarında ve sergi sonuna doğru doğal aydınlatmaya yönelimin artmasıyla yönelim tercihleri aydınlatma türü ile değiştiği görülmüştür. Genel olarak, heykel sergisinde doğal aydınlatma, resim sergisinde yapay aydınlatma tercih edilmiştir. Anketin ikinci ve üçüncü kısmında, aydınlatma düzeninin ışık renk sıcaklığına göre tercihler ve izlenimlerde daha baskın bir etkisi görülmüştür. En iyi aydınlatma düzeni nötr renk sıcaklığı ile tekli spot ışık olmuştur. Sıcak ışık renk sıcaklığı olan ambiyans aydınlatması iyi değerlendirilmemiştir. Sonuç olarak, aydınlatma tercihleri ve algısının farklı oda ve sergi koşullarında değiştiği görülmüştür.

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CCT	Correlated Color Temperature
CRI	Color Rendering Index
LED	Light Emitting Diode
SSL	Solid State Lighting
UV	Ultraviolet
CIE	International Commission on Illumination
IES	Illuminating Engineering Society
HDR	High Dynamic Range
ANOVA	Analysis of Variance
OLS	Ordinary Least Squares
GLM	General Linear Method
PCC	Pearson Correlation Coefficient

CHAPTER 1

INTRODUCTION

1.1. Meaning of Exhibition Lighting

Architecture starts with light so does the act of exhibiting. Light makes objects visible. It reveals their identity by defining their form, texture, scale and surrounding space. In other words, light transmits the information that shared with the people in spaces like museum and galleries. It can change the perception so it can influence the whole exhibition experience (Cuttle 2007). Ultimately, lighting is a vital tool in exhibitions to connect the visitor with the pieces beyond providing user comfort and architectural quality when compared to other architectural spaces.

Every interior space has its own needs and principles in terms of lighting design. Fundamentally, increase in the ability to see, increase in the working efficiency, maintaining visual health and comfort of the user, making the space adequate to function and decrease in accidents are expected in the lighting design of most of the interior spaces (CIBSE 2002). After providing these basic conditions, interiors start to detach from each other in terms of needs or tasks that need to be done under certain conditions. Still, exhibition lighting remains special and distinct from other interior lighting principles. This difference heavily relies on the aim of the exhibiting spaces which are museums and galleries.

To understand their aim, the definition of these spaces must be cleared first. Although the meaning of museum has changed over the years, the museums are the places broadly responsible for conserving, researching, communicating and exhibiting the heritage of humanity (ICOM 2007). Galleries are simply areas or buildings which are used to exhibit artworks (Merriam-Webster 2019). The aim of these exhibition spaces can be extracted from their definitions: lighting becomes a communication tool, a language between people such as artist to audience (visitor), ancient civilizations to modern society. They involve human and its perception more than any other space. In terms of lighting, museums, galleries and exhibitions have similar concerns so all three of the terms is going to be used throughout the thesis.

Exhibition places have a dynamic meaning in the society. Earlier, people visited the museums simply to get information about history and art, in a way which is experiencing and interacting with the exhibited object. Although, these places were not designed for exhibiting at the time. The design principles of exhibition spaces have been shaped with the visitor expectation over its short history. This progress changed the reasons of people's visiting museums and galleries. Now, museums offer a unique visual experience created by many tools like lighting design. They have become cultural and social interaction points for the people. In this sense, they are taken as the "artistic presentation of humanity", "the peak point of mankind" in the daily life (Kandemir and Uçar 2016). Whether the impressive atmospherics in museums or new forms of artistic expressions, visitor anticipation constantly changes with the evolution of "the peak point".

Representation of humanity is a sensible issue for many disciplines such as designers, conservators, artists and curators. The meaning of exhibition gets layered with the increase of these specializations. Perspective on the meaning of representation may be different for each of them (ICOM 2007; Garside et al. 2017). These perspectives immerse as the input for the whole process, later to connect with the output which is the perspective of the visitors.

1.2. Problem Statement

A complex combination of various quantitative and qualitative aspects such as conservation, displaying, expression, safety, visual comfort, sustainability and navigation should be regarded in lighting design for museums and galleries (RFW Kommunikation 2007). For example, existence of light is already a critical problem in conservation which contradicts with the act of displaying. Low illuminance levels are expected to minimize the amount of damage to the displayed object which can compromise visual quality (Schanda, Csuti and Szabo 2016). A meticulous balance between these parameters is expected in lighting design in museums and galleries.

To clear the path, there are some guides and standards that can be referenced. However, every lighting design eventually develops into a unique work with set of choices made specifically for the exhibition and its area along with priority order of aspects mentioned above. The inevitability of case-by case approach obliges each designer to set their own rules by developing design approaches like using trial and error method or passing undocumented knowledge disorderly among their network. Additionally, a group of advisors are most likely needed in large museums to manage multi-disciplinary aspects (Garside et al. 2017; Druzik and Eshoj 2007).

New technologies do not always help lighting designers either. They create another obstacle with a wide range of options which alienates designer to pick one. For example, LED lighting is getting popular in many building types including museums and galleries with a variety of application techniques. Many researches and governmental programs claim that LED is far better when compared to other lighting options with notable improvements in multiple aspects such as visual quality, preservation and energy efficiency. Still, museums are not quite eager to use LED since the effects of it especially on materials are not fully understood and experienced (Piccablotto et al. 2015).

Daylight is a more controversial topic in museum lighting. Almost no daylight is wanted among lighting designers due to preservation concerns. Direct daylight and glare are not approved in any condition while controlling its dynamic behavior is considered as too much risk. Therefore, beneficial elements like visual quality and energy efficiency are often disregarded. Nowadays, sustainability is considered as a requirement even in special buildings like museums so usage of daylight become more important. On the other hand, daylight is one of the components that shaped the museum concept. Over time, it became a crucial element for architects. Sometimes the reasons of daylighting can be more meaningful in museums than other building types, like recalling the atmosphere of the time when the object was created (Zaag 2017; Navvab 1998).

Another problem is that only surface is scratched with museum lighting in terms of user perception and the type of the response. Beyond meeting all the requirements and tasks regarding lighting, the quality of lighting design is mostly evaluated through subjective appreciation (Lo and Steemers 2014). Usually, Subjective assessment and surveys are used in the studies to understand the patterns between aesthetic preferences and lighting. Although, a little attention has been given in the studies to issues like visitor behaviors, exhibition sequence or the structure of questionnaire itself (Forrest 2014).

Since it is hard to control and investigate all parameters of museum lighting, most studies focused on specific topics, correlation several factors. This complicates the integration between research and practice. For example, Carvalhal et al. (2005), Pinto, Linhares and Nascimento (2008), Csuti et al. (2015) studied the relation between color pigment of paintings and color temperature of LED lamps. Zhai, Luo and Liu (2016) studied the relation CCT, CRI and preference with LED lamps. Parameters like light types, source, occupation, type of response are not considered.

Museum staff or lighting designers mostly cannot comprehend and apply the findings, along with not catching up with the pace of the publications. The comprehensive studies highlight the challenge and necessity of applying a clear approach. Even case-by-case method is considered as beneficial and effective. Interestingly, the possibility of creating complex heuristic models by using case-by-case data is suggested. It is found out that main concerns in museum lighting are conservation, visual quality and their conflict. Additionally, data from experiments and simulations are compared to correlate and set the limits with the qualitative data (Garside et al. 2017).

1.3. Purpose of the Study

Despite this chaotic status in exhibition lighting, there is also a demand to investigate and enhance the “formula” behind it. Studies have increased recently with a growing trend on improving interior quality of all building types including museum and gallery lighting (Kaya and Afacan 2017). With improved tools and knowledge, there is no reason to not explore the potential of exhibition lighting.

Understanding human perception is the key to figure out reasoning behind lighting decisions. However, users not only respond with stating their impressions, they can respond in instinctive behavior like movement. User choices on navigation and impressions can be obtained to understand human perception. Another problem of studying human perception is to figure out the true meaning of the response. Structure of the questionnaire can be arranged to systematize and increase reliability of subjective response.

The response on the final appearance of the object is inevitably subjective. In the end, an exhibition of the object is a one-time personal experience to a visitor, an artist and a lighting designer. Acknowledging different view and priorities and their impact on preferences can be used to communicate between disciplines and to construct a common ground. Common ground is the basis to create a systematized knowledge. One of the aims of this thesis is to give lighting designers or museum staff an insight of each mindset with reasons, especially visitors' mindset as the target audience.

To conclude, the main aim of this study is to conduct a comprehensive study on the relation between exhibition lighting and user by including multiple parameters such as light source, lighting setting, color temperature, exhibition type and size, occupation and other personal information of the participant. To guide lighting designers, the priority and the level of impact of the parameters need to be sorted and understood. The relevant parameters must be detected to overcome multiple objections of exhibition lighting. Additionally, there are some minor objectives of this study such as testing visual reliability of the used software and the efficiency and of the asked questions with additional questions in the questionnaire.

To summarize the purpose with research questions:

- How lighting source, setting, color temperature affects the preference in exhibition lighting?
- How the relation between exhibition conditions and lighting preferences work?
- Can lighting preferences be obtained from impressions and behavior regarding exhibition?
- Do occupations which are involved in exhibiting and general visitors have a tendency or certain preferences in exhibition lighting?
- Do daylight have more potential in terms of exhibition experience?

1.4. Limitations

There are several limitations in the questionnaire. Firstly, it must be noted that all models used for the questionnaire are imaginary spaces.

Some lighting parameters are generalized especially when creating the first model of the questionnaire. Since the main aim is to make participant to move towards either daylit or artificially lit of the same exhibition space in a series of spaces, parameters like dimension, type, transmittance values in windows and sun position are not considered. A standard is determined in side-lit windows and the skylight. In the same model, parameters like layout, illuminance, intensity, luminance, flux, CCT are not considered in artificial lighting but settings related to these parameters are kept same throughout the exhibition. This limitation is happened due to program abilities of Lumion since there are no options to set lighting with real lighting parameters and measurements. Lumion is used to have movement inside the rendered model.

Another limitation is the personal differences of the participants. Firstly, virtual experience may differ with age. Perception of virtual environment may be an obstacle for old ages but this factor is not considered in this study. The participants are picked from all ages and movement inside virtual environment controlled by the interviewer but in further studies a limited range of age could be selected. Secondly, three occupation groups are determined from the participants. Their focus on whether exhibited objects, space or lighting is not considered.

1.5. Structure of the Thesis

The literature review in the second chapter starts with elements of exhibition lighting. Its components, parameters and role are explained. Main issues related with lighting are mentioned such as the most discussed which is the conflict between preserving and displaying when applying light on an object. With the heavy involvement of subjectivity and human perception, parameters related to the conflict between fidelity and artistic purposes are explained. The practice of exhibition lighting in the field is mentioned discussed in the second part. Lastly, the reasons and solutions for the miscommunication between theory and practice are discussed.

To understand the involvement of human perception, user preferences need to be obtained and analyzed. In the third chapter, methodology of this study is explained. The elements such as model making, the purpose of the questions in the questionnaire, the procedure and the planning of statistical analysis are explained separately in sections. A questionnaire and virtual scenes were prepared based on the literature review to see the preference on light source, lighting configuration and color temperature. Participants were asked to complete the questionnaire by looking at three different virtual exhibition scenes through computer screen.

In the fourth chapter, results are summarized and discussed by the order of the questions in the questionnaire which includes the commentaries on exhibition lighting by the participants who are practicing in the field. In the last chapter, discussions and conclusion, key findings of each model are explained. Paralleling outcomes of different analyses are mentioned in the end. The purpose and the contribution of the study are discussed.

Table 1.1. Questionnaire model (virtual exhibition scene) planning

	Model 1. Virtual Exhibition Model for Navigation	**Model 2. Paintings in Virtual Model**	**Model 3. Sculptures in Virtual Model**
Used Program	Lumion	3dMax	Relux
Parameters	Light Source Exhibition type Room Size	Lighting Setting Color Temperature	Lighting Setting Color Temperature
Response	Navigation Choice Selection & Evaluation	Selection & Evaluation	Selection & Evaluation

CHAPTER 2

LITERATURE REVIEW

In this chapter, studies and books regarding exhibition lighting are explained in two sections which are theory and practice since the theory is not always projecting well on practice. The reasons of this miscommunication are explained. Some overlooked parameters and problems in theory and solutions in practice are regarded in methodology such as understanding the effect of light source, exhibition, light setting, color temperature on user behavior and preference.

2.1. Theory of Exhibition Lighting

Exhibition spaces differ from other interior spaces with the design approach of lighting. Fundamentally, function shifts towards the object and the viewer more than work has to be done inside the space. Usage techniques of light sources, main lighting parameters and role of lighting in exhibition are discussed in this section.

2.1.1. Light Sources

There are many contradicting views and reasonings on daylight and artificial light application in museums and galleries. First and foremost, both light sources should exist together for all conditions (Cuttle 2007). Instead of eliminating one of them instantly, each source has a potential to cover multiple problems and requirements of exhibition spaces. Although density of light sources may vary according to the purpose of the space.

2.1.1.1. Daylight

Despite the negative view against daylight in the field of exhibition lighting, daylight still exists in museums and galleries due to its irreplaceable qualities. Daylight integrates with the building while reaching interiors and the object. The advantages of daylight can be listed as: energy efficiency, better visual quality, improved human health and visual connection to exterior. On the contrary, daylighting basically means preventing direct sunlight interiors. One of the most mentioned problems is that unsteady and unbalanced amount of daylight causes both visual and preservation problems like glare or light damage. Additionally, dynamism of daylight is another debated topic. Usually fixed light levels are desired among museum staff (Kim and Chung 2011). Although, daylight's atmosphere change and involvement of circadian rhythm are considered experimental and valuable (Cannon-Brookes 2000).

Figure 2.1. Daylighting examples (Source : Cuttle, 2007)

Over the years, typologies and techniques are developed to overcome obstacles in daylighting museums. Cuttle (2007) reviewed the daylight performance of various opening types. For example, tilted placing of paintings is recommended in side lit spaces to avoid reflection. Despite the unbalanced daylighting, side lit windows are recommended for sculpture exhibiting to add a shading layer on the object (Figure 2.1 (left)). Usually, top light types are considered as the best daylighting system for exhibitions spaces due to its direction and diffusing effect. However, additional control systems may be needed in skylights. To eliminate direct light, polar-oriented openings like saw-tooth skylights are suggested in a study (Figure 2.1 (middle)) (Kim and Chung 2011). Besides the form of the top light, adding layers on glass (filters and frosted glass) is an effective way to diffuse and control the amount daylight (Figure 2.1 (right)) (Cuttle 2007).

2.1.1.2. Artificial Light

The artificial light relatively has a recent in history of exhibition lighting than daylight. Even the introduction of electricity changed the perception of lighting as static rather than dynamic component. The static behavior is the reason of preference of artificial light and the strengths of it can be summarized as precision and constancy. With artificial light, lighting designer is in full control of the lighting environment. Preservations risks are easily estimated as the lighting is evolved with conservational concerns.

Figure 2.2. Washington National Gallery and Sprengel Museum (Source: Cuttle, 2007)

Artificial light can be applied in many ways though there are three main types of application which are focal lighting (spotlight), wall-washer (Figure 2.2) and ambient. Different from other building types, objects are in focus rather than surrounding space in exhibition spaces. In artificial light, the focus and the direction can be adjusted easily with focal lighting. Surrounding space can be illuminated with an ambient lighting to adjust the contrast and to provide a safe circulation (Garside et al 2017). Since the direction and the application possibilities of lighting are endless, even surfaces of the room can be used with wall-washer. The key point of artificial light is that the strategy has to change when lighting 3D or 2D objects since different components are involved like shadow or background (Cuttle 2007).

Over the years, many lamps types have been used in exhibiting. Recently, solid state lighting (SSL), which is also known as LED, is popular among museum and gallery community with its advantages like energy efficiency, color rendering and spectral quality (Almeida et al. 2013). Most importantly, its dimmable characteristic changes the static approach of artificial light to dynamic approach.

2.1.2. Parameters of Exhibition Lighting

Although there are numerous parameters of light, lighting design in exhibition spaces mainly revolves around illuminance, CCT and CRI in exhibition lighting. Their usage in the field by lighting designers, the relation between each other and the recommended values are explained in this section. Effects of these parameters on human perception are discussed.

2.1.2.1. Illuminance

Besides conservational aspects, there is any recommended range for light levels in exhibition lighting though certain studies covers the relation between appearance and illuminance. A satisfactory range is determined in a study which is between 50 and 400 lux. Scoring of quality increased as the illuminance value increased (Cuttle 2007). Another study points out that at least the range of 100-200 lux is needed to perceive the detail of the object. For paintings, minimum 200 lux is needed (Thomson 1986). Illuminance values should be balanced to avoid glare (CIBSE 2002).

2.1.2.2. Correlated Color Temperature

Correlated color temperature is a relative measurement which shows the color appearance of light shown with Kelvin temperature unit. CCT changes with the wavelength spectrum of light. From conservation aspect, CCT is only used to set the limit of UV radiation since cold temperatures, high CCTs, have higher UV values. Lower CCTs are preferred to minimize the damage (Thomson 1986).

The visual effect of color temperature is mostly ignored in practice though many lighting designers in museums support the idea of unbiased view of exhibition which CCT and CRI are not distorted to have a more appealing or dramatic effect. Some of them acknowledges the enhancing impact of lighting effects on overall exhibition experience, though they consider this as another field that needs a meticulous approach with high level of expertise (Garside et al 2017).

Color appearance of light is a popular research topic. Relation between light damage and CCT is explored in a study by Piccablotto et al. (2015). It is suggested that amount of UV may change with in different light sources even CCT is higher. CCT and light damage is not consistent. The study explicitly focused on the effect of material and light behavior on damage factor. Two types of material with various colors are tested under various CCTs. Materials are exposed to excessive amount of light (to have a better curve) for long and short terms. It is found out that cumulative light exposure give different outputs so accelerated aging method must be investigated. Also, it is found out that wool fades faster in lower CCTs while silk fades faster in high CCTs. The key factor in the results is the difference between LED and traditional lamps. The results show that impulse to avoid high CCTs is not always right while using LED. Study also showed the strength LED in balancing visual quality and preservation. Also, LED showed a lower risk damage compared to other light sources (Piccablotto et al 2015). Another study also reached to the same outcome (Ajmat et al. 2011).

2.1.2.3. The Relation between Illuminance and CCT

In 1941, Kruitrof studied the relation between CCT and illuminance and their effect on human perception. He used fluorescent and incandescent lamps in his study. The curve determines an area as pleasing. Overall, the range of "pleasing" increases as the illuminance value increases. When the illuminance values are set between "acceptable" levels of exhibiting standards, CCT should be between 2700 and 4000K. The CCT below 3300K is considered as warm. Between 3300 and 5300K is considered as intermediate and above 5300K is considered as cold (European Standards 2002). Regarding this, CCTs in interiors like exhibition spaces should be warm or intermediate to be pleasing. However, there were some objections on the curve over the years that it may change with different the task or LED's performance (Luo et al. 2016).

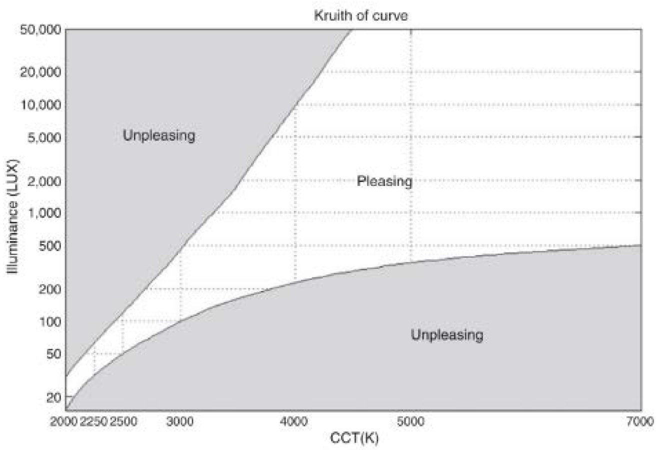

Figure 2.3. Kruitrof Curve (Source: Luo et al. 2016)

2.1.2.4. Color Rendering Index

Color rendering is an important factor in visual quality to see lighting's ability on color appearance. CIE set an index by comparing rendering quality of the light source to ideal daylight which is the highest score as 100. Although, this index is highly criticized due to its complex calculation method and adaptive factor of the human eye to perceive color appearance (Thomson 1986). Regardless the accuracy of this index, light sources which have 80 or higher CRI values are considered suitable in exhibition lighting. LED lamps mostly satisfy this threshold (Graaf, Dessousky and Müller 2014). However, color rendering index is not enough to assess the quality of lighting in color appearance. Many researches highlighted the effect of illuminance and color temperature in color rendering quality.

2.1.3. Role of Lighting

There is no particular start point for exhibiting art and exhibition lighting, art is already exhibited during its creation process to its artist. Rembrandt was used to place his paintings next to a north-facing large window to have diffused daylight on his work. Many other painters developed their daylight control system in their working area with sheets both to block and reflect daylight (Cuttle 2007). There was already a personal conscience of the artist on lighting. In 18th century, exhibiting art started to evolve with private art collections and later with national art galleries (Klonk 2009). This time, multiple perspectives started to get involved. All these consciences developed before the introduction of electricity while lighting is provided with daylight. Even with a limited aspect, solutions and techniques had been developed at that time to display the artwork properly. For example, paintings were usually placed with a downwards tint to prevent glare and reflection.

Over time, lighting's role changed with the growth of knowledge. New concerns appeared in mid-20th century (Cuttle 2007) such as conservation. ICOM (2007) summarized the role of lighting as conserving, researching, communicating and exhibiting the heritage of humanity. Nowadays, museums and galleries are monumental spaces with ambitious designs. Even the sustainability is considered as a required goal both in architectural and lighting design (Perez-Lombard, Ortiz and Pout 2008).

In the Lighting Handbook (2017), lighting's role in interior is explained in three aspects which are visual functioning, biological and emotional affects. Firstly, lighting design has to provide visual comfort and safety with adequate illuminance and zero glare. Secondly, interior spaces need to be adapted to our biological rhythm with lighting. The first two aspects are similar with what CIBSE (2002) suggests in lighting of interior spaces which are increase in the ability to see, increase in the working efficiency, maintaining visual health and comfort of the user, making the space adequate to function and decrease in accidents are expected in the lighting design.

Philosophy of expression is recently introduced with LED as a concern in lighting design. Un-biased or artistic approach in lighting design are considered as the ways of expressing the art which can change the whole exhibition perception. On the other hand, perception does not only rely on the expression but also relies on the impression. In this sense, there is one more aspect which is the response of the user on the impression of the lighting. However, the respond can be also obtained with behavior. In museums, there are several behaviors that the user can show and one of them is the navigation choices throughout the exhibition (Forrest 2014). Lighting can be evaluated with navigation choices so does the navigation of the exhibition area can be designed with lighting.

With the development, role of lighting in museums and galleries can be summarized in these aspects:

- Conservation of the object
- Displaying and expressing the object
- Safety and visual comfort
- Sustainability
- User behavior: navigation through exhibition

2.1.3.1. Conservation of the Object

The degrading effects of light on paintings or other display objects have been acknowledged since 17th century. Before 20th century, some minor retrofitting like glass filters were applied to prevent damage. Light is a radiant energy so changes material chemically. It causes irreversible fading in pigmentation, drying and cracking in materials (Druzik and Eshoj 2007). Multiple parameters contribute the damage effect directly: color temperature, light source, illuminance, exposure duration and used materials. Therefore, balancing between these parameters is an effective way to conserve the object.

Color temperature and Light Source

Light is also examined in three ranges of the spectrum: UV, visible light and infrared. Contrary to common misunderstanding, damaging effects of light are not concentrated in UV range. Filtering UV light energy is an easy choice since the invisible energy is not needed. In infrared range, heat damage becomes a problem. Though infrared range is not common in the used light sources and filtering the infrared is still an option. Still, UV factors overshadows the damage effect of infrared and visible light in many cases (Thomson 1986, Ajmat et al 2011).

Illuminance and Exposure Duration

Illuminance is also seen as a critical component in preservation. Fundamentally, illuminance values are set between 50 and 200 lux for sensitive materials focusing visual quality (Zaag 2017; Kaya and Afacan 2017). Although, illuminance values may extend due to many factors regarding displayed object and the visitors' visual impairment. Since single illuminance values is not enough for these multiple factors, a scale is used. Starting with 20 lux (distinction of faces), each time the value should be increased to its 1.5x amount for further needing in illuminance (CIBSE 2002).

Additionally, it is unhealthy and unpractical to simplify the cause light damage to as illuminance values (Druzik and Eshoj 2007). It is recommended to use annual exhibition time of exposure values when considering light damage (Ajmat et al. 2011). Recommended annual exposure values varies between 15,000 and 600,000 lux hours regarding object's sensitivity. For example, moderately sensitive object can be lit with 200 lux up 8 hours (Cuttle 2007). This method can be used in the optimization of preservation and visual quality.

Material Behavior

In terms of preservation, it is important to not rely on simple correlations between just two parameters. Many recent studies highlight that each material and color pigmentation behave differently to light components (Piccablotto et al 2015). Even case-by case approach might be needed to configure lighting since environmental history of the material can alter the behavior too. Lighting should be determined by regarding material's responsiveness to light (Cuttle 2007).

Table 2.1. Material classifications on illuminance (Source: Cuttle 2007)

Material responsiveness classification	Limiting illuminance (lx)	Limiting exposure (lxh/y)
R0. Non-responsive	no limit	no limit
R1. Slightly responsive	200	600000
R2. Moderately responsive	50	150000
R3. Highly responsive	50	15000

2.1.3.2. Displaying & Expressing the Object

The visual assessment of both object and light ends with how people see it. Therefore, displaying or expressing the object are primary concerns in lighting design. There are different approaches to this issue.

Beyond providing the adequate visibility and sustaining the conservation of the displayed object with lighting, the visitors anticipate to see objects truest representation, the time of its creation or its artistic meaning behind it (Cuttle 2007). Since any of them can be an impactful purpose for the exhibition, there is a dilemma between artistic and true expression when approaching lighting. Just like many other concerns about lighting, there are different approaches of the disciplines to this issue. The first option is honest and unbiased displaying by preferring neutral CCTs and high color renderings. Overall, this approach is preferred among many museum staff who are mostly focused on conservation. On the other hand, light manipulation may be needed in some cases to compose a theme between objects while compromising conservation or even visibility (Cuttle 2007). In this option, CCT and CRI can be manipulated to create interesting atmosphere in which color fidelity is distorted. Light effects are mostly seen as creativity issue thus handled by exterior lighting designer or architects (Garside 2017; Kim and Chung 2011).

In the end, whether the aim is to bring out the "truest form", every lighting design creates a different experience therefore all can be considered as light effects. Although, a little attention has been given to understand the pattern, reasons and the techniques behind it. Foremost, they can be used to set exhibition purpose and the atmosphere that should inspire the viewers (Leccese et al 2018). Color rendering can be discussed to understand the impact of light effects. Another option is to capture similar conditions where object was created.

A little attention has also been given to the psychological impact of displaying choices. Although, there are some studies and methods cover the relation between lighting/object parameters with human perception and preference. Monza is a lighting method acknowledged by many lighting designers for many years in a basic way with different names such as "three-dimensional lighting". With the recent introduction of LED in museum and gallery lighting, it has been studied by the architects Francesco Iannone and Serena Tellini. LED's high spectral quality encouraged lighting designers and researches to aim higher standards. Ongoing problems in artwork lighting like different behavior of pigments is handled again with the method. Design process even involves "Neuroaesthetics" which uses neuroscience to understand art ("Museum Lighting Workshop" 2014). In a way, artwork-based lighting design focus shifted to perception. It encourages lighting designer to acknowledge visitors' perception.

Figure 2.4. Monza Method application (Source: Iannone 2017)

One of the starting points is that the perception and existence of neutral light. Researchers claim that neutrality never existed in reality and the imperfected neutrality of nature must be aimed to connect with the past. It aims to represent the most neutral form of the artwork and its creation process. The method is mainly associated with artifacts, old buildings and artwork since one of the goals is to bring out the authenticity of the time period. The method got the recognition and its name with the lighting design of San Maurizio Church in Monza. One of the principles is to analyze the concept of the artwork and design the lighting integrated with the context.

The method basically uses various types of lighting elements differentiating in type, color temperature, intensity, beam range and focal points to create an “immersive” composition. Multiple focus points layer the perception, work harmoniously with the complexion of brain and the details. Lighting is constantly played to create alternatives so the process heavily relies on testing or in other words, trial-and-error method. It aims to revive dynamic characteristic of lighting which ironically lost with the technology (introduction of artificial light) over time. It can bring out the circadian rhythm, seasonal effect, fractality of daylighting. New technologies like LED allow the flexibility to it. This method also tests the needs of better lighting solutions by observing lighting configurations so it is considered as a continuous work (Iannone 2017).

A study by Leccese et al. (2018) used this method to evaluate multiple configurations of LED spotlights on two historical paintings in National Museum of San Matteo The relation between human perception and physical measurements such as color temperature of lamps, their illuminance and luminance values are analyzed. For each configuration, various types of spotlights are combined while one configuration contained two color temperatures (3000 and 4000 K). The significance of this evaluation is that physical measurements are taken from multiple points on paintings to detect focal points where observers can perceive the “enhancement” and better visual quality. Some of these points are located outside of the painting to understand relation between painting and its background. Results show that higher illuminance values and uniformity enhances the quality along with warmer color temperature (Leccese et al. 2018).

Figure 2.5. Monza Method configurations (Source: Feltrin et al)

2.1.3.3. Safety and Visual Comfort of the User

The illuminance values in museums and galleries differ from other spaces for many reasons. The lighting is mostly evaluated with the impact on the object or the subjective appreciation of the visual outcome. Even it is not the displaying and conserving concerns, one of the biggest differences is that the general illuminance is measured to be evaluated since there is no particular task area throughout the exhibition. Therefore, general illuminance must be sufficient for safety reasons.

When the object's material sensitivity is high, the illuminance values could be extremely low, barely visible for regular vision. Lighting designer must consider visual impairment of the visitor especially for ageing reasons. In elderly people, light transmission through eye decrease dramatically which can cause loss in vision. Visitors are mostly mobile in exhibition areas so loss in the vision could be dangerous for elderly visitors and others around them. Also, it is a requirement to provide safe movement in exhibition areas. Therefore, extreme illuminance values could be avoided if the safety is a vital concern for the exhibition. An elderly visitor could need three times the existing brightness level to have the same experience Beyond safety and visual comfort of the visitors, visual quality of the exhibition can only be appreciated fully by providing visual appearance to a range of people including elderly. A good balance between these aspects can be achieved with adjusting different illuminance levels on floor and object surfaces, creating adaptation zones to different illuminance values with light direction, ambient light, different surfaces (CIBSE 2002; Cuttle 2007).

2.1.3.4. Sustainability

All around the world, buildings consume 20 to 40% of the total energy and the growing trend continues each year. Even in current growth, energy demand must be controlled to preserve the resources and prevent further environmental damage. Economically developed countries need more energy in all types including the service sector buildings. The service sector buildings like museum and galleries usually aim for the ambitious environments. Various types of high-quality and high energy-consuming equipment are needed to maintain the expected interior environment and digital building systems along with the non-compromising strategy of thermal and visual comfort (Perez-Lombard, Ortiz and Pout 2008). As the expectation increases, the energy demand for artificial light keeps increasing by making almost 19% of the energy consumption (Almeida 2014). Therefore, a sustainable strategy is needed.

Although, sustainability has one more meaning than energy efficiency in museums and galleries which is object conservation of light damage. Daylight is the ultimate solution for energy savings though daylight itself and some of its fixed controlling systems cannot meet the conservation requirements with high exposure of light. However, application of automatic control systems for both daylight and artificial light are the ways to balance energy and conservation requirements effectively. Nowadays, sustainability concerns are more apparent in the design process of the building (Graaf, Dessousky and Müller 2014).

Above all the possibilities and solutions, the best possible lighting is usually aimed for art's sake and most of the time their energy consumption is overlooked. One of the energy efficient solutions which is acknowledged by the museum and gallery community is LED lamps. Even it is a secondary concern, these buildings are not an exception to not adapt the energy saving concept. Though there are some hesitations and prejudgment to these new technologies. Many museums prefer to not sacrifice lighting quality for energy efficiency. Some of them are also skeptic of LEDs' long-term effects on objects in terms of lighting since it has not been tested. High cost of LED lamps is another reason for the hesitancy (Garside et al. 2017).

2.1.3.5. Navigation through the Exhibition

A place is experienced by moving through them (Cullen 2015). Light creates zones, in other words "bubbles", by descending into interior space in spherical forms. These places are perceived as either defined spaces or transition areas. Various types of light, even only the elements in daylight itself (eg. placement of openings) can create a series of light-zones. Madsen analyzed light zones in several cases. In the analysis of foyer in Le Corbusier's apartment, foyer differentiates in light source which is daylight and illuminance level from other spaces. Combination of these places works as a "shadow zone" which motivates people to move (Madsen 2007).

In exhibition spaces, wayfinding is especially important to allow visitors to plan their route through the exhibition easily. It can help visitors to adapt to the space and focus more on exhibition (Hidayetoğlu, Yıldırım and Akalın 2012). Wayfinding can be provided by using architecture and objects such as distinctive pathways or landmarks but "environmental cues" is another way to achieve it (Blake 2011). There is no comprehensive research about the impact of lighting on navigation in exhibitions though studies about general lighting or retail lighting can be referenced. In an experiment, lighting is used as an environmental cue. Results show that people have a tendency to choose "right" when moving through the same conditions though when the left side is brighter, people leave their tendency significantly (Taylor and Socov 1974). In other words, people move towards light.

In retail lighting, there should be focus and relief points in order to not exhaust visitors with constant attention (Yılmaz 2018). Same effect could be discussed in museums and galleries. In terms of lighting, space should not be monotonous and constantly dense. Dividing exhibition into parts with transition areas like foyers, corridors and circulation areas which lit differently is a common way to achieve it (Good Lighting for Museums 2007). Daylight can be useful to break the maze effect and to guide the visitor. Characteristics of daylight, visual connection to surroundings and revelation of form can create the in-and-out dynamism (Kim and Chung 2011). Relation between different light zones should be planned carefully. Cuttle proposed a scheme to plan the sequence of these zones regarding parameters like material responsivity and light type (Cuttle 2007).

2.2. Practice of Exhibition Lighting

Field application is the key point to understand problems regarding museum and gallery lighting. A recent study by Garside et al. investigated qualitative reasons behind the decisions in lighting design. Twelve museum representatives are interviewed with semi structured questions to understand the field of museum lighting: how guidebooks, recent research and developments affect the practice. Answers showed that, there are multiple steps museum staff usually go through when finding appropriate lighting. The first step is to meet several objective parameters such as setting lux exposure and UV values to recommended values since controlling the damage potential of lighting on objects is a priority. Still, some of the parameters such as CCT or CRI, their recommended values and arguable damage impact are overlooked (Garside et al 2017).

2.2.1. Standards versus Field Application

In terms of conservation, there were attempts of establishing standards in lighting in 1950s (Thomson 1986). Although, the first extensive books were published in 1980s, like the most popular, Thomson's comprehensive guide, "The Museum Environment". A recent survey shows that "Guidelines for Selecting SSL for Museums" by Druzik & Michalski; IES and CIE's museum guides are also the most followed.

Table 2.2. Summary of exhibition lighting issues and relevant literature (Source: Kesner 1997)

Exhibition Lighting Issue	Relevant Literature Title, Year
Occupant Comfort	1) deBoer & Fischer, 1981 2) Egan, 1983 3) Moreno, 1989 **4) Thomson, 1986**
Artifact Appearance and Detail Visibility	1) Berns & Grum, 1987 2) Feller, 1964 3) Judd, 1967 4) Kaufman & Christensen, 1989 5) Loe, Rowlands, & Watson,1982 6) Thomson & Staniforth, 1985 7) Thornton, 1972, 1974
Visual Quality	1) deBoer & Fischer, 1981 2) Egan, 1983 3) Flynn, Segil, & Steffy, 1988 **4) Thomson, 1986**
Artifact Preservation	1) Kaufman, 1987 **2) Thomson, 1986** 3) Weintraub & Anson, 1990
Electrical lighting System	1) Chartered Institution of Building Services, 1980 2) Kaufman, 1987 **3) Thomson, 1986** 4) Thornton, Chen, Morton, & Rachko, 1980
Daylighting System Quality	1) Egan, 1983 2) Lam, 1986 3) Robbins, 1986 **4) Thomson, 1986**

The problem museum staff faces mostly with recommendations and studies is to catch up with improvements; they find existing solutions such as conferences and workshops useful not new studies (Garside et al. 2017). Same problem appears with the usage of LED lamps. Since it is a new technology, interviewees are not sure about the long-term effects on materials. A broad survey also showed similar results. Despite this uncertainty, they are encouraged to use LEDs for energy efficiency (Perrin et al. 2014).

2.2.2. Case by Case Approach

In the study of Garside et al. (2007), almost all interviewees claimed to approach case by case to each object lighting after meeting fundamental requirements. Final appearance of lighting is mostly determined with the collective opinions of employees in exhibition spaces. All of these employees claimed to be specialized in one aspect which also ensures to meet requirements. In this approach, if the main aim is to capture the best appearance of object with lighting, the strategy is to conduct a visual test for all lighting options includes different lamp types, brands, color temperature, etc. The study concluded with listings of common acknowledgements in museum lighting while highlighting the fact that multi-disciplinary mastery is needed to truly improve museum lighting. Every exhibition space and object are unique but field work is the best way to understand it (Garside et al 2017).

2.2.3. Simulation Approach

Simulation is an effective way to understand the behavior of light, especially daylight. It enables to test numerous scenarios virtually. Nowadays, either it is a new design or a retrofitting project, simulation data is expected during the design process. Daylight, artificial light performance and various lighting techniques, visualization, object sensitivity, energy consumption, and cost can be simulated with various methods and software.

Enhancing simulation tools is a popular research topic in environmental control. In a research, daylight performances of various skylight types are evaluated via daylight simulation software Radiance. Beyond optimizing and detecting effective parameters in daylight, research investigates the effectiveness of software along with the process of daylighting simulation integrated architecture. Measurements of scale model and simulation model are used calculate a “correction factor” to calibrate the simulation when testing skylight scenarios. It is found out that monitor-shaped and sawtooth-shaped skylights have a better daylight performance compared to existing pyramid-shaped skylight. Strengths and optimum dimensions of these skylight types are also mentioned (Kim and Chung 2011).

A study in 2007 commented on the future of the museum lighting by analyzing its development over the years along with reviewing the problems which are highlighted in recent studies. It questions standard parameters and their inconsistent outcomes and the application in the field. Limitations in parameters like illuminance must be corrected including advanced parameters like surface reflectance, exposure time, amount of object detail, material and observer age. Study points that construction of a communal approach is increasingly needed in current status. It addresses a study which calls for a heuristic model in museum lighting (Druzik and Eshoj 2007).

CHAPTER 3

THE METHODOLOGY

3.1. Modelling the Questionnaire Visuals

Since there are multiple objectives in the study, multiple sample visuals were needed. Participants were expected to state their choices between different options and evaluate the determined points in each visual. For each step of the questionnaire, three different programs were used for different needs. In the first step, exhibition model was visualized in Lumion. Although similar processes happened, 3DMax and Relux were used respectively for the second and third steps of the questionnaire.

3.1.1. Navigating Through a Virtual Exhibition

A series of virtual exhibition rooms were planned to figure out effecting factors in participants' navigation preference. Although the main objective is to see the distinction between daylight and artificial light impacts on navigation, different lighting and room settings were also included to detect the driving factors to choose between these two light sources such as exhibition type, size, window type and room function (exhibition or transition).

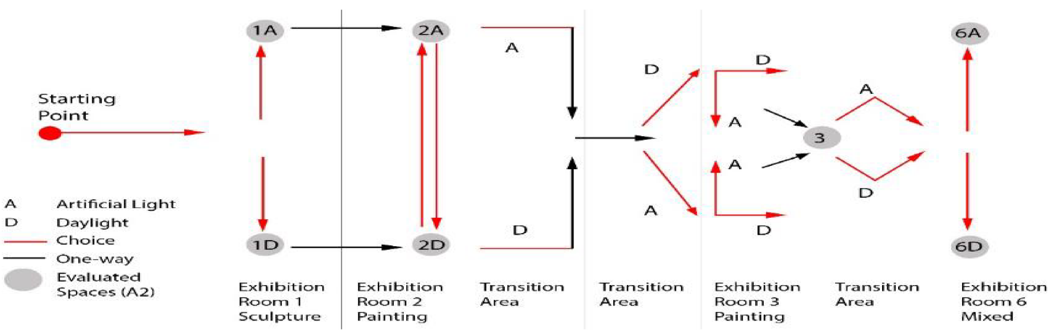

Figure 3.1. Diagram of the space composition

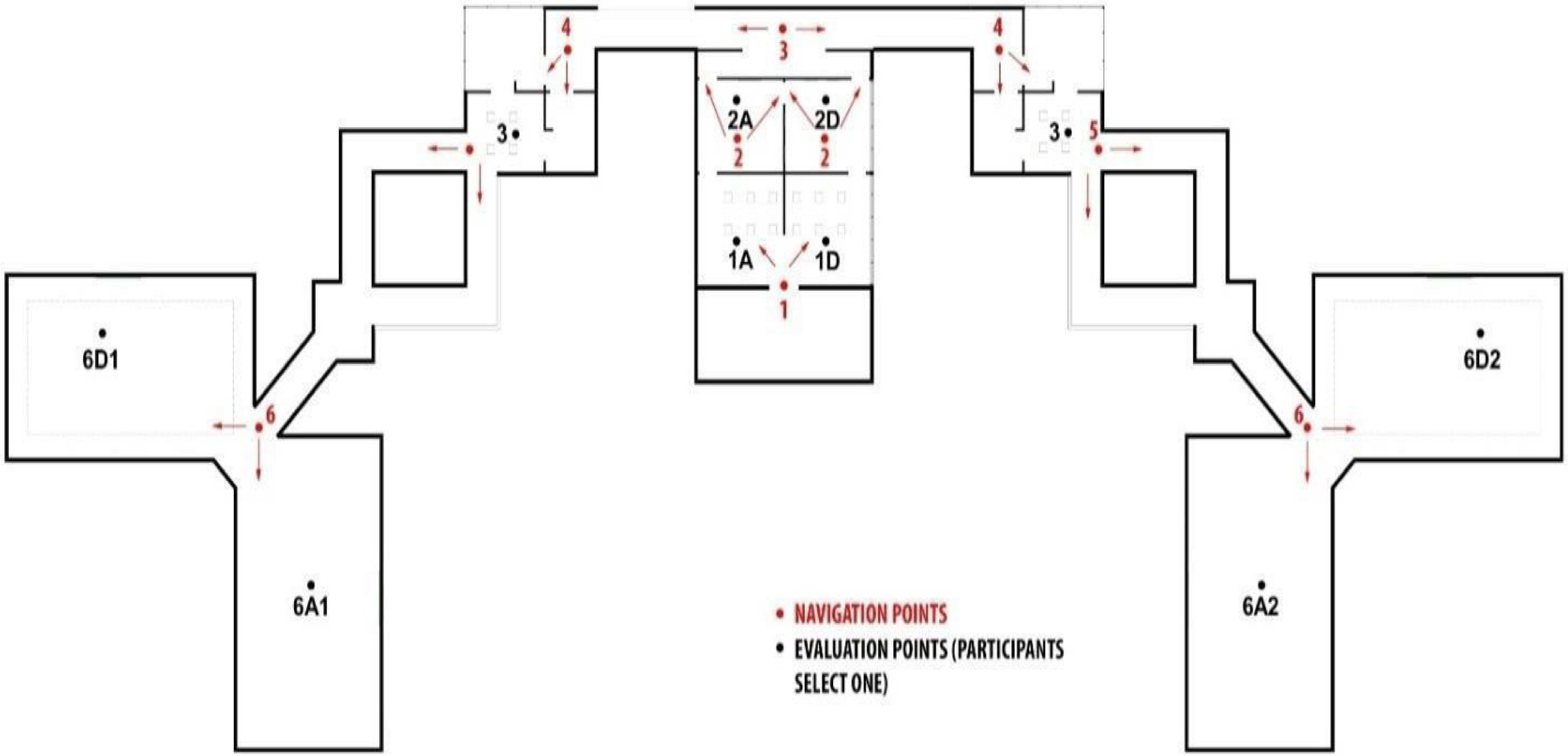

Figure 3.2. Plan of the exhibition space

To see the consistency in choices and the impact of the stated factors, multiple steps were needed. Different exhibition spaces and transition areas were brought together to generate 6 steps of choices (Figure 3.1). Except the type of the light source, identical exhibition rooms were placed next to each other as a choice to see clear results in each step. Participants were expected choose one room to continue with when they reach these navigation points. A group of 7 rooms were selected which participants were expected to pick one and evaluate after the tour. Selected rooms were classified according to the objectives (Table 3.1).

Table 3.1. Classification of the Evaluated Rooms

Exhibition Spaces	Space Dimensions	Meter Square	Exhibition Type	Light Source
1A 1D	Medium	34	Sculpture	Artificial Daylight
2A 2D	Medium	30	Painting	Artificial Daylight
3	Small	20	Sculpture	Both
6A 6D	Large	150	Both	Artificial Daylight

Figure 3.3. (a) A view of a window, (b) a skylight in a museum (Source: Cuttle 2007)

A model was prepared in ArchiCAD software. The plan of the whole exhibition area formed like symmetrical branches, showed the combination of the navigation choices (Figure 3.2). Transition areas like corridors were also used to locate navigation choice points in red: 1, 2, 3, 4, 5, and 6 apart from splitting the areas. The evaluation areas were marked in black in the plan. The ceiling height is kept 4.2 m in every room. To understand the impact of opening, different types and dimension of windows were applied. Except the skylight in room 6D all windows openings are same which an example is used (Figure 3.3 (a)).

After designing process, the model was imported into real-time visualization software Lumion 6.0 to navigate the participant through the model. It must be noted that as solely architectural visualization software, Lumion is not validated for lighting simulation and calculations. Adjusting lighting parameters in their units and obtaining lighting values had to be disregarded to provide movement. Although, brightness, beam angle, color temperature levels can be adjusted. All spotlights had the same color temperature, brightness and beam angle (Figure 3.4). Despite these limitations, the main reason why Lumion is used is to allow movement inside the model while the software is visualizing the model.

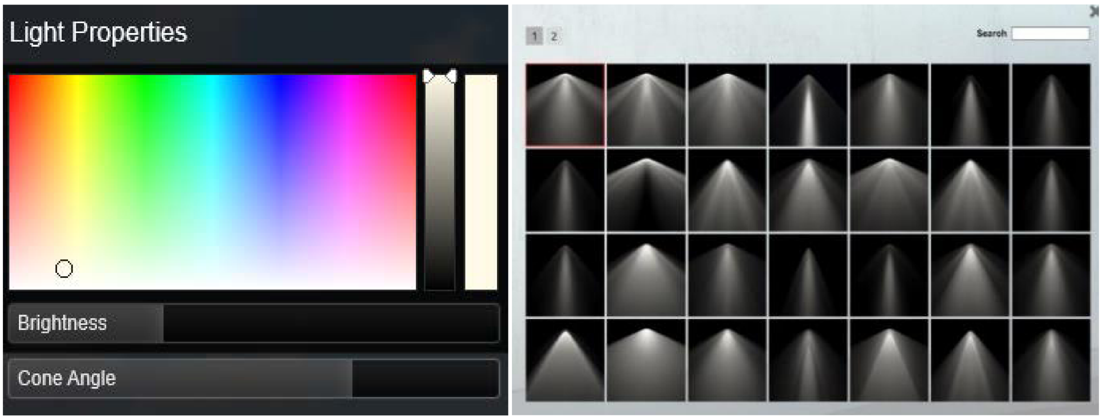

Figure 3.4. Lighting settings in Lumion

Sculptures and paintings were added into the model also in Lumion. Spotlights were mounted to illuminate determined areas artificially and these areas were labelled with “A” in the classification table. Clear sunlight was adjusted in daylit areas which were labelled with “D”. Single orientation of sun is kept through the exhibition. Direct sunlight is controlled with shading elements. In exhibition space 6D, ceiling material was illuminated to generate skylight effect.

Since Lumion is not designed for lighting simulations but simply visualizing 3D environments, visual fidelity is needed to be tested. A question was added to the first part of the questionnaire just to see the reliability of the software for this study. In a 1 to 5 Likert scale question, participants were asked to address the light source in their evaluated room. Results are shown in the shown in the Table 4.5 discussed in section 4.1.3. It was found that Lumion's lighting rendering is reliable for this study.

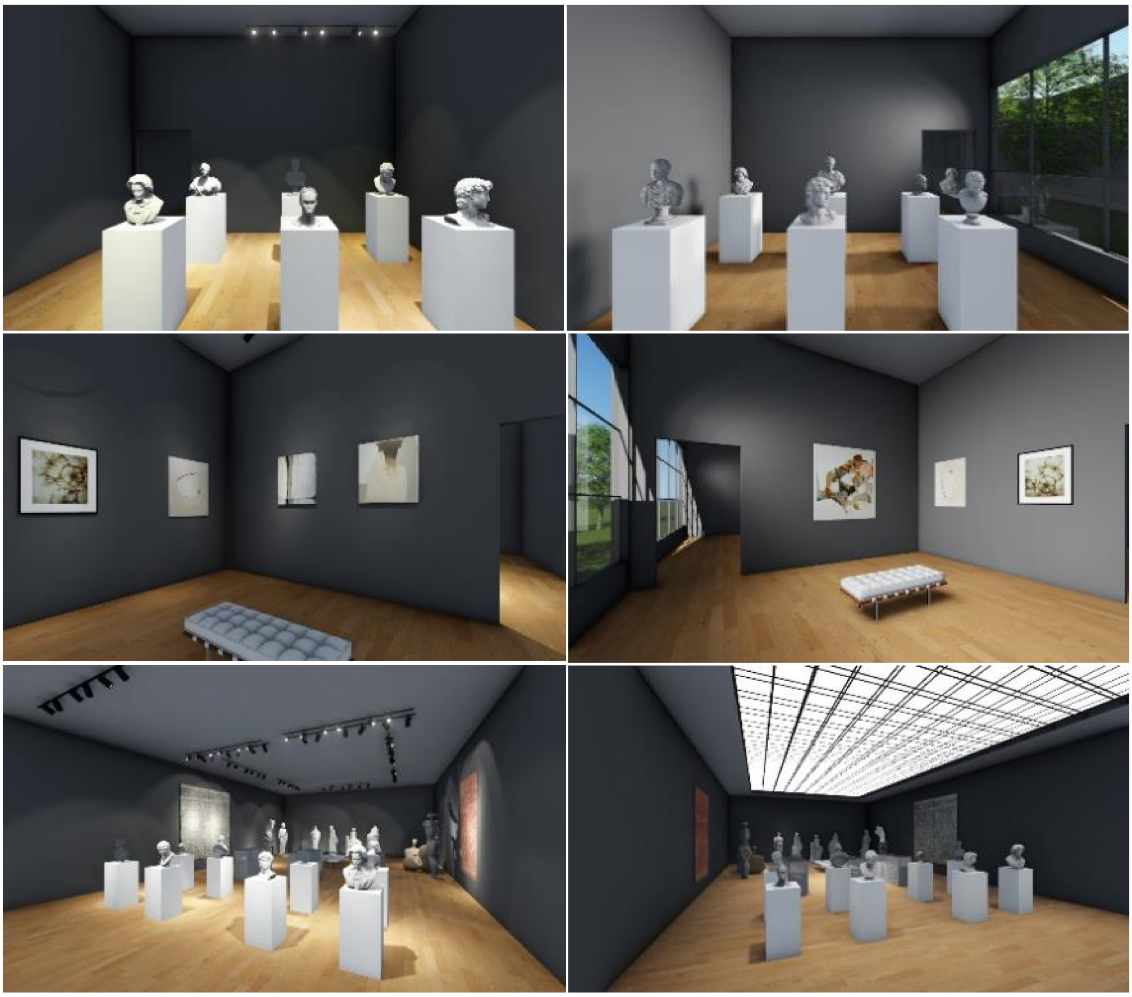

Figure 3.5. From above to below and left to right 1A-1D, 2A-2D, 6A-6D

3.1.2. Virtual Models for Painting and Sculpture Exhibition

Two different exhibition rooms were modelled to see the relation between user preferences and lighting parameters which are color temperature and light type. These two exhibitions rooms determined as painting and sculpture rooms to see the factor of exhibition type on user impressions. In the painting room, 3DMax was preferred to apply painting as textures easily. Relux was preferred in the sculpture room. Similar processes happened when modelling in 3DMax and Relux. Relux is specifically designed to simulate artificial light and daylight and obtain lighting values easily. Nevertheless, both programs allow importing photometry information, adjusting lighting parameters in units and calculating illuminance values when modelling. Both programs were found sufficient enough to continue the study.

Base models were designed for each room which room dimensions, materials, objects and camera angles were set. Later, 3 different lighting configurations for each exhibition type were placed separately to the base models. Since the both object types, painting and sculpture, need different lighting, different lighting configurations were determined.

Table 3.2. Diagrams of 9 renders for painting and sculpture room respectively

		LIGHTING SETTING		
		1	2	3
COLOR TEMPERATURE	warm	1 -Single Spotlight 3000k	2 -Multi Spotlight 3000k	3 - Ambient 3000k
	neutral	4 -Single Spotlight 4000k	5 -Multi Spotlight 4000k	6 - Ambient 4000k
	cold	7 -Single Spotlight 5500k	8 -Multi Spotlight 5500k	9 - Ambient 5500k

		LIGHTING SETTING		
		1	2	3
COLOR TEMPERATURE	warm	1 -Additional Spotlight on Background 3000k	2 - Spotlight on Object 3000k	3 - Ambient 3000k
	neutral	4 -Additional Spotlight on Background 4000k	5 - Spotlight on Object 4000k	6 - Ambient 4000k
	cold	7 -Additional Spotlight on Background 5500k	8 - Spotlight on Object 5500k	9 - Ambient 5500k

Lighting calculations were made in each model to have accurate exhibition environment. Illuminance values were kept between 50-300 lux on objects. After the illuminance, four color temperatures which are 3000, 4000, 4500 and 5500 Kelvin were set in each lighting configuration. Later, elimination between 4000K and 45000K was made since they are close. For the questionnaire, 3000, 4000, 5500K lights were selected as warm, neutral and cold light settings respectively. A total of 9 renders were gathered for each exhibition type. All visuals were obtained as HDR outputs in both of the models.

3DMax

In the 3DMax base model, an exhibition room with the dimensions of 10x4 m and 3m height was made. Reflectance values of floor, walls and ceiling were determined as 0.5, 0.9 and 0.9 respectively. A set of five paintings with similar style, colors and dimensions were placed on three walls that are in view. Camera was located 8 m away from its counter wall and its height set 1.7 m above from the ground. After completing the base model, three lighting settings were applied. The first lighting configuration is single spotlight on each painting. Actual lighting was used in each setup by importing their photometry information. Zumtobel LED-Spot Arc 3's was selected in spotlights. The second lighting configuration is multiple spotlights on each painting which was applied by following "Monza Method". Zumtobel's Arcos 3 Xpert LED light was selected. Different color temperatures were set for spotlights which are focusing different parts around the painting frame.

A 500 Kelvin range was determined to have different color temperatures. 3500, 4500, 5000 K secondary lights were used with 3000, 4000, and 5500 K respectively. Although the ambient lighting is generally not used in exhibitions, it was added as the third configuration to see the distinction from spotlight and its behavior with different color temperatures. For the last setting, Zumtobel's Light Fields Evolution light was used. Intensity in each lighting setting was adjusted in accordance with calculations. After applying lighting on the base model, renders are obtained via Mental Ray calculation.

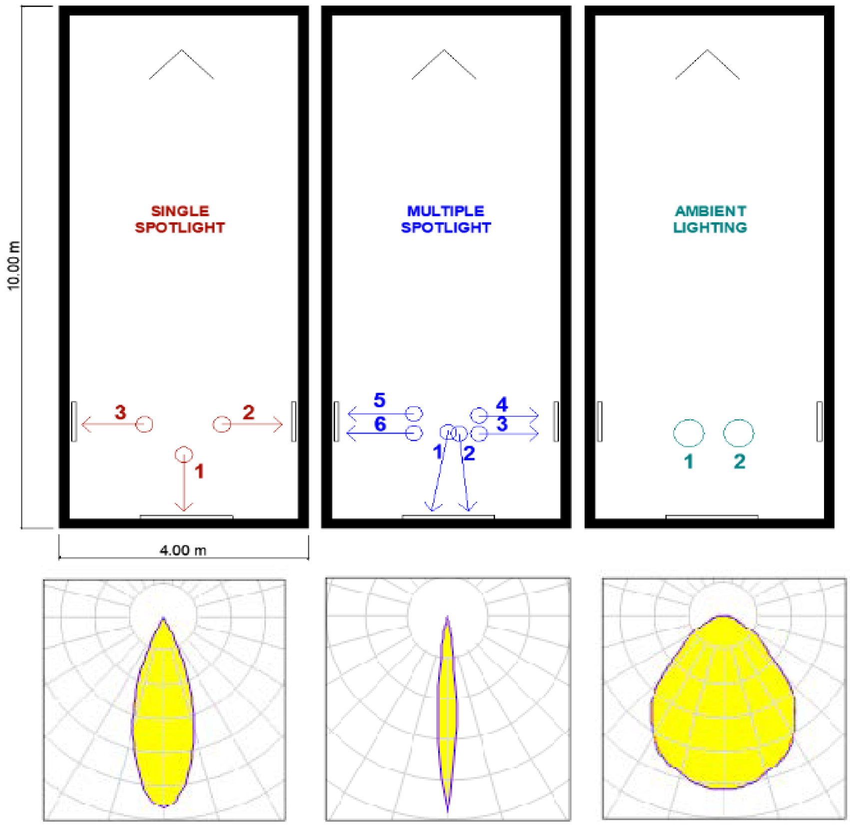

Figure 3.6. Drawings and distribution of each light setting respectively

Relux

In the Relux base model, sculptures were placed into a room with the dimensions 6x3.5m and 3 m ceiling height. Reflectance values of floor, walls and ceiling were determined as 0.5, 0.9 and 0.9 respectively. A total of 5 plinths were placed in u-shape into the room as a base for the busts. The dimensions of these plinths were determined as 0.8x0.8 m with a 1.1 m height. Reflectance value of their surface is 0.9. A different set of lighting settings from the painting room were applied to the base model since lighting behaves differently with 3D objects. Illuminance was tracked with light meters which were set on working plane and walls.

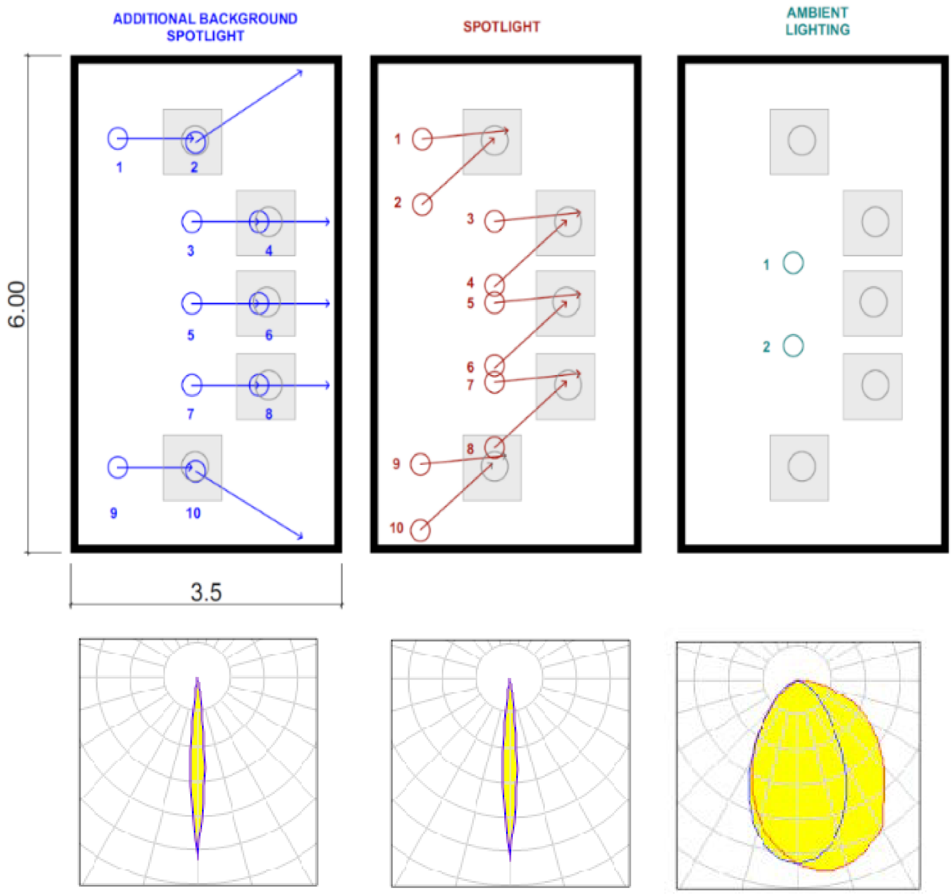

Figure 3.7. Drawings and distribution of each light setting respectively

The first setting contains 10 spotlights, two for each bust. One of them is directed at the bust while the second one is directed at wall behind each bust. This is one of the lighting methods to define space around the object (Cuttle 2007). Similarly, two lights for each bust were determined in the second configuration. This time both lights were directed to the bust from different angles. Zumtobel's Supersytem II LED Spot midi lights were selected for the first two settings. Ambient lighting was determined for the last setting. Zumtobel Basys LED II was picked. When visualizing, only artificial light was calculated via Raytracing.

Figure 3.8. Visuals of the questionnaire for the second and third parts respectively

3.2. Questionnaire

3.2.1. Questions and the Procedure

A three-part questionnaire was prepared in accordance with the models. Each part is labelled with a letter to group their questions in the questionnaire. In the first question of the first part, participants were asked to move towards between two similar exhibition areas by stating their choice as "left" or "right" and camera inside the model moved towards either daylit or artificially lit of the same exhibition area. This process is repeated 6 times. The participants were kept uninformed about the intention of the study to maintain intuitional navigation choices throughout the question. Their direction response data were entered as 1 and 2 for artificial and natural light respectively for statistical analysis.

Figure 3.9. A view from navigation choice point

In the second question of the first part, participants were asked to select their favorite exhibition space and continue to answer Likert scale questions based on 11 criteria for this space. Likert scale was set between 1 and 5 through the whole questionnaire. In the first Likert-scale question, recognition of light source is asked to see the visual fidelity of the Lumion software. In the questions between 2 and 9, participants are asked to evaluate both displaying and the space of the exhibition. Since human perception is deceiving when evaluating color temperature (Zaag 2017), question 10 was put deliberately to find a relation between room and light parameters on color temperature perception. Lastly, question 11 is put to measure the level of preference of evaluated spaces. At the end of these questions, participants were asked to pick 3 important questions to assess lighting in the last question.

For the second and third part of the questionnaire, participants were asked 5 questions each. In the first questions B1 and C1 for each part, participants picked one setting from each column out of 9 setting which is displayed full-screen. They have been informed that they could pick them for any reason since the catchiness is tested and they would pick the catchy setting intuitively. After selecting the setting, each visual of the setting is displayed full-screen separately by the order of lighting configuration groups. For example, if picked instead of first visual, fourth visual is displayed and evaluated before the second visual. The participants were asked to answer 9 Likert scale questions almost same with the first part for each visual. Only lighting type and catchiness questions were taken out because assessing lighting fidelity and catchiness become redundant with only artificial lighting and the last question. Later, they were asked to pick the setting that they most liked, disliked and found the most interesting out of 9 settings. The format of the questionnaire is inserted in the Appendix section for further examining.

3.2.2. The Participants and the Environment

A total of 90 people around Izmir participated in the questionnaire. Three main occupation groups were determined as participants: 30 architects (including architecture students), 30 artists (sculptors, painters and curators) and 30 visitors (other occupations). Participants were divided into these groups to understand priorities and reasoning in lighting preference in each group. Since the progress of questionnaire is highly individual and interactive due to the choices and controlling of the virtual environment; participants joined the questionnaire one-by-one.

Questionnaire has been done within 3-month period; lighting conditions of the questionnaire environment are included as variables along with personal information and possible visual impairments. 59 women and 31 men participated while 33% of them are between the ages 17-25, 37% are between the ages 26-35 and 30% are between the ages

36 and 75. Average age is determined as 33 years. Out of 90 people, 54 participants had some visual impairment 43 of them use either glasses or lenses for it.

Environmental conditions were also tracked. Overcast sky conditions were observed during 50 questionnaires while 31 and 9 questionnaires were conducted under clear and night sky conditions respectively. Artificial light was present in 58 questionnaires while only daylight was available in 32 questionnaires.

3.3. Statistical Analysis Methods and Planning

Since all questions are structured differently various types of statistical analysis methods such as OLS, ANOVA, T-test, GLM, covariance and correlation are used. These analyses were run in software Minitab, Excel and R. Sometimes, the same data set is analyzed with multiple methods. Analysis for each method is listed numerically:

- Ordinary Least Squares Regression: In this study OLS method is used to figure out the relevance of determined criteria in different exhibition conditions at a 5% level of significance. It must be noted that, one data is eliminated in each analysis to run the method properly.
    1. The significance of each 11 criteria which are asked in A3 in 6 selected spaces (1A, 2A, 1D, 2D, 6A and 6D) which are stated in question A2. Space number 3 is eliminated.
    2. The significance of each 9 criteria which are asked in B2 in the 8 visuals of the painting room. All three evaluations of each participant are gathered to be analyzed under their visual number. Least picked visual is eliminated.
    3. The significance of each 9 criteria which are asked in C2 in the 8 visuals of the painting room. All three evaluations of each participant are grouped in their visual number. Least picked visual is eliminated.
- ANOVA is only used in the first part at a 5% level of significance.
    1. The difference in the navigation choices in each step which is asked in question A1 to find whether there is a significant relation between the steps which differ in room and exhibition parameters.

2. Previous analysis is split into occupation groups (architects, visitors and artists).

- T-test is used five times for five pairings of selected spaces in part A. The difference between each pairing in 11 criteria which is asked in question A3 are analyzed at the 5% level of significance.
- General Linear (Regression) Method is used when a parameter is determined as a factor on some response parameters at a 5% level of significance.
    1. The impact on personal and environmental information which are asked in the end on selection-based questions which are A1, A4, B1, B3, B4, B5, C1, C3, C4 and C5.
    2. Visual quality as the factor on the response of other criteria which are asked in question A3.
    3. A total of 3 analyses where responses to 9 criteria in the painting model (question B2) are grouped into three color temperature groups and analyzed separately (visual 1-2-3 as warm, visual 4-5-6 as neutral, visual 7-8-9 as cold) which lighting setting differentiates as the factor.
    4. A single analysis where responses to 9 criteria in the painting model (question B2) are grouped into three lighting setting and analyzed together which lighting setting differentiates as the factor.
    5. A total of three analyses where responses to 9 criteria in the question B2 are grouped into three light setting groups and analyzed separately (visual 1-4-7, visual 2-5-8, visual 3-6-9) which color temperature differentiates as a factor.
    6. A single analysis where responses to 9 criteria in the painting model (question B2) are grouped into three color temperature groups and analyzed together which color temperature differentiates as the factor.

  GLM analyses 3, 4, 5 and 6 are also applied in sculpture model.
- Pearson Correlation is used to find relation between parameters. The relation increases as the value of correlation coefficient increases. Negative values mean there is an inverse relation.
    1. Between 11. criterion, visual quality, and other criteria which are asked in A3.
    2. Between responses of B1 and B3, B1 and B4, B1 and B5.

3. Between responses of C1 and C3, C1 and C4, C1 and C5.

- Although covariance is similar to correlation, it shows multiple relations of parameters at once. It was used:
  1. Between 11 criteria of question A3.
  2. Between 9 criteria of question B2. All three evaluation groups are gathered as one since their groups are unimportant for this analysis.
  3. Between 9 criteria of question C2.

CHAPTER 4

RESULTS AND ANALYSIS

In this chapter, each step of the questionnaire's results is discussed separately under three sections. Firstly, questionnaire results for virtual exhibition area are analyzed in Section 4.1 In sections 4.2 and 4.3, questionnaire results for painting exhibition visuals and sculpture exhibition visuals are analyzed respectively.

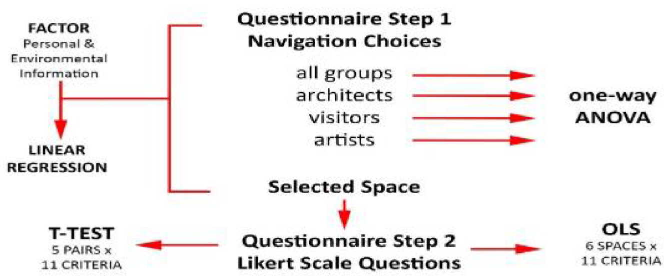

Figure 4.1. Statistical analysis diagram for the first part of the questionnaire

4.1. A Virtual Exhibition Model for Navigation

Results for the first section are analyzed under six sub-sections. For the first question, ANOVA results, percentages, occupation factor of navigation choices are explained. For the second question, the most selected spaces are analyzed with percentages. Later participant and environmental factors are determined according to their navigation choices and space selection. Likert scale responses in the third question are analyzed under three sub-sections. Dual comparisons of exhibition areas are made via T-test in section 4.1.3 to see the relation between room parameters and lighting criteria. In the next chapter, same relation is analyzed with OLS method. Paralleling results of these methods are discussed in the Discussions section. Since visual quality is the primary criteria, its relation with other criteria is explained in section 4.1.5. Lastly, participants' choices on the importance of questions are listed.

4.1.1. Navigation Choices in Exhibition Spaces

Difference in navigation choices are observed in each step though non-lighting factors like space and display positioning should be noted. Possible effects of these factors are explained along with the results. Firstly, means and deviations are shown in figures in Table 4.1. If mean value is closer to 1, preference artificial light is more while from number 1.5 towards 2, preference of natural light increases. Initial analysis shows that participants preferred to move towards artificial light with 51%, 56%, 36%, 44%, 30%, and 43% respectively in 6 steps.

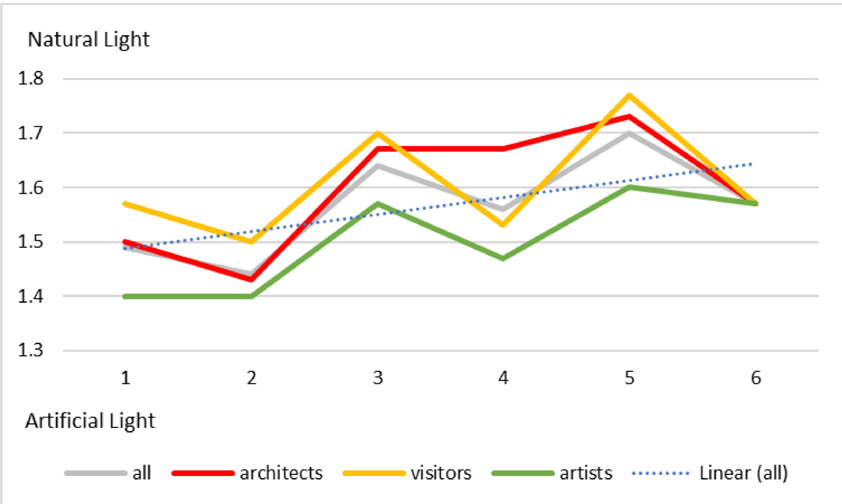

Figure 4.2. Mean graph includes each step and groups separately

Results indicate that participants are almost divided into half in first steps. Some participants stated that they kept certain orientation (right or left) when touring exhibitions to see everything in their own route. Regardless of the factors, it is clear that the tendency to move towards daylight increases when approaching the end of the exhibition by following the trendline in Figure 4.2. This increase can be interpreted as the fatigue by focusing exhibited objects or the different opening type in 6D space. Visual fatigue mostly happens due to using continuous spotlight to abstract the space around the displayed object to attract the visitor (Thomson 1986). This technique consumes the visitor's focus after a while. Focusing has to be relieved to keep the attention (Cuttle 2007).

Table 4.1. Means and standard deviations of each step in the model

Steps	1		2		3		4		5		6	
Choices	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
all	1.49	0.50	1.44	0.50	1.64	0.48	1.56	0.50	1.70	0.46	1.57	0.50
architects	1.50	0.51	1.43	0.50	1.67	0.48	1.67	0.48	1.73	0.45	1.57	0.50
visitors	1.57	0.50	1.50	0.51	1.70	0.47	1.53	0.51	1.77	0.43	1.57	0.50
artists	1.40	0.50	1.40	0.50	1.57	0.50	1.47	0.51	1.60	0.50	1.57	0.50

When the orientation is examined room by room, results show noticeable differences in exhibition types which can be seen clearly in Figure 4.3. Four means (all groups & architects, visitors, artists separately) and the deviations of navigation choices are shown in this diagram. Movement towards daylight in means increase upwards while movement towards artificial light increases downwards. Although there are differences in preferring light source in exhibitions rooms (steps 1, 2, 4 and 6), participants distinctively preferred daylight in transition areas (3 and 5). Participants tend to move towards artificially lit room more when the pieces are paintings rather than sculpture (steps 1 and 2).

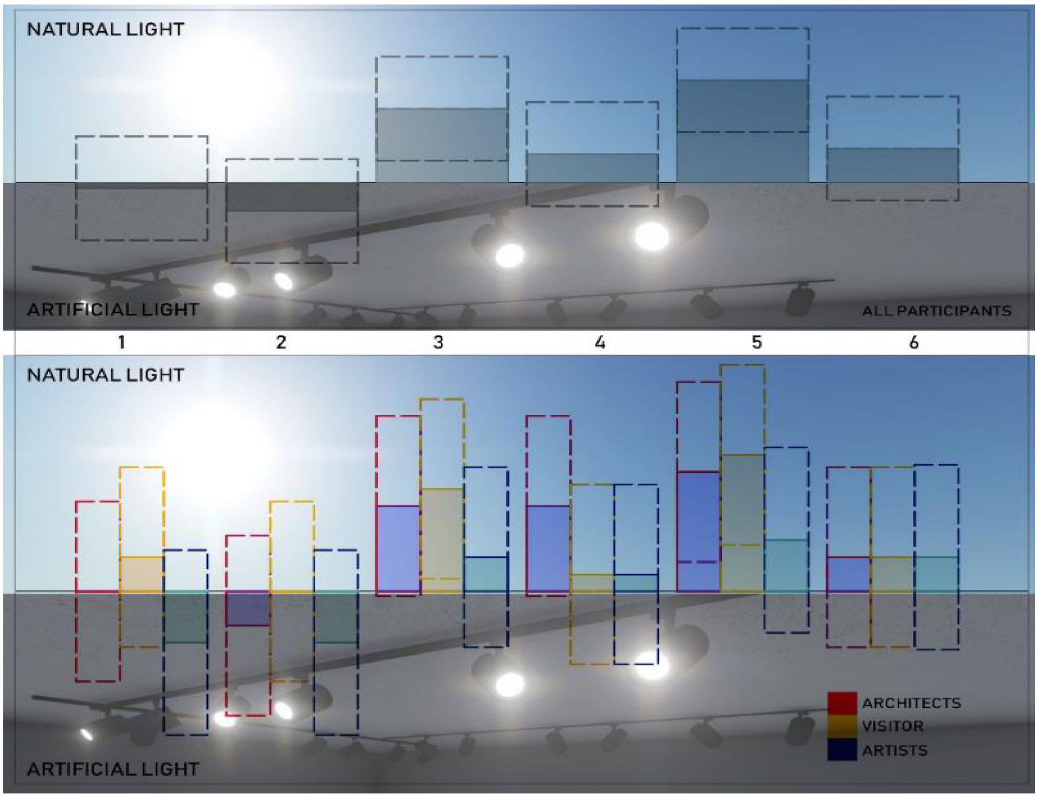

Figure 4.3. Lighting preferences in each navigation point

To understand distinctiveness in each navigation choice, ANOVA was used for all groups; both gathered and separated (Table 4.2). In the analysis of variance for all groups, there is a significant difference between light choices in each navigation point (*p*=0.005). The difference fades when all occupation groups are analyzed separately. Although the decrease in the number of data in the analysis is possibly the main cause of it, occupations groups tend to go along with a certain light type. For example, architects preferred daylit areas except step 2. Visitors favor moving towards daylight in all steps. On the contrary, artists moved towards artificial light except point 6 while movement towards daylight in transition areas is also lower in this group.

Table 4.2. ANOVA results (P-value) of navigation choices

Occupation	ANOVA P-Value
All	0.005*
Architects	0.15
Visitors	0.238
Artists	0.448

4.1.2. Selected Spaces and Participant and Environment Factor

Results show that, participants' most selected space is 6D with 29%; other spaces are shown in Figure 4.4. The main difference of this space from other spaces is that the opening type which is skylight. The second most selected place is 2D which is again another daylit space. This contradicts the relations between daylight-sculpture, artificial light- painting in other results. On the other hand, selection alone is not enough to understand preference, catchiness must be eliminated. To integrate "selection" and level of "preference", selection percentages are compared with the ratings to questions 11 (Table 4.5). Even though, its selection percentage is 11%, 6A is the highest rated space. With the significance value of 0.125, no relation is found between occupation and the selected spaces in general linear model.

General linear method was used to other selection-based answers like navigation to understand the impact of all factors. Personal information and environmental variables were replaced and grouped as figures for factors (Table 4.3). For example, age groups were divided into three and labelled in figures such as 1, 2 and 3. Results show that, age is a determining factor in the first navigation choice, moving towards either 1A or 2A. For this choice, moving towards daylight significantly increases between the ages 25 and 35 and moving towards artificial light significantly increases between the ages 35-75. On the second and third navigation choices, gender is important. Female participants moved toward artificial light more in the second choice (exhibition area) while male participants moved towards artificial light in the third choice which is transition area.

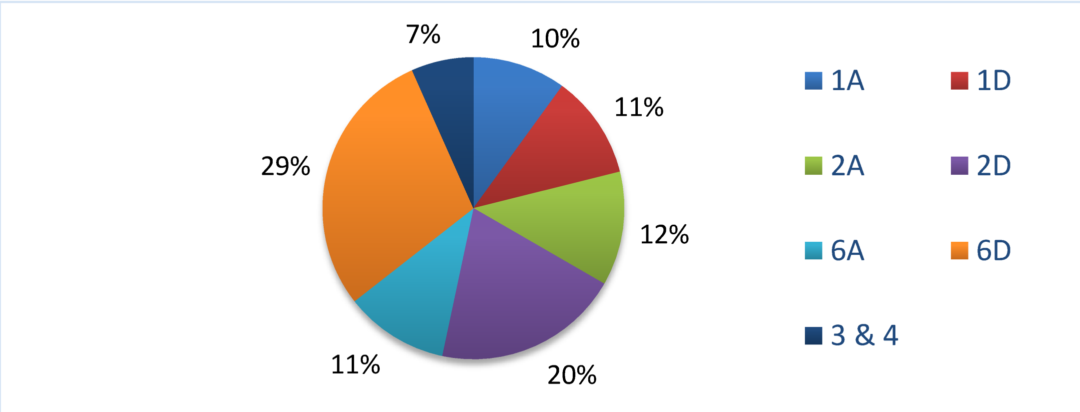

Figure 4.4. Selected space percentages

Table 4.3. Categorization of personal and environment information

Age	group	Gender	group	Occupation	group	Visual Impair	group
17-25	1	female	1	architect	1	none	1
25-35	2	male	2	visitor	2	other	2
35-75	3			artist	3		

Visual Gadget	group	Sky Condition	group	Light Type	group
none	1	overcast	1	natural	1
other	2	clear	2	artificial	2

Since the questionnaire had to be done in various environments, sky condition and light type of the questionnaire environment are included as a factor in the selection-based choices. Results show that both environmental factors and visual factors such as impairments or used gadgets do not have significant impact on choices.

4.1.3. Dual Comparisons Regarding Light Source and Exhibition Type

To understand and detect the impact of the space and exhibition factors, dual comparisons are made by using T-test. For analysis, five paired spaces are determined with the responses given to 11 different criteria. These spaces are paired deliberately to have single difference such as light source type or exhibition type (Figure 4.5), while rest of them stayed identical. Significance values in the Table 4.4 are analyzed with the mean values in Table 4.5. For the change in light source, 1A-1D, 2A-2D, 6A and 6D pairs are made while 1A-2A and 1D-2D pairs are made for the change in exhibition type.

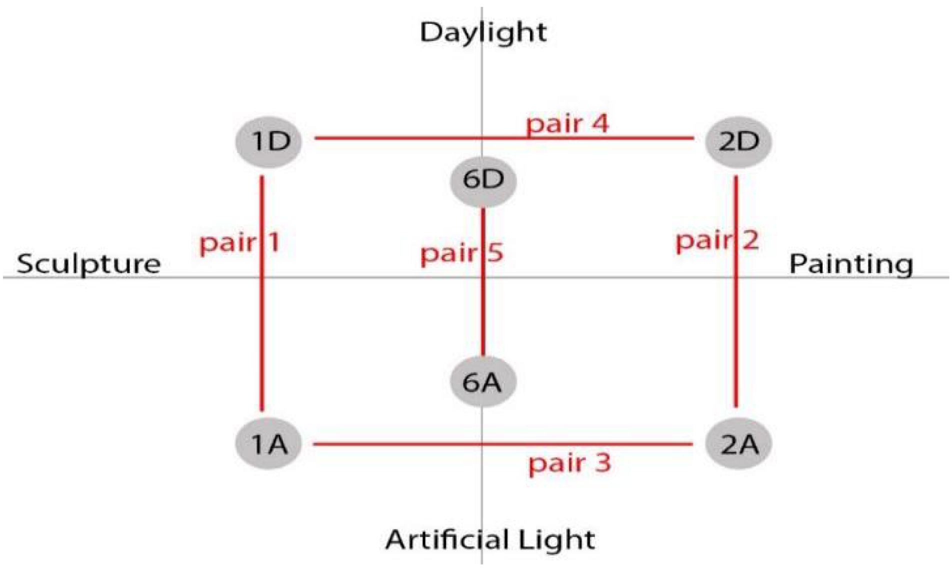

Figure 4.5. Pairing diagram for t-test

In pair 1A-1D, same sculptures are exhibited. In the T-test, difference in four criteria showed significant results (Figure 4.6). In question 1, software's visual fidelity is tested to be successful as the distinction of light source is easily addressed by the participants with significance value of 0.0013. As for the harshness-softness scale in question 7, daylit exhibition is significantly found softer (p=0.0142). Spotlights create coarser shadows when compared to daylight on 3D objects. Linked to the question 7, daylit exhibition is found visually more comfortable (p=0.0426). Less contrast and soft shadows are perceived more comfortable as found in many other studies. Lastly, daylit sculpture exhibition is rated 0.7 point higher in terms of visual quality, preference (p=0.0398).

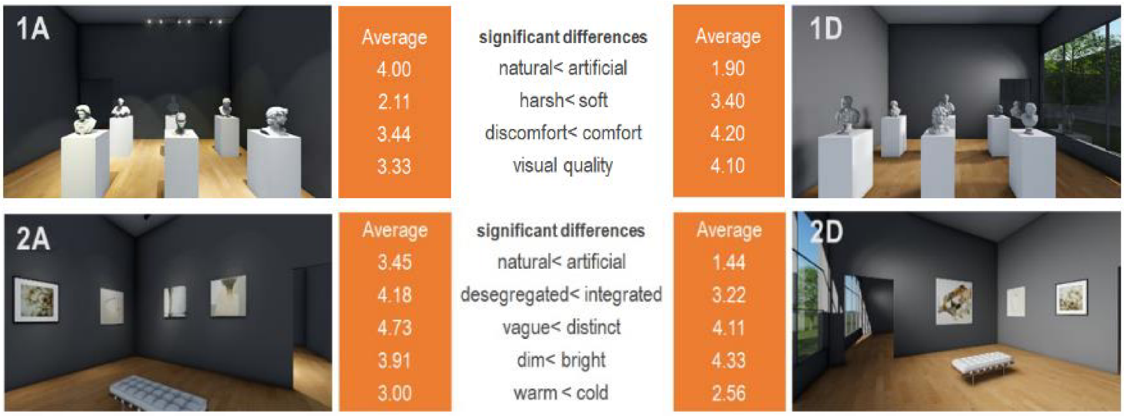

Figure 4.6. Significant differences of pair 1A-1D (top) and pair 2A-2D (bottom)

Same painting exhibition with different light sources are examined in pair 2A-2D. Five questions (criteria) show significant results in the T-test (Figure 4.6). Just like in pair 1, participants addressed the light source successfully (p=0.0001). Artificially lit painting space is perceived more integrated (p=0.0155). Balanced contrast areas are achieved with spotlights. Equally highlighting paintings abstracts the rest of the space which is perceived as a visual rhythm. Supporting the results of question 3, artificially lit painting space is found more distinct which again can be explained as the spotlights create more focusing points (p=0.0489). Despite of the similar illuminance levels with pair 1, daylit painting space is perceived brighter in pair 2 (p=0.0925). Lastly, artificially lit space is found significantly colder in terms of light color (p=0.0555).

Figure 4.7. Significant differences of pair 1A-2A

In the third pairing, sculpture exhibition 1A and painting exhibition 2A which are both illuminated by artificial lighting are compared. Five questions show significant results (Figure 4.7). The meaningful difference on light source type is not found since both spaces have the same lighting type. Painting exhibition is perceived 1.20 point more relaxing compared to sculpture exhibition. (*p*=0.0170). Same significant difference is found in the comparison (1D and 2D) of same spaces in daylight. Regardless of light type, proportion of exhibited object in a space is the determining factor for this criterion. Paralleling to this, painting exhibition is found softer (*p*=0.0019) and visually more comfortable (*p*=0.0040). Just like in the pair 1A and 1D, shadows in artificially illuminated sculpture exhibition are coarser compared to same daylit space or painting these four criteria, painting exhibition is rated "positive" and lastly higher in visual quality exhibition. Additionally, painting exhibition is perceived more balanced (*p*=0.0865). In (*p*=0.0531).

Table 4.4. T-test results for pair of spaces

SPACE PAIRS / CRITERIA	1 1A-1D	2 2A-2D	3 1A-2A	4 1D-2D	5 6A-6D
1- Natural / Artificial	**0.0013**	**0.0001**	0.1872	0.1375	**0.0001**
2- Desegregated / Integrated	0.4841	**0.0155**	0.2378	**0.0888**	**0.0020**
3- Vague / Distinct	0.1518	**0.0489**	0.4079	0.3305	0.4648
4- Dim/ Bright	0.4445	**0.0925**	0.2672	**0.0492**	0.4738
5- Dull / Catchy	0.3676	0.3484	0.3169	0.3551	0.2660
6- Tense / Relax	0.1194	0.2781	**0.0170**	**0.0391**	0.1062
7- Harsh/ Soft	**0.0142**	0.4580	**0.0019**	0.1904	0.3102
8- Discomfort / Comfort	**0.0426**	0.3078	**0.0040**	**0.0806**	0.1885
9- Imbalanced / Uniform	0.3488	0.3432	**0.0865**	0.2246	0.2079
10- Color of Light	0.1136	**0.0555**	0.2930	0.3115	0.4907
11- Visual Quality	**0.0398**	0.4055	**0.0531**	0.2836	0.1491

In the fourth pairing, sculpture exhibition 1D and painting exhibition 2D which are both illuminated by daylight are compared (Figure 4.8). Sculpture exhibition is found more integrated (*p*=0.0888). Different from painting exhibition, shadows in sculpture exhibition form a composition. In question 4, painting exhibition is perceived brighter despite having the same illuminance level (p=0.0492). Painting exhibition enables light to radiate more with less shadow. Related to this, painting exhibition is found more relaxing (p=0.0391) and visually comfortable (p=0,0806).

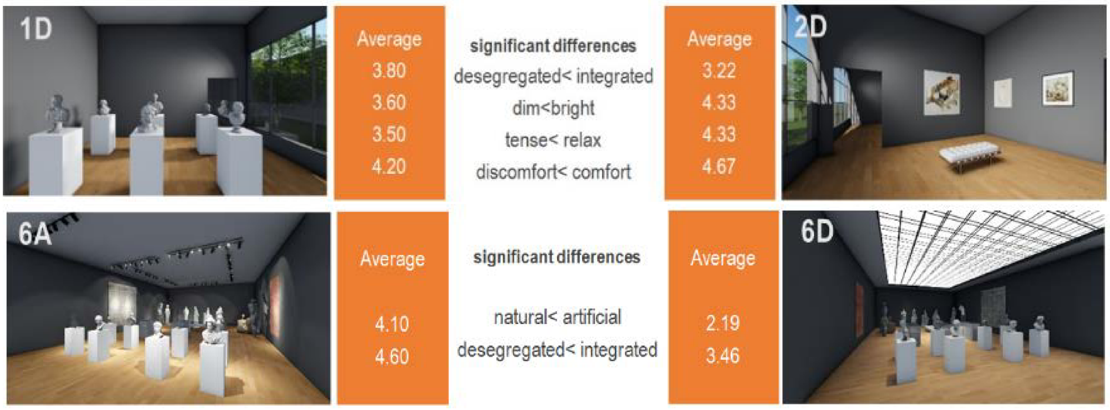

Figure 4.8. Significant differences of pair 1D-2D (top) and pair 6A-6D (bottom)

Finally, identical exhibition spaces 6A and 6D which have different light source are compared (Figure 4.8). In question 1, visual accuracy of the software was again found successful since the light types are differentiating (p=0.0001). Artificially illuminated space was perceived more integrated (p=0.0020) with the average rating of 4.60 while same space with daylight was rated 3.46. It can be explained with the rhythm formed by focal lighting and the shadows which creates a composition.

Table 4.5. Mean and standard deviation values of spaces between 1-5

SPACES /CRITERIA		1A	1D	2A	2D	3	6A	6D
1-Natural / Artificial	Mean	4.00	1.90	3.45	1.44	2.50	4.10	2.19
	Std. Dev.	1.41	1.10	1.21	0.86	0.84	1.10	1.23
2-Desegregated / Integrated	Mean	3.78	3.80	4.18	3.22	3.67	4.60	3.46
	Std. Dev.	1.39	0.92	0.98	1.26	1.03	0.70	1.50
3-Vague / Distinct	Mean	4.67	4.30	4.73	4.11	3.50	4.00	4.04
	Std. Dev.	0.50	0.95	0.65	1.28	1.05	1.15	1.15
4- Dim/ Bright	Mean	3.67	3.60	3.91	4.33	3.67	3.60	3.58
	Std. Dev.	0.87	1.17	0.83	0.77	1.21	0.84	1.14
5-Dull / Catchy	Mean	3.56	3.70	3.73	3.83	4.00	4.10	3.85
	Std. Dev.	0.88	0.95	0.65	0.79	0.89	0.99	1.26

(continued on the next page)

Table 4.5 (continued)

6- Tense / Relax	Mean	2.78	3.50	4.09	4.33	3.00	2.80	2.23
	Std. Dev.	1.30	1.27	1.22	0.69	1.67	1.14	1.31
7- Harsh/ Soft	Mean	2.11	3.40	3.82	3.78	3.33	2.90	3.08
	Std. Dev.	1.17	1.17	1.08	0.81	1.03	0.74	1.35
8-Discomfort / Comfort	Mean	3.44	4.20	4.55	4.67	3.17	4.20	3.77
	Std. Dev.	0.88	0.92	0.69	0.49	1.33	1.32	1.14
9- Imbalanced / Uniform	Mean	3.78	4.00	4.45	4.33	3.17	4.10	3.69
	Std. Dev.	1.20	1.25	0.82	0.69	1.17	1.37	1.12
10- Color of Light	Mean	3.22	2.70	3.00	2.56	2.83	3.30	3.31
	Std. Dev.	0.97	0.82	0.77	0.51	0.75	0.95	0.62
11- Visual Quality	Mean	3.33	4.10	4.00	3.94	3.33	4.20	3.81
	Std. Dev.	1.00	0.74	0.63	0.54	0.82	1.03	0.80

4.1.4. Analysis of Impressions of Spaces

Apart from T-test, the relation of exhibition space parameters and criteria/questions is analyzed with OLS (Table 4.6). Third criterion, vague-distinct, is found significant in artificially illuminated spaces 1A and 2A. In exhibition space 6A, this criterion is not significant because both exhibition types are included and the space gets bigger. Painting exhibitions 2A and 2D were found significantly relaxing when compared to other spaces. Daylit 2D space was found even more relaxing. There is a significant relation between harshness criteria and exhibition space 1A since the space is both artificially illuminated and sculptures are exhibited which cause coarser shadows. Same criteria were found equally significant in painting exhibition illuminated by both artificial light and daylight (2A and 2D). Except the spaces 1A and 6D, comfort criterion was found relevant in all spaces. Paralleling with the relaxing criteria, painting exhibitions 2A and 2D were perceived visually comforting. Daylight was perceived more comforting in sculpture exhibition significantly while in other exhibition spaces too. Uniformity criterion was found significant in painting exhibitions. Artificial light was found more balanced due to focal lighting. Lastly, 6A was significantly rated the highest. Following, daylight in sculpture exhibition and artificial light in painting exhibition were significantly found successful.

Table 4.6. OLS coefficients of the relation between exhibition space and criteria

	1A	1D	2A	2D	6A	6D
2- Desegregated / Integrated	0.865	0.835	0.413	0.446	0.146	0.714
3- Vague / Distinct	**0.039**	0.146	**0.025**	0.223	0.362	0.263
4- Dim/ Bright	1.000	0.897	0.631	0.157	0.897	0.842
5- Dull / Catchy	0.397	0.559	0.589	0.722	0.845	0.732
6- Tense / Relax	0.726	0.421	**0.077**	**0.021**	0.747	0.160
7- Harsh/ Soft	**0.040**	0.908	0.391	0.398	0.345	0.611
8- Discomfort / Comfort	0.592	**0.044**	**0.007**	**0.002**	**0.044**	0.177
9- Imbalanced / Uniform	0.283	0.136	**0.020**	**0.024**	**0.096**	0.283
10- Color of Light	0.317	0.725	0.655	0.424	0.221	0.157
11- Visual Quality	1.000	**0.061**	**0.097**	0.101	**0.035**	0.184

4.1.5. The Relation between Visual Quality and Other Criteria

Since visual quality is the ultimate output when evaluating lighting, its covariance with other criteria is analyzed separately in this section. Firstly, covariance coefficients between the criteria were calculated (Figure 4.9). It was found that criteria 8 and 9 which are discomfort/comfort and imbalanced/uniform have a high positive covariance with the coefficient of 0.84. Selected spaces which were found visually comfortable were regarded as uniform. Other notable positive covariance is between tense/relax (6) and harsh/soft (7), tense/relax (6) and discomfort/comfort (8) with the values 0.62 and 0.56 respectively. This means that relaxing spaces were regarded as soft and visually comfortable. On the contrary, natural/artificial (1) and harsh/soft (7) criteria have a negative covariance with the coefficient 0.43.

Covariances

	1	2	3	4	5	6	7	8	9	10
2	0.37									
3	0.04	0.17								
4	-0.28	0.02	0.14							
5	-0.09	0.30	-0.04	0.21						
6	-0.39	0.04	0.11	0.40	0.17					
7	-0.43	-0.01	0.10	0.23	0.18	0.62				
8	-0.27	0.39	0.11	0.16	0.41	0.56	0.28			
9	-0.17	0.34	0.28	0.20	0.29	0.25	0.06	0.84		
10	0.34	-0.04	-0.09	-0.19	-0.10	-0.19	-0.23	-0.08	-0.12	
11	-0.28	0.14	0.10	0.17	0.25	0.22	0.18	0.41	0.38	-0.03

Figure 4.9. Covariance between the criteria in virtual exhibition

Since Pearson correlation is more reliable due to standardization, first 10 criteria were correlated separately. Significant correlations are shown bold in Table 4.7. Coefficients and the p-values show that visual comfort correlates with the eight criteria, visual comfort, the most significantly. Users appraise the visual quality more when they find the space visually comfortable with the correlation coefficient of 0.49.

Table 4.7. Pearson correlation coefficients (PCC) and p-values between visual quality and other criteria in virtual exhibition

	Pearson Correlation	P-value		Pearson Correlation	P-value
1- Natural / Artificial	-0.24	**0.03**	6- Tense / Relax	0.19	**0.07**
2- Desegregated / Integrated	0.14	0.20	7- Harsh/ Soft	0.19	**0.07**
3- Vague / Distinct	0.11	0.30	8- Discomfort / Comfort	0.49	**0.00**
4- Dim/ Bright	0.21	**0.04**	9- Imbalanced / Uniform	0.43	**0.00**
5- Dull / Catchy	0.33	**0.00**	10- Color of Light	-0.05	0.63

All correlations parallel the covariance method. Similar significant correlation can be seen with uniformity and visual quality with the coefficient of 0.43. The catchiness of the space has a positive correlation with visual quality. Harshness/softness and tense/relax criteria both have equal correlation coefficients and significant p-values. Brightness criterion has a low but significant correlation with visual quality. Visual quality has a negative correlation with light type significantly. It can be claimed that spaces illuminated with daylight were considered visually more appealing.

To support covariance and correlation method, the data was analyzed one more time with GLM method. Visual quality was placed as a factor while other criteria remained as responses into the analysis. In a way, ratings from 1 to 5 for visual quality were taken as levels of this factor. Significant relations are highlighted in Table 4.8. Out of 10 criteria, 7 of them were found significantly related with visual quality just like correlation coefficients.

Table 4.8. Visual quality as the factor on the response of other criteria

Other Criteria	P-value
1- Natural / Artificial	**0.064**
2- Desegregated / Integrated	0.112
3- Vague / Distinct	0.195
4- Dim/ Bright	**0.016**
5- Dull / Catchy	**0.004**
6- Tense / Relax	**0.040**
7- Harsh/ Soft	**0.032**
8- Discomfort / Comfort	**0.000**
9- Imbalanced / Uniform	**0.000**
10- Color of Light	0.481

4.1.6. Importance of Questions

At the end of the questionnaire, participants were asked to pick three important criteria/questions to understand their awareness on the role and impact of lighting. As the most important criterion in lighting, the light source type (artificial/natural) (1) was picked 47 times while brightness (4) and color temperature (10) are picked 35 and 36 times respectively. Relaxing (6), visual quality (11), uniformity (9) and comfort (8) are picked 26, 28, 24 and 20 times respectively. The least picked criteria are listed as integration (2) with 15 times, vagueness (3) with 10 times, catchiness (5) with 14 times and softness (7) with 15 times. The most picked combinations of questions are 1-4-8 and 1-4-10 with 5 times each. In other words, users care about light type, brightness and color temperature (or visual comfort) at first when assessing the lighting.

4.2. Paintings in the Virtual Model

The participants' responses for painting room visuals are analyzed under 5 sections. In the first section, participants' selection of visuals, the relation between selection and affecting factors are explained. In other sections, participants' response to question B2 which are impressions of visuals evaluated under three sets of 9 criteria are analyzed from different aspects.

In the second section, impressions to all visuals are analyzed all together with OLS method. In the third section, the effect of different lighting settings to the impressions are analyzed. Visuals were divided into three color temperature groups which differentiated in lighting setting. The inverse of this categorization, the effect of different color temperatures is analyzed in the fourth section (Figure 4.10). Lastly, correlation between impressions, especially visual quality criterion with other criteria are explained.

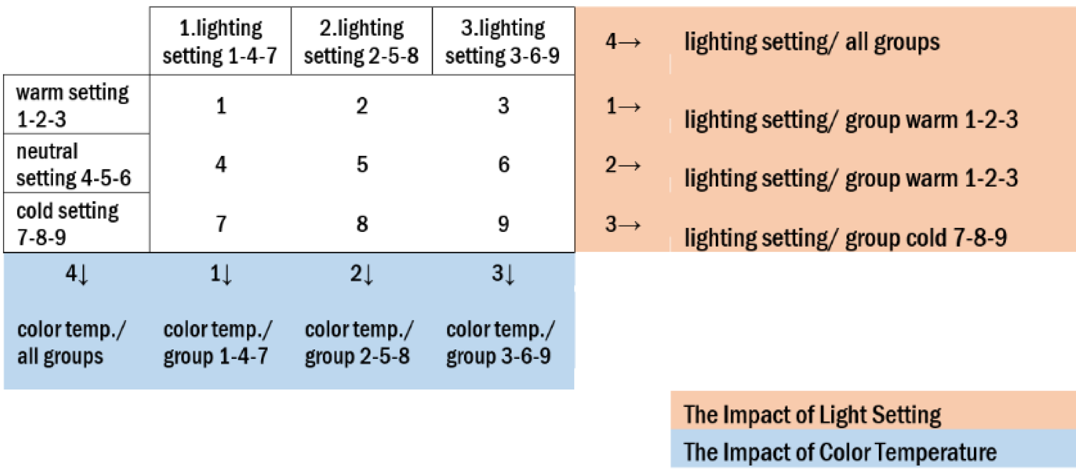

Figure 4.10. Analysis diagram of section 4.2.3 and 4.2.4.

4.2.1. Participants' Selection

In the painting room, the participants were asked to pick one visual from each column (which is three different color temperatures of a lighting setting) in question B1. In all lighting settings, neutral color temperature become the most picked one varying between 48-54% of the selections in all lighting settings (Table 4.9). The second most picked color temperature also remains the same in all settings which is cold color temperature with 30, 31 and 28% of the time respectively. The least picked color temperature set is warm color in lesser than one fifth of the selections (16-19%) while the least picked setting in ambient lighting with warm color temperature (3). Regarding this, visual number 3 is picked to be excluded in the OLS method.

Table 4.9. Selection count and percentages in each lighting setting for all and each occupation groups separately

	No	Color Temp.	Count (All)	%	Count (Arch)	%	Count (Vis)	%	Count (Art)	%
Single Spotlight	1	warm	19	21	5	17	9	30	5	17
	4	neutral	44	49	14	47	16	53	14	47
	7	cold	27	30	11	37	5	17	11	37
Multiple Spotlight	2	warm	19	21	11	37	4	13	4	13
	5	neutral	43	48	13	43	11	37	19	63
	8	cold	28	31	6	20	15	50	7	23
Ambient	3	warm	16	18	7	23	5	17	4	13
	6	neutral	49	54	13	43	16	53	20	67
	9	cold	25	28	10	33	9	30	6	20
		Total	270	%	90	%	90	%	90	%

For further understanding, selection differences between professions are also investigated. It can be seen that the ratios of selecting between different color temperatures are almost same in each occupation group although there are some different tendencies in each group. When compared to all participants, responses of architects' selection inversed in multiple spotlight setting. Architects picked the cold color temperature least in this setting with 20% of the time. The visitors group varied the most out of all. In single spotlight setting, the visitor picked the cold color temperature least.

In multiple spotlight setting, the most picked color temperature switched to cold when compared to all groups. Tendency to select neutral color temperature of multiple spotlight setting increased from 48 to 63% of the time in the last group, artists. Similar rise can also be seen in ambient lighting.

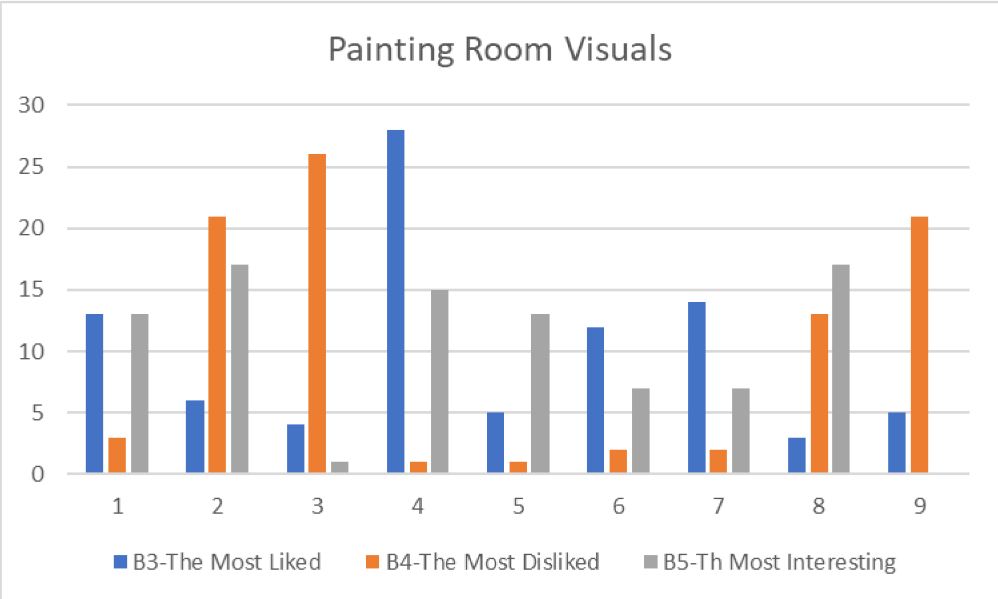

Figure 4.11. Selection count of the visuals in questions B3, B4 and B5

The responses to questions B3, B4 and B5 are shown in Figure 4.11. The most liked visual is number 4 with 31% of the time which combines neutral CCT with single spotlight. From the same lighting setting group, visuals 1 and 7 were picked as the most liked 14 and 16% of the time respectively. In other words, single spotlight setting is picked as 61% of the time. Ambient lighting group (3, 6, 9) is the second most picked in this question with a total of 23%. From color temperature aspect, neutral CCT is the most picked with half of the selections. Following, warm and cold color temperature visuals were picked almost evenly in this question.

The most disliked visual is number 3 which is warm ambient lighting. It is also one the least picked in the most liked visual question with 4%. Supporting this, neutral and cold ambient lighting were rated lowest in terms of visual quality. However, there is still a slight conflict between the first two questions. Visual number 2 and 9, which are warm CCT multiple spotlight and cold CCT ambient lighting, are the second most picked with 23% each. Ambient lighting is regarded as the most disliked setting with 54% of the time though it is not the least picked in the first question. The second most picked group in this question is multiple spotlight with 39% though neutral CCT multiple spotlight (5) is one of the least with 2%. In terms of CCT, warm and cold color temperature were mostly picked with 56 and 40% respectively while the neutral color temperature visuals were picked 7% of the time.

Cold and warm color temperature from multiple spotlight group were picked as the most interesting with both 19% of the time. They are also rated lowest in terms of visual quality. From the same group, neutral color temperature (5) was also picked notably with 14%. More than half of the time, application of multiple spotlights was found the most interesting and rated the lowest. Following, single spotlight application was picked 39% of the time. As expected, the least picked group in this question is ambient lighting. Moreover, cold temperature ambient lighting (9) was never picked. In terms of color temperature, neutral CCT was picked as the most interesting with 39% of the time which is followed by warm temperature with 34%.

Table 4.10. Correlations between questions B1 and B3, B4, B5

The correlation between Selected visuals (B1) and	Pearson Correlation	P-value
The Most Liked (B3)	0.327	**0.000**
The Most Disliked (B4)	-0.250	**0.000**
The Most Interesting (B5)	0.167	**0.006**

One of the reasons why questions B1 is an intuitive selection, B3-5 is asked one after is to understand human perception of appraisal and catchiness. The answers to these questions are expected to be in correlation. Since there is a combination of three in the selection, each selection in the combination was taken as one answer in correlation analysis. In other words, 270 rows of data are analyzed instead of 90 rows. Results show that, the participants' selections (B1) significantly correlate to these last three question but their relation level varies. The most liked visual responses have the strongest correlation in a positive way. As expected, the most disliked visual responses correlate with selection (-0.250). Results clearly show that the participants are in favor of selecting the visual that they most liked (0.327) than the visual that they found the most interesting (0.167), although both have impact.

Table 4.11. Means (highlighted) and standard deviations of impression

No. of Visuals	1-des/ integrated	2- distinct / vague	3- dim/ bright	4- tense/ relax	5- harsh/ soft	6- dis/comfort	7- imbalanced/ uniform	8- Color of light	9- Visual Quality
1	4.32	4.32	2.16	3.95	4.47	4.53	4.68	2.00	**3.95**
	0.75	1.16	1.12	1.13	0.77	0.84	0.67	0.58	0.78
2	2.95	2.89	1.79	2.53	2.79	3.32	3.26	2.21	3.37
	1.27	1.45	1.08	1.35	1.47	1.42	1.56	0.79	1.16
3	3.38	3.50	3.19	3.88	3.94	3.44	4.00	2.31	3.44
	1.26	1.41	1.22	1.15	1.00	1.31	1.26	0.87	1.21
4	3.89	4.20	2.73	3.73	3.77	4.07	4.18	3.00	3.82
	1.19	1.11	1.04	1.02	1.12	1.09	0.92	0.78	1.04
5	3.26	3.30	1.77	3.44	3.14	2.93	3.21	3.37	3.12
	1.35	1.24	0.81	1.35	1.34	1.35	1.42	0.79	1.10
6	3.92	4.08	3.65	3.90	3.78	3.69	3.90	3.10	3.43
	1.19	1.06	1.23	1.07	1.10	1.31	1.03	0.80	0.98
7	4.07	4.04	2.52	3.67	3.37	3.93	4.07	3.59	3.59
	1.04	1.06	0.98	1.21	1.24	1.14	1.21	0.75	0.80
8	3.11	3.21	1.86	2.79	2.54	2.68	3.64	3.96	2.86
	1.55	1.34	1.08	1.42	1.17	1.06	1.13	0.64	1.01
9	3.76	3.68	3.00	3.68	3.60	2.92	3.84	3.92	2.80
	1.20	1.35	1.26	1.18	1.32	1.29	1.07	0.81	1.12

In the Table 4.11, the mean values and standard deviations of each question is shown. Results in sections from 4.2.2 to 4.2.4 are discussed with these values. In terms of the most important criterion, visual quality, single spotlight setting with warm color temperature (visual 11) is rated the highest (3.95). Interestingly, the most liked, visual 4, is rated lower (3.82) than visual 1 but both have single spotlight setting (Figure 4.12).

Figure 4.12. The most liked (visual 4, left), the highest rated (visual 1, right)

4.2.2. Analysis of Impressions of Visuals

To analyze the relation between multiple impressions and parameters together in one time, OLS method is used. Results show that which criteria are relevant with lighting type and color temperature when evaluating lighting. The key finding is that evaluating color temperature (8) is more reliable as CCT increases (gets colder). Other important finding is that harshness-softness criterion can be assessed reliably in multiple spotlight setting regardless of color temperature. In relation with the previous finding, brightness (3), tense-relax (4) and the uniformity (7) criteria can be evaluated better with the same lighting setting. According to these findings about multiple spotlight, it can be argued that this particular setting stimulates the perception especially on contrast. As for single spotlight setting, integration (1), distinct-vague (2) and visual comfort (6) criteria are significantly relevant with warm and cold temperature single spotlight setting (1 and 7).

CRITERIA	1-desegregated/ integrated	2-distinct/ vague	3- dim/ bright	4- tense/ relax	5- harsh/ soft	6- discomfort /comfort	7-imbalanced /uniform	8- Color of light	9- Visual Quality
Visual 1	0.02490	0.04880	0.00559	0.85936	0.18650	0.00905	0.08170	0.22928	0.14390
Visual 2	0.30610	0.14310	0.00018	0.00108	0.00493	0.76901	0.06100	0.69447	0.84270
Visual 4	0.15530	0.04790	0.14779	0.67424	0.63656	0.07780	0.58990	0.00228	0.20440
Visual 5	0.74080	0.57880	0.00001	0.21980	0.02318	0.15690	0.02010	0.00000	0.28550
Visual 6	0.12590	0.09740	0.13772	0.94718	0.63765	0.46621	0.75900	0.00040	0.97590
Visual 7	0.07250	0.16220	0.05194	0.58338	0.13310	0.20565	0.83890	0.00000	0.63190
Visual 8	0.48740	0.45350	0.00012	0.00417	0.00022	0.04822	0.32430	0.00000	0.07200
Visual 9	0.32870	0.64380	0.59014	0.61293	0.37774	0.18641	0.66530	0.00000	0.05310

Figure 4.13. OLS results, significant values are shown in gradient orange shading

4.2.3. The Impact of Lighting Setting

The impact of lighting setting is analyzed in two parts with GLM method. Firstly, every visual was analyzed in their color temperature group as a factor. Visuals were analyzed in their color temperature groups which are determined as 1, 2, 3 in warm; 4, 5, 6 in neutral and 7, 8, 9 in cold temperature group. In the second part, light settings groups (Table 4.12) were put into analysis as levels. Out of 36 probability values, 27 of them were found significant. It can be said that lighting settings have a dominant effect on impressions though there are some variances.

Table 4.12. Lighting setting significance on impressions (P-value)

	1. Color Temperature			2.As light setting groups
	Warm 1-2-3	Neutral 4-5-6	Cold 7-8-9	
1-Desegregated /Integrated	**0.001**	**0.020**	**0.021**	**0.000**
2-Vague/ Distinct	**0.008**	**0.000**	**0.057**	**0.000**
3- Dim/ Bright	**0.002**	**0.000**	**0.001**	**0.000**
4- Tense/ Relax	**0.001**	0.166	**0.016**	**0.000**
5- Harsh/ Soft	**0.000**	**0.017**	**0.006**	**0.000**
6-Discomfort /Comfort	**0.006**	**0.000**	**0.000**	**0.000**
7-Imbalanced /Uniform	**0.003**	**0.000**	0.377	**0.000**
8- Color of Light	0.452	**0.078**	0.133	**0.049**
9- Visual Quality	0.200	**0.008**	**0.006**	**0.000**

Results are also evaluated in their groups and criteria individually. The impact of lighting setting may change in different color temperatures. Indifferent probability values (higher than 0.005) are more important to understand the effect on color temperature when analyzing lighting setting factor. In warm color temperature group (visuals 1, 2, 3), only responds to criteria 8 (p=0.452) and 9 (p=0.200) were found insignificantly different. In warm light, evaluation difference of light color and visual quality get less different. In neutral color lighting settings, the participants were only indifferent in determining tense-relax criterion (p=0.166). Different from other color groups, lighting setting has more impact on the perception of color temperature in neutral color temperature. In cold color lighting settings, participants were indifferent to uniformity (p=0.377) and color temperature criteria (p=0.133). Similar to the relation of warm color light and lighting type, it can be said that cold color temperature the evaluation of light color gets less indifferent. Warm and cold color temperatures have more influence on the perception of light color when compared to neutral light color.

Similar with the initial evaluation of the results, it was found out that lighting type is a driving factor, with almost 0.000 significance value in all criteria. It was found out that lighting setting have a secondary impact on color temperature perception (p=0.049) after the impact of color temperature impact on the impressions in 4.2.4 (p=0.000).

4.2.4. The Impact of Color Temperature

The impact of color temperature on impressions is analyzed in two parts with GLM method. Firstly, every visual was analyzed in their lighting setting groups. For example, since visuals number 1, 4 and 7 are all color temperature variations of "single spotlight" setting, they were taken as levels of the lighting setting factor in the analysis. Same thing goes for other visuals in setting groups which are 2, 5, 8 in "multiple spotlight" and 3, 6, 9 in "ambient" lighting setting. In the second part, the method was applied as the setting groups were taken as the levels.

The most important outcome of all these analyses regarding 4.2.3. is that lighting types are the secondary factor to alter the perception of color temperature while color temperature is the primary factor. In three separate analyses of the lighting setting groups, participants successfully addressed the color temperatures correctly with a significant difference (p=0.000). Out of 36 significance values, only 13 of them were found significant. When the impact of lighting setting and color temperature are compared, results clearly show that lighting setting more impactful than light color.

The impact of color temperature is analyzed for each lighting setting separately. Mean values in Tables 4.11 is also used to discuss the findings. In single spotlight setting, color temperature variance significantly affected the perception of harshness/softness criteria (p=0.005). In multiple spotlight setting, tense-relax impression changed with color temperature variance (p=0.030). Criteria 3, 6 and 9 were affected by color temperature in the ambient lighting. It shows that brightness perception changes with light color variation (p=0.083). Difference in color temperature also changes the impression of visual comfort (p=0.060) and visual quality (p=0.046).

Table 4.13. Color temperature significance on impressions (P-values)

	1.Lighting Setting			2. As color temperature Groups
	Single spotlight	Multiple spotlight	Ambient	
1-Desegregated /Integrated	0.334	0.716	0.296	0.781
2-Vague/ Distinct	0.685	0.532	0.170	0.231
3- Dim/ Bright	0.141	0.927	**0.083**	**0.057**
4- Tense/ Relax	0.678	**0.030**	0.719	0.124
5- Harsh/ Soft	**0.005**	0.166	0.649	**0.018**
6-Discomfort /Comfort	0.155	0.253	**0.060**	**0.022**
7-Imbalanced /Uniform	0.093	0.409	0.899	0.558
8- Color of Light	**0.000**	**0.000**	**0.000**	**0.000**
9- Visual Quality	0.407	0.282	**0.046**	**0.012**

When all color temperature groups are analyzed together, results show that brightness (3), harshness/softness (5), visual comfort (6), light color (8) and visual quality were found to be significantly in relation with color temperature. Color of light alters the perception of brightness (*p*=0.057). The room is perceived darker in warm color temperature. Another effect of color temperature is to harshness/softness perception (*p*=0.018) since warm CCT increases the perception of contrast.

4.2.5. The Relation between Visual Quality and Other Criteria

The correlation between criteria in painting room is analyzed. Since this model differs from the previous one, the relevance and correlation of the criteria may change so this analysis are done separately for each model. Firstly, covariance between the set of criteria was found out (Figure 4.14). Compared to virtual exhibition model results, criteria have stronger covariance in the painting model.

Covariances:

	1	2	3	4	5	6	7	8
2	0.710							
3	0.176	0.442						
4	0.529	0.545	0.093					
5	0.676	0.386	-0.043	0.795				
6	0.865	1.000	0.225	0.457	0.755			
7	0.832	0.795	0.280	0.517	0.539	0.962		
8	-0.217	-0.098	-0.012	-0.152	-0.365	-0.367	-0.183	
9	0.662	0.691	0.244	0.249	0.341	0.925	0.701	-0.192

Figure 4.14. Covariance between visual quality (9) and other criteria

Results show that the highest covariance is between criteria 1 and 6, 2 and 6, 6 and 7, 6 and 9 varies between 0.9-1 which are all in positive correlation. Other notable positive covariance coefficients are between criteria 1 and 7, 2 and 7, These highest covariance coefficients have the visual comfort (6) and uniformity (7) criteria in common which is a similarity with the first model results.

Table 4.14. PCC and p-values between visual quality and other criteria

	Pearson Correlation	P-value		Pearson Correlation	P-value
1- Desegregated / Integrated	0.483	**0.000**	5- Harsh/ Soft	0.248	**0.000**
2- Vague / Distinct	0.504	**0.000**	6- Discomfort / Comfort	0.652	**0.000**
3-- Dim/ Bright	0.179	**0.003**	7- Imbalanced / Uniform	0.541	**0.000**
4- Tense / Relax	0.184	**0.002**	8- Color of Light	-0.187	**0.002**

In the second part, correlation between visual quality criterion and other criteria was calculated. According to Pearson correlation results, all eight correlations are significant (Table 4.14). Results show that, visual quality criterion correlates with the visual comfort criterion the most, in a positive direction with the coefficient of 0.652. Once again, it is shown that these two criteria are not in conflict. Paralleling with the covariance results, the second highest correlation coefficient is with uniformity (0.541). Other strong and positive correlation are with integration and vague/distinct criteria. Integrated and distinct visuals were found more appealing. In the painting model, the negative correlation with light color is stronger. Since the rating increases as the color temperature increases, it can be said that warmer color temperatures were found more appealing. The correlation coefficient may not be high due to the involvement of neutral color temperature.

4.3. Sculptures in the Virtual Model

Similar to the analysis of painting room, the responses to sculpture room are analyzed under 5 sections. Firstly, the distribution of participants' selection is discussed. In the same section, affecting factors and correlation of the selection are explained. In the second part, the relation between visual parameters (lighting setting and color temperature) and participants' impression is analyzed with different methods such as OLS and GLM. The analysis strategy of GLM is same with the previous model (Figure 4.12). With OLS, the relevance of each criterion is investigated. Later, the impact of lighting type and color temperature are analyzed separately. In the last section, paralleling results are detected with covariance and correlation analysis.

4.3.1. Participants' Selection

The participants picked one color temperature from each lighting setting in Question C1 in the sculpture room. Table 4.15 show the selection count of all participants and occupation groups. In all groups, neutral color temperature was picked the most in spotlight settings. It is dominantly favored in additional background spotlight with 48% of the selections while it remained 40% for spotlight on object setting. Individually, cold color temperature was picked the 42% in the ambient lighting. Apart from the tendency to select neutral color temperature, the selection rankings are not the same in the lighting settings. The least picked visual is 7 which is cold additional background spotlight, it is eliminated in OLS analysis.

Selections are also analyzed under their occupation groups, all occupation groups differentiated from combined data. Similarly, architects dominantly picked neutral color temperature in additional background spotlight with 53% of the time. In other lighting setting, architects directed towards cold light color with 40% in both settings. There is no pattern for the second and thirds pickings for each lighting settings in architects' group. Interesting results were obtained in visitor group selections. Again, neutral color in additional background spotlight was picked the most with 47% of the time. However, in spotlight on object setting, the visitors picked all color temperatures equally.

Table 4.15. Selection count and percentages in each lighting setting for all and each occupation groups separately

	No	Color Temp.	Count (All)	%	Count (Arch)	%	Count (Vis)	%	Count (Art)	%
Spotlight with Back-ground	1	warm	28	31	6	20	10	33	12	40
	4	neutral	43	48	16	53	14	47	13	43
	7	cold	19	21	8	27	6	20	5	17
Spotlight on Object	2	warm	27	30	8	27	10	33	9	30
	5	neutral	36	40	10	33	10	33	16	53
	8	cold	27	30	12	40	10	33	5	17
Ambient	3	warm	22	25	11	37	3	10	8	27
	6	neutral	30	33	7	23	10	33	13	43
	9	cold	38	42	12	40	17	57	9	30
		Total	270	%	90	%	90	%	90	%

In the ambient lighting setting, cold color temperature was picked the most. The most differentiated occupation group is artists. In all lighting setting, artists picked the neutral color temperature. To summarize with regarding painting room results, the selection of architects and visitors drifted to other color temperatures in spotlight on object and ambient lighting against the dominance of neutral color temperature. Although these findings represent the catchiness of the color temperatures for certain lighting settings rather than the appreciation of lighting. To understand the relation between these aspects, which are questions C3, C4 and C5. Correlation analysis is shown in Table 4.16.

Figure below shows the responses in questions C3, C4 and C5. When compared to painting room, the participants' selections are more concentrated. The most liked visual is number 5, spotlight on object with neutral color temperature, with 24% of the time. The second and third most liked is cold (8) and warm (2) light version of the same with 16% and 14% respectively. Similar to painting room, the participants favored conventional spotlight setting which is spotlight on object in this case. All light color variations of ambient lighting were picked the least in this question. No participant regarded visual number 6, neutral light color ambient lighting, as their favorite. Warm (3) and cold (9) ambient lighting were also picked 1% and 3% of the time respectively.

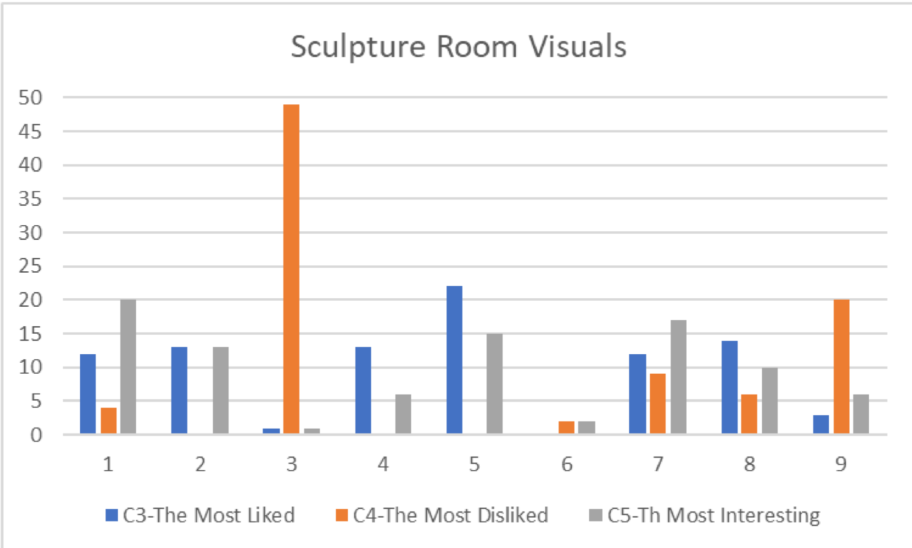

Figure 4.15. Selection count of the visuals in questions C3, C4 and C5

In the next question, participants stated the most disliked visual. The participants again picked warm ambient lighting as the most disliked in the painting room. Although, in sculpture room, the combination is picked 54% of the time rather than 29%. Visual 3's average rating in visual quality question is also the lowest with the value of 1.95 (Table 4.17). Following, cold color temperature ambient lighting is picked as the second most disliked with 22%. In this question, selection counts are similar within their color temperature groups. Regardless of lighting type, cold color temperature visuals 7, 8 and 9 are notably disliked 10, 7 and 22% of the time respectively. The other visual picks vary between 0-4% for this question. The inverse relation between likes and dislikes is apparent when the count of likes and dislikes of each lighting setting are ordered. For example, spotlight on object setting is the most liked and the least disliked. Additional spotlight on background is the second in both questions.

In the last question, the participant picked the most interesting visual. Cold light color and additional background light (visual 1) is the most picked visual in this question with 22% of the time. The second most interesting is warm color version of the same lighting setting with 19%. Other notable selections are visuals 7 and 5 with 19% and 17% respectively. Both spotlights settings were dominantly selected as the most interesting with 48% and 42% respectively. When combined, all light color variations of ambient lighting make up only 10% of the responses as the most interesting. The least picked visual is number 3 which is also strongly the most disliked. Color temperature distribution is relatively even compared to light setting distribution, which is 38% for warm, 26% for neutral and 37% for cold. There is a distinctive drop in neutral color temperature in the first spotlight setting. These results again correlate with painting results as the color temperatures on the edge (warm and cold) are found more interesting.

Since the relations between aspects like selection, liking, disliking and catchiness are chaotic and unclear, three questions are added to the end of second and third parts which are painting and sculpture room. The relations are analyzed with obtaining correlation coefficients between selection and other questions (Table 4.16). All three correlations are found significant. As expected, liking and disliking aspects are inversely correlated with selection question. Correlation coefficients are quite close with the coefficient which are found in the painting room (Table 4.10). It can be said that room, exhibition and light affect the relation between these four. When the coefficients are analyzed separately, the most liked question correlates the most with the selection with the Pearson correlation value of 0.233. With a close value of 0.210, the most disliked question correlates negatively with the selection. Although the selection correlates with the most interesting question (0.161), liking/disliking have more impact on the selection.

Table 4.16. Correlation between questions C1 and C3, C4, C5

The correlation between Selected visuals (C1) and	Pearson Correlation	P-value
The Most Liked (C3)	0.233	**0.000**
The Most Disliked (C4)	-0.210	**0.001**
The Most Interesting (C5)	0.161	**0.008**

In the Table 4.17, the mean values and standard deviations of each question is shown. Results in sections from 4.3.2 to 4.3.4 are discussed with these values. In terms of the most important criterion, visual quality, spotlight on object setting with cold color temperature (visual 8) is rated the highest (4.04). The most liked, visual 5, is rated lower (3.42) than visual 8 (Figure 4.16).

Table 4.17. Means (gray) and standard deviations of impression in sculpture model

Criteria - Visuals	1-des/ integrated	2- distinct / vague	3- dim/ bright	4- tense/ relax	5- harsh/ soft	6- dis/comfort	7- imbalanced/ uniform	8- Color of light	9- Visual Quality
Warm 1	4.39	4.11	2.39	3.18	3.86	4.11	3.75	2.46	3.79
	0.83	1.26	1.17	1.31	1.04	0.92	0.84	0.79	0.88
Warm 2	4.04	4.04	2.85	3.22	3.63	3.70	3.74	2.07	3.33
	1.19	1.02	1.26	1.34	1.08	1.03	1.06	0.73	1.00
Warm 3	3.36	2.41	1.36	3.23	4.00	2.05	2.77	2.36	1.95
	1.59	1.44	0.66	1.48	1.20	1.33	1.38	1.18	1.17
Neutral 4	3.93	4.12	2.79	3.28	3.35	3.93	3.88	3.02	3.72
	1.08	0.91	0.97	1.18	1.11	0.96	1.00	0.74	0.88
Neutral 5	3.97	4.03	2.75	3.25	3.42	3.56	3.75	2.83	3.42
	0.88	0.91	1.13	1.05	1.32	1.25	1.20	0.70	0.87
Neutral 6	3.53	2.90	2.00	3.40	3.70	2.93	3.23	3.27	2.90
	1.11	1.27	1.11	1.10	1.18	1.14	1.19	0.94	0.92
Cold 7	3.58	4.00	2.74	2.74	2.53	3.58	3.58	3.79	3.68
	1.07	1.25	1.05	0.99	1.22	1.07	1.17	0.42	1.00
Cold 8	3.93	4.22	3.37	3.15	2.67	3.74	4.04	3.52	**4.04**
	1.14	1.01	1.28	1.23	1.04	1.10	0.90	0.85	1.02
Cold 9	3.18	2.58	1.97	3.47	3.21	2.24	2.95	4.13	2.18
	1.27	1.27	1.17	1.22	1.34	1.13	1.29	0.66	1.06
Average Mean	3.63	3.69	2.52	3.51	3.49	3.50	3.87	3.05	3.37

Figure 4.16. The most liked (visual 5, left), the highest rated (visual 8, right)

4.3.2. Analysis of Impressions of Visuals

The relation between multiple impressions and parameters are evaluated in a single analysis with OLS method. As having the least amount of data, visual 7 is eliminated for this calculation since it is a requirement for an OLS model. The main aim is to understand the relevance of criteria for a certain room, light or object setting to make a better assessment. For example, how brightness criterion is relevant when evaluating a warm light color spotlight illuminating a group of busts.

CRITERIA	1-desegregated/ integrated	2-distinct/ vague	3- dim/ bright	4- tense/ relax	5- harsh/ soft	6-discomfort /comfort	7-imbalanced /uniform	8- Color of light	9- Visual Quality
Visual 1	0.01620	0.75132	0.29690	0.22150	0.00019	0.10830	0.60940	0.00000	0.72560
Visual 2	0.17750	0.91340	0.72900	0.18250	0.00200	0.70590	0.63140	0.00000	0.22906
Visual 3	0.54400	0.00001	0.00010	0.19770	0.00009	0.00001	0.02290	0.00000	0.00000
Visual 4	0.26080	0.71058	0.86000	0.10580	0.01200	0.24870	0.32630	0.00053	0.89102
Visual 5	0.22140	0.93136	0.96660	0.13680	0.00829	0.94040	0.59230	0.00003	0.33257
Visual 6	0.89070	0.00109	0.02400	0.06330	0.00080	0.04690	0.29570	0.02531	0.00634
Visual 8	0.30680	0.51426	0.05710	0.25840	0.69161	0.62460	0.17510	0.25470	0.22649
Visual 9	0.21550	0.00001	0.01480	0.03150	0.04009	0.00002	0.04670	0.12574	0.00000

Figure 4.17. OLS results, significant values are shown in gradient orange shading

Different from the OLS results in painting room, the main finding in sculpture room analysis is that the most of the criteria revolved around ambient lighting. Criteria vague-distinct (2), dim-bright (3), discomfort-comfort (6) and visual quality (9) are effectively evaluated in all ambient lighting visuals. Evaluating criteria tense-relax (4) and imbalanced-uniform (7) are more reliable in only warm and cold variations of ambient lighting. There are patterns for the criteria harsh-soft (5) and color of light (8). In each setting, the criteria get less relevant as the color temperature of light gets colder. In terms of evaluating color temperature, color temperature of light on painting and sculpture act inversely. The evaluation of desegregated-integrated criteria (1) was found relevant only in warm background spotlight setting.

4.3.3. The Impact of Lighting Setting

The impact of lighting type on impressions differentiates in color groups. For example, visuals 1, 2 and 3 are different type of lighting with "warm" 3000K color temperature. The other groups are 4,5 and 6 as "neutral" 4000K color temperature and 7,8, and 9 as "cold" 5500K color temperature. Apart from color temperature groups, the analysis between lighting groups itself is the second way where lighting factor can be analyzed. This impact is investigated via GLM method. Findings are explained with the means of each criterion in 9 visuals (Table 4.18). Out of 36 probability values, 25 of them were found significant. Similar to painting room, it can be said that lighting setting plays a major role on impressions.

Table 4.18. Lighting setting significance on impressions (P-value)

	1. Color Temperature			2. As lighting setting groups
	Warm 1-2-3	Neutral 4-5-6	Cold 7-8-9	
1-Desegregated /Integrated	**0.014**	0.169	**0.050**	**0.000**
2-Vague/ Distinct	**0.000**	**0.000**	**0.000**	**0.000**
3- Dim/ Bright	**0.000**	**0.004**	**0.000**	**0.000**
4- Tense/ Relax	0.990	0.850	0.087	0.348
5- Harsh/ Soft	0.493	0.450	0.081	0.215
6-Discomfort /Comfort	**0.000**	**0.001**	**0.000**	**0.000**
7-Imbalanced /Uniform	**0.003**	**0.049**	**0.001**	**0.000**
8- Color of Light	0.260	0.089	**0.003**	**0.000**
9- Visual Quality	**0.000**	**0.001**	**0.000**	**0.000**

To understand the effect of lighting setting in different color temperature conditions, all groups are analyzed separately. Indifferent probability values (higher than 0.005) are more important to understand the effect on color temperature when analyzing lighting setting factor. In terms of indifference, there are some common results for all groups. The effect of lighting type on the responds to tense-relax and harsh-soft criteria were found insignificant in all groups. However, in cold light color group, the values get less indifferent 0.087 and 0.081 in the criteria respectively. It can be said that color temperature has less influence on the impact of lighting setting on these criteria. In warm and neutral light color groups, the difference of light color assessment between lighting types was found insignificant (p=0.260 and 0.089). Similar to the pattern in fourth and fifth criteria, cold color temperature has less influence than lighting setting when evaluating light color. In neutral light color group, desegregated-integrated criterion was found indifferent to lighting type (p=0.169).

When all groups are combined, it was found out that responses to seven criteria changes significantly as the lighting type changes (p=0.000). In relation to the findings in 4.2.3, this time results show that change in lighting type has the same significant impact with the change in color temperature on perception of color temperature (p=0.000).

4.3.4. The Impact of Color Temperature

To understand the color temperature effect more clearly, the visuals are analyzed in their lighting setting groups which are 1-4-7, 2-5-8 and 3-6-9 respectively. In these groups, visuals differentiate in color temperature. After these three analyses, visuals are gathered into their color temperature groups (Table 4.19). In the last analyses, these groups are the levels of the color temperature factor. Similar with painting exhibition results, the participants successfully addressed color temperature in their lighting setting groups (p=0.000). There is another common finding that the responses to harshness-softness criteria is significantly determined by color temperature in all four analyses. As color temperature gets warmer the rating of softness increases. Overall, 15 probability values were found significant. out of 36 values. When compared to lighting setting, color temperature has a minor impact on impressions.

In terms of the impact of color temperature, there are some differences in each lighting group. In additional background spotlight, desegregated-integrated criterion is found significantly responsive to color temperature (p=0.024). The rating of distinctiveness decreases as the color temperature gets colder. In spotlight setting, color temperature has more influence in visual quality criterion (p=0.014). The participants' rating increase as the color temperature gets colder. In ambient lighting setting, color temperature is the major determining factor in criteria discomfort-comfort (p=0.015) and visual quality (p=0.003). Neutral color temperature is rated higher in terms of visual quality in ambient lighting.

Table 4.19. Color temperature significance on impressions (P-values)

	1.Lighting Setting			2.As color temperature groups
	Additional Background Spotlight	Spotlight on Object	Ambient	
1-Desegregated /Integrated	**0.024**	0.928	0.550	**0.034**
2-Vague/ Distinct	0.924	0.697	0.382	0.238
3- Dim/ Bright	0.279	0.119	0.060	0.154
4- Tense/ Relax	0.251	0.944	0.763	0.809
5- Harsh/ Soft	**0.001**	**0.008**	**0.054**	**0.000**
6-Discomfort /Comfort	0.191	0.790	**0.015**	**0.023**
7-Imbalanced /Uniform	0.534	0.504	0.421	0.365
8- Color of Light	**0.000**	**0.000**	**0.000**	**0.000**
9- Visual Quality	0.924	**0.014**	**0.003**	0.150

When all color temperature groups are analyzed together, the responses to integration (1) and visual comfort (6) criteria are determined mostly by the difference in color temperature exclusively (p=0.034 and 0.023 respectively). Cold color temperature settings are found harsher. Overall, the pattern in significance results are similar with the results of painting exhibition. For example, in both rooms criteria 5 and 8 were found significant in single spotlight.

4.3.5. The Relation between Visual Quality and Other Criteria

Visual quality is the main objective to evaluate different exhibition and lighting settings. Its relation with other criteria is investigated in this section. Firstly, covariance between the set of criteria was found out (Figure 4.18). The high covariance coefficients are between criteria 2 (vague/distinct) and 6 (dis/comfort), 6 and 7 (uniformity), 6 and 9 (visual quality) which all are positive. The highest coefficient is between visual comfort and quality (1.088). Additionally, it can be said that uniformity of light provides visual comfort (1.026). There is almost the same pattern with covariance in painting room. Other notable covariance coefficients are between criteria 2 and 3, 2 and 9, 7 and 9.

Covariances:

	1	2	3	4	5	6	7	8
2	0.550							
3	0.236	0.764						
4	0.089	0.037	-0.019					
5	0.236	0.081	-0.188	0.731				
6	0.565	1.033	0.512	0.309	0.423			
7	0.520	0.747	0.385	0.299	0.238	1.026		
8	-0.347	-0.256	-0.079	-0.030	-0.409	-0.327	-0.127	
9	0.453	0.914	0.414	0.108	0.117	1.088	0.804	-0.196

Figure 4.18. Covariance coefficients

Table 4.20. PCC and p-values between visual quality and other criteria

	Pearson Correlation	P-value		Pearson Correlation	P-value
1- Desegregated / Integrated	0.330	**0.000**	5- Harsh/ Soft	0.081	0.186
2- Vague / Distinct	0.593	**0.000**	6- Discomfort / Comfort	0.720	**0.000**
3-- Dim/ Bright	0.291	**0.000**	7- Imbalanced / Uniform	0.581	**0.000**
4- Tense / Relax	0.076	0.210	8- Color of Light	-0.166	**0.006**

Table 4.20 shows the Pearson correlation coefficients between visual quality and other criteria. Out of 8 values, two of them were found insignificant which are in criteria tense-relax and harsh-soft. Apart from this, the pattern of the correlations is similar with the pattern in the painting room. Similarly, visual quality correlates with visual comfort the most (0.720). The other high correlations are again with vague-distinct and uniformity criteria. Differently, the correlations with tense-relax and harsh-soft are weak. For the third time, the correlation between light color and visual quality is negative. It can be said that warm color temperature was found more successful.

4.4. Interviewee Commentaries

An additional question (Question D) was added at the end of the questionnaire for the participants (occupation group: artists) who are qualified in the field of exhibition lighting. They were asked to comment on the questionnaire visuals and questions and to share their knowledge and insights about lighting design in exhibition spaces. Their commentaries were noted and listed by their participant number below. A total of seven artists, five sculptors and two artists commented while eight of them are also academics.

Table 4.21. Distributions of occupations of the commenters

Participant Number	Commenters				
	Painter	Sculptor	Curator	Other Art	Academic
61	x				
63		x			x
66	x				
68	x		x		x
72	x				x
74		x	x		
75		x			x
76	x				x
79	x				x
80	x				x
81				x	x
82			x	x	
89		x			
90		x			

A painter (participant 61) mentioned the preference of warm color temperatures when applying lighting on the artwork. The participant preferred spacious exhibitions to display painting areas rather than small partitioned exhibition areas (Figure 4.19).

A sculptor and art professor (participant number 63) agreed that there are standards in lighting design which curators or museum staff can follow. Although, the participant claimed that prioritizing and following a standard is not useful in art styles like contemporary art because of the dynamism. Eventually, case-by-case approach has to be made to have an appropriate lighting design after following a standard. The participant commented that since every artwork has its own characteristic, it is also not healthy to determine standards based on limited number of artworks.

Figure 4.19. Unpartitioned exhibition area ((left) Source: www.contrado.co.uk/blog/wp-content/uploads/2018/03/banner-886x500.jpg) and partitioned exhibition area ((right) Source: www.castlefineart.com/assets/img/resized/galleries-icc.jpg)

The participant number 66, who is an artist, claimed that natural light works better with sculpture visually, but not with the paintings.

One of the artists and a curator (participant number 68), mentioned the common practice of trial-and-error method when deciding on lighting and illuminance value. Existence of artificial light was considered necessary to maintain steady light levels throughout the day. Applying various types of lighting was found beneficial to create dynamism. Similar with the Monza Method, the sculptor mentioned using multiple color temperature lighting at once and creating focal points on a single piece to create rich visual quality. On the usage of daylight, frameless skylight was preferred to get uniform lighting without frame patterns. On the usage of artificial light, the sculptor acknowledged usage of spotlights which to abstract the piece from the exhibition area.

The participant number 72, who is a senior painter and an art professor, commented on both current exhibition lighting practice and the questionnaire. The participant mentioned that art gallery managers decide on the lighting most of the time. Natural light was considered as an unstable light source throughout the day. The importance of creating contrasts over the exhibition was mentioned though these contrasts must be similar to create balance and rhythm throughout the space. When evaluating questionnaire questions, "vagueness" was regarded as a positive attribute in order to highlight the artwork. Monochromity of the exhibition space is preferred, so walls and floor should have the same color.

A curator and a sculptor (participant number 74) emphasized the usage of natural light in the sculpting process. The participant claimed that since the natural light is already involved in the sculpting process in the ateliers, so it should have a role in the display process to maintain authenticity and continuity.

The participant number 75, who is a sculptor and an art professor, mentioned the common exhibition design strategy called “white box”. This strategy disables the effect of surrounding environment. The participant claimed that artwork should not be exhibited in a condition which can create visual rivalry with the architecture and the view. When discussing the effect of lighting on user preferences, impact of other senses such as smell were mentioned. Any kind of stimuli in senses can cause catchiness, so surrounding environment needs to be designed as a secondary element. Exhibitions were considered as exhausting spaces because of the mental activity. Using natural light in buffer zones between exhibition areas is regarded as positive.

The participant also evaluated the visuals and questions in the questionnaire. Again “vagueness” is regarded a positive attribute when displaying an artwork. In the virtual exhibition from the first part of the questionnaire, exhibition 6A’ lighting was found ideal for sculpture atelier. In the second part of the questionnaire, multi-spot lighting setting was found exclusive for the artwork (Figure 4.20).

Figure 4.20. Exhibition area 6A (left) and multi-spot lighting (right) visual

Both artist and art professor (participant number 76), commented on the second part of the questionnaire. Multi-spot lighting was not regarded effective when lighting paintings. Single spot lighting with cold color temperature (visual number 7) was described as the most dramatic with its abstracting effect. Neutral color temperature (visual number 4) was found softer and more appropriate for lighting. Enhancing the artistic purpose of the painting was described as the most important. Ambient lighting was found more suitable for living and work areas.

Another artist and an art professor (participant number 79), suggested using opposite colors when lighting an artwork. For example, if the artwork has warm colors, cold light color would be more appropriate. The participant also suggested to select neutral light colors when lighting sculptures. When evaluating the models created for the questionnaire, the participant suggested to use same color on walls and floors which is similar to "white box", "abstracting the space strategy".

A painter and an academic, participant number 80, also mentioned the exhibiting strategy, "white box". Regardless of "white box", it was suggested that it is always safe to minimalize the surrounding space for better exhibiting. The distinctions between natural light and artificial light in exhibiting were discussed. The participant claimed that natural light does not create a dramatic scene which separates an exhibition atmosphere from other interior atmospheres. It was also claimed that navigation has its own natural process. On the color temperature of lighting, the participant claimed that it has to determined according to the color of the artwork and the concept of the exhibition but still using opposite colors was considered as the initial approach. It was also acknowledged that lighting positioning should change with the scale of the artwork.

The participant 81 evaluated questionnaire questions, especially the discomfort and comfort scale, participant implied discomfort may not be a negative attribute but may be wanted for artistic purposes.

The participant number 82, who is an art professor, thinks each art piece need a special lighting design. For this, exhibition spaces must have flexibility for lighting. He also commented on the navigation in art galleries. Direction signs are mostly used for this purpose, although creating buffer zones and layout of the exhibition are addressed as important. When curating an exhibition, separating notable pieces of the exhibition is a common strategy. Applying a different lighting design was regarded as an effective way to achieve it. The participant also commented on the rivalry between the art piece and the exhibition space with high architectural quality. Most of the visitors will focus on the art piece more than its surrounding space. Although, the art piece has to co-exist with its surrounding space even the building has a historical value while both art and architecture need to reveal their features with light. Even the "white box" and "black box" approaches are fundamental in many exhibitions, abstracting the space is not appropriate in these cases. When asked about the importance of the light source, artificial light is seen as a must especially for supporting natural light. Neutral color temperature in lighting and color rendering are considered as the advantages using natural light. Another issue that is addressed by the art professor is the change in the way of exhibiting, so in the lighting design. Exhibiting becomes more public and more interactive each day. Lighting strategies must be improved for outdoor exhibiting.

The participant number 89, who is a sculptor, put forward the idea that appreciation of art depends on the space quality where the interaction happened. These qualities also involve lighting. With mentioning skylight application of his own sculpture atelier, the participant found skylight appropriate for lighting sculptures. Warm light was found more suitable for dramatic effect. The participant claimed that cold and warm color temperatures enhances the sensation.

Another sculptor, participant number 90, suggested the idea of balancing the density of the exhibition area. For example, if the artwork is dense then space has to be minimized. Size of the space is one way to reduce the density of the space.

To summarize the main insights in the commentaries:

- Most of the artists tend to abstract the exhibition space such as the most known technique “white box”.
- Following, using contrasting elements with the object such as color temperature or wall color were mentioned.
- Adequacy to use daylight when lighting sculptures and adequacy of artificial light usage when lighting paintings were mentioned by multiple artists.
- Focusing the spotlight to the object is regarded as the most conventional technique. Creating a composition or rhythm with spotlights is implied more than once.
- They tend to trust artificial light. Option of having artificial light is wanted even just as a backup.
- Warm color temperature is appreciated more than once in both art types.
- Regardless of the guidelines, the importance of trial-and-error and case-by-case approach were mentioned several times.
- Multiple times, skylight is found the most adequate type of getting natural light inside the exhibition space.
- The importance of flexibility is implied in almost all interviewee commentaries.
- Negativity of attributes such as “vagueness” and “discomfort” are questioned since they could be intentional.

CHAPTER 5

DISCUSSIONS AND CONCLUSIONS

5.1. Key Findings from Navigation Model

In terms of navigation, there are two apparent results. Firstly, daylight is preferred more in transition zones. Secondly, tendency to move towards daylight increases when approaching to the end of exhibition. There are different navigation choices in occupation groups. Architects and visitors preferred more daylight while artists preferred artificial light.

Daylit exhibition space 6D is the most selected space while 6A is found visually more successful both in T-test and OLS methods. The most important lighting criterion when evaluating lighting is determined as light type which are daylight or artificial light by the participants. In other words, light type is the main influence on the impression of the exhibition area and its lighting.

Similar results are found in the second step of the questionnaire with the methods T-test and OLS. Firstly, Lumion is found successful in visual accuracy in every condition. Daylight is perceived softer in T-test, visually more comfortable in both methods. Artificial light is evaluated over spotlights. Since spotlights are focal, the composition of bright and dim areas is perceived significantly integrated and balanced. Sculpture exhibition is found more integrated and better.

Another difference in exhibition types is that usage of space and the amount of shadows. In both methods, painting exhibition is perceived relaxing, bright, soft and visually comfortable due to less space usage and less shadows. Apart from exhibition and space parameters, a positive relation is found between visual comfort and uniformity criteria.

5.2. Key Findings from Painting Model

A room of three paintings was modelled in 3DMax, three different lighting setting and three light color temperatures were applied to create 9 visuals. The participants were asked to pick and evaluate 3 visuals from each lighting setting group. The responses are analyzed in 5 sections which are selections, impressions, the factors of lighting setting/color temperature and visual quality's relation with other impressions.

Single spotlight and neutral color temperature combination is the most liked for paintings. Warm and cold variations of the same lighting setting are also found successful. The most disliked is visual 3 which is a combination of warm color temperature and ambient lighting. Cold light color in single spotlight and neutral light color multiple spotlight were also disliked. Warmer spotlight settings were less liked. Multiple spotlight setting was regarded as the most interesting. The settings which are regarded as interesting are not liked. Overall, lighting setting is found as the major factor when evaluating the exhibition though color temperature also has some minor effects. It was found out that warm and cold color temperature are dominant in the perception of light color and brightness.

5.3. Key Findings from Sculpture Model

A group of busts were placed and modelled in Relux. A total of 9 different variations (differentiating in lighting setting and color temperature) of the same room are gathered. The participants were asked to pick and evaluate 3 variations from each lighting setting group. Single spotlight and neutral color temperature combination is the most liked for sculpture. Warm ambient lighting is distinctively disliked. As stated in the commentaries, additional background light was regarded as the most interesting in the analysis. On the contrary to the painting room, the most interesting visuals are also liked. Cold light color temperature was not liked though it is picked the most in ambient lighting. The impact of color temperature was found lower on impressions compared the painting model.

5.4. Mutual Findings

One of the side objectives of this study is to find whether lighting setting can change the perception of color temperature. Results of the second and third parts show that lighting setting secondarily alter the perception of color temperature though when the lighting settings are analyzed separately, they do not alter the perception of color temperature, especially in non-neutral color temperatures. Although, lighting setting is the major factor in the evaluation of lighting design in both exhibition types.

Lighting can be evaluated in many criteria and criteria determine the expected impression on the lighting design. Multiple objectives on impressions can be achieved at the same time by understanding the relation between them. Correlation analyses were made. Results in all three models have almost the same pattern in term of correlation between the criteria. Visual comfort and uniformity are positively correlated. Many studies argue that visual comfort and quality are in conflict and compromising must be made according to the intention of the exhibition. Results show that visual comfort and visual quality are not in conflict in all of the models.

Just like the practice by the museum staff, multiple alternatives of lighting configurations (two spotlight configurations and ambient lighting for each model) are tested subjectively but this time with participants from different fields. Set of configurations are different in each model since exhibition types differ. In both models, single spotlight was found the most successful in all color temperatures. Warm light color ambient lighting was rated lowest in both models. It was found out that warm color temperature has influence on the effect of lighting settings. Experimental lighting settings which are multiple spotlight in painting model and additional background light in sculpture room were found the most interesting.

The second and third part of the questionnaire were structured specially to find out the relation between aspects “selection”, “liking”, “disliking” and “catchiness”. The balance or the structure may diversify with the priority of these aspects in an exhibition. For example, catchiness could be the main objective. Results show that liking and disliking were found more related with the selection. Since the findings in second and third part are the same, it can be said that exhibition type does not have an impact on the relations between aspects “selection”, “liking”, “disliking” and “catchiness”. When these aspects are projected on parameters, non-neutral color temperatures in settings were found more interesting than neutral. In both models, conventional technique of spotlight with neutral light color setting were regarded as the most liked yet experimental settings adjusted by following Monza method were regarded as the most interesting.

5.5. Conclusion

The relation between space, exhibition and user parameters in exhibition lighting are investigated in this thesis. Elements and problems of exhibition lighting are defined, a methodology is prepared based on the research. Since the appreciation of lighting in exhibition areas heavily rely on user's subjective response, a questionnaire was prepared. The questionnaire was structured in three parts to meet multiple objectives. Answers to the questionnaire are analyzed with multiple methods. The significance of the study is that a comprehensive research was conducted on user preferences including many parameters.

Since exhibiting involve multiple disciplines, participants are selected equally from architects, visitors and artists to see difference in preference. One of the aims and the contribution of the study is to create a mediating platform of multiple disciplines by detecting their priorities and motivations through preferences on lighting.

In the first part of the questionnaire, virtual model is used to find out the effect of light type in navigation. Although there are studies on navigation on light, this study focused on the effect of light type on navigation with different room conditions. Additionally, the visual fidelity of the visualization software is tested with the questionnaire. The participants toured an exhibition area through a monitor. It was found out that light type has an effect on navigation along with the effect of room conditions. Moreover, it was found out that navigation tendencies on lighting type differ in each occupation group. In further studies, different real-time visualization and displaying techniques can be used.

In the second and third part, a painting room and a sculpture room were modelled with three lighting settings and three different color temperatures. The same methods are used to detect the differences and similarities between in exhibition types. Additionally, the structure of the questionnaire and planning of the analyses are used as tools to understand the impact of multiple parameters separately. For example, the relation between “preference”, “selection” and “catchiness” is examined by correlating the responses.

Overall, it was found out that lighting is an important design element for an exhibition space, especially lighting type. However, it must be noted that many parameters especially in daylighting like window size was disregarded due to the main and aimed objectives. On the other hand, many different factors are included in the study such as the participant, light type, light setting, color temperature, exhibition environment and type. Some findings in this study may be generalized due to this inevitable disregarding. In further studies, parameters and objectives can be narrowed down such as the relation between daylight parameters and navigation solely.

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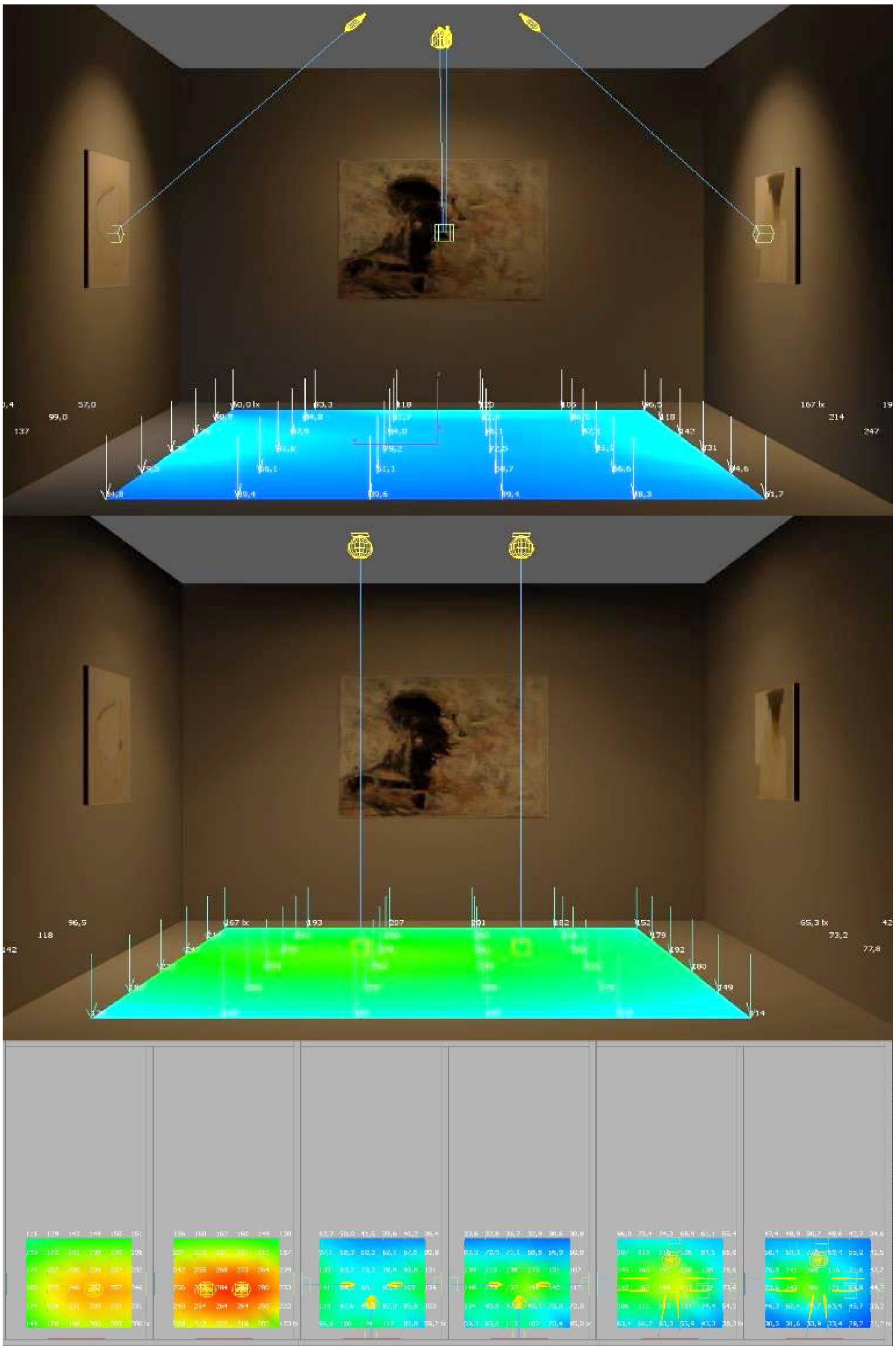
APPENDIX A

3DMAX MODELLING



APPENDIX B

QUESTIONNAIRE

Questionnaire for Lighting Preferences in Museums and Galleries

DATE:__:__

HOUR:__:__

PARTICIPANT NUMBER: __

SKY CONDITIONS: CLEAR / OVERCAST / NIGHT

LIGHT: DIRECT DAYLIGHT / ARTIFICIAL LIGHT

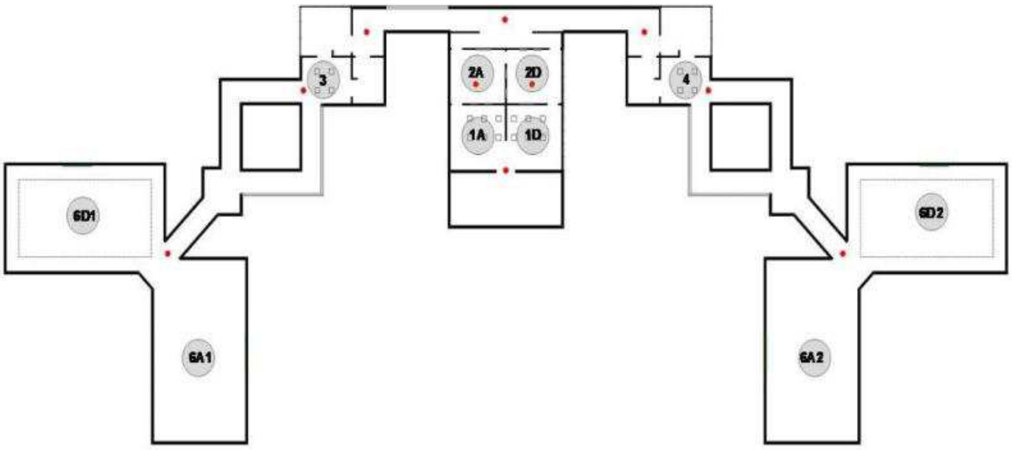
A1) Museum/Gallery Navigation

Used software for questionnaire: Lumion 6.0

Please mark turning points you selected in the gallery.

TURNING POINT	LEFT	RIGHT
1		
2		
3		
4		
5		
6		

A2) Of all shown rooms you've seen which one's lighting did you like the most? _____



A3) Please evaluate the selected room lighting in question A-2? (Rate 1 to 5 regarding descriptions)

SETUP:		**1**	**2**	**3**	**4**	**5**	
Lighting Type	1-natural						artificial
Displaying of the pieces	2-desegregated						integrated
Quality of the space	3-vague						distinct
	4-dim						bright
	5-dull						catchy
	6-tense						relax
	7-harsh						soft
	8-discomfort						comfort
	9-imbalanced						uniform
10-How pleasant is color temperature? (circle the option)		Too warm	warm	Fine	Cold	Too Cold	
11-Overall visual quality of the space?	Bad						Good

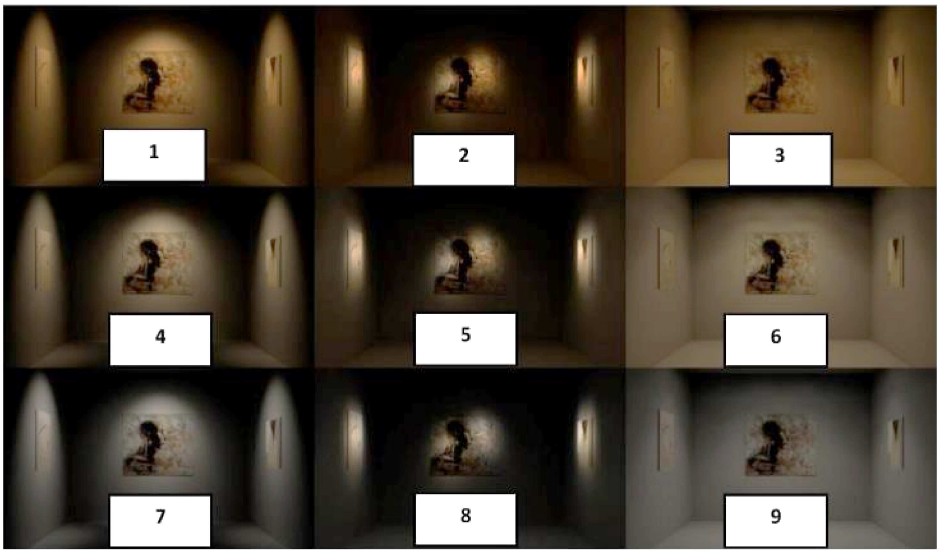
A4) Circle up to 3 questions/characteristic that you find the most important for assessing museum lighting quality.

1-natural/artificial__
2-desegregated/integrated__
3-vague/distinct__
4-dim/bright__
5-dull/catchy__
6-tense/relax__
7-harsh/soft__
8-discomfort/comfort__
9-imbalanced/uniform__
10-color temperature__
11-overall quality of space__

B: Lighting Evaluation of Paintings (used software for questionnaire: 3d Max 2016)

B1) Circle 3 lighting setup you would like to rate.
Important: You must select at least one image from each column (See sample right)

	SAMPLE (SETUP)		
COLOR TEMP	(1)	2	3
	4	(5)	(6)
	7	8	9



B2) Please evaluate the selected setups.

Image 1		1	2	3	4	5	
Displaying of the pieces	1-desegregated						integrate d
Quality of the space	2-vague						distinct
	3-dim						bright
	4-tense						relax
	5-harsh						soft
	6-discomfort						comfort
	7-imbalanced						uniform
8-How pleasant is color temperature? (circle the option)		Too warm	warm	Fine	Cold	Too Cold	
9-Overall visual quality of the space?	Bad						Good
Image 2		**1**	**2**	**3**	**4**	**5**	
Displaying of the pieces	1-desegregated						integrate d
Quality of the space	2-vague						distinct
	3-dim						bright
	4-tense						relax
	5-harsh						soft
	6-discomfort						comfort
	7-imbalanced						uniform
8-How pleasant is color temperature? (circle the option)		Too warm	warm	Fine	Cold	Too Cold	
9-Overall visual quality of the space?	Bad						Good

3

Image 3		1	2	3	4	5	
Displaying of the pieces	1-desegregated						integrated
Quality of the space	2-vague						distinct
	3-dim						bright
	4-tense						relax
	5-harsh						soft
	6-discomfort						comfort
	7-imbalanced						uniform
8-How pleasant is color temperature? (circle the option)		Too warm	warm	Fine	Cold	Too Cold	
9-Overall visual quality of the space?	Bad						Good

B3) Out of all 9 lighting setups which setup did you like the most? ___
B4) Out of all 9 lighting setup which setup did you dislike the most?___
B5) Which setup did you find the catchiest (It can be same with question B3 or B4) ?___

C: Lighting Evaluation of Sculptures (used software for questionnaire: Relux)

C1) Select 3 lighting setups you would like to continue with **Important: You must select at least one image from each column**. How would you describe the room lighting?

	SAMPLE (SETUP)		
COLOR TEMP	1	2	3
	4	5	6
	7	8	9

C2) Please evaluate the selected setups.

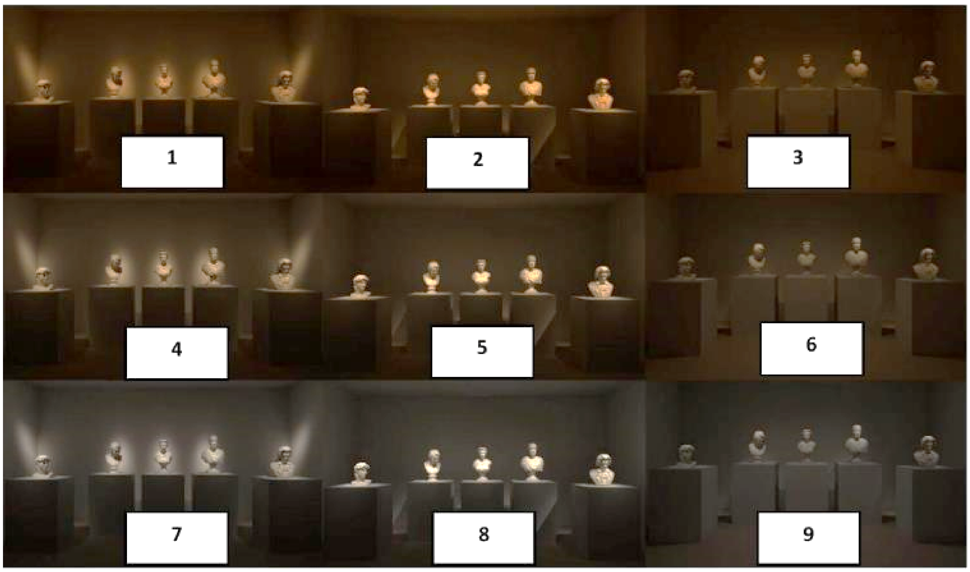


Image 1		1	2	3	4	5	
Displaying of the pieces	1-desegregated						integrated
Quality of the space	2-vague						distinct
	3-dim						bright
	4-tense						relax
	5-harsh						soft
	6-discomfort						comfort
	7-imbalanced						uniform
8-How pleasant is color temperature? (circle the option)		Too warm	warm	Fine	Cold	Too Cold	
9-Overall visual quality of the space?	Bad						Good

Image 2		1	2	3	4	5	
Displaying of the pieces	1-desegregated						integrated
Quality of the space	2-vague						distinct
	3-dim						bright
	4-tense						relax
	5-harsh						soft
	6-discomfort						comfort
	7-imbalanced						uniform
8-How pleasant is color temperature? (circle the option)		Too warm	warm	Fine	Cold	Too Cold	
9-Overall visual quality of the space?	Bad						Good

Image 3		1	2	3	4	5	
Displaying of the pieces	1-desegregated						integrated
Quality of the space	2-vague						distinct
	3-dim						bright
	4-tense						relax
	5-harsh						soft
	6-discomfort						comfort
	7-imbalanced						uniform
8-How pleasant is color temperature? (circle the option)		Too warm	warm	Fine	Cold	Too Cold	
9-Overall visual quality of the space?	Bad						Good

C3) Out of all 9 lighting setups which setup did you like the most? ___
C4) Out of all 9 lighting setup which setup did you dislike the most?___
C5) Which setup did you find the catchiest?___

Personal Information

Gender (F/M)		**Age**		**Occupation**	
Auxiliary element for your sight		glasses	contact lenses	Don't use	Other (please define)
Sight problems	myopic	hypermetropic	astigmatism	No problem	Other (please define)

D) Do you have any comment or knowledge that you want to share about the topic or the questionnaire?

THANK YOU FOR YOUR PARTICIPATION

APPENDIX C

RESPONSE ORGANIZATION

PERSONAL INFORMATION & ENVIRONMENT									A-NAVIGATION					
									A1 NAVIGATION					
NO	AGE	GENDER	Occupation Group	Occupation	Visual Impairments	Visual Gadget	Sky Conditions	Interior Lighting	1	2	3	4	5	6
1	31	F	AR	Architect	None	None	OVERCAST	NATURAL	A	D	D	A	D	D
2	28	M	VIS	IT	None	None	OVERCAST	NATURAL	A	A	D	D	D	D
3	29	F	AR	Architect	M+A	None	OVERCAST	NATURAL	A	A	D	D	D	A
4	24	F	AR	Architect	H+A	Glasses	OVERCAST	NATURAL	A	A	A	D	D	D
5	21	M	AR	Student (AR)	None	None	OVERCAST	NATURAL	A	D	D	A	D	A

A NAVIGATION														
	A3 EVALUATION											A4 IMPORTANCE OF QUESTIONS		
A2 SELECTED	1-natural/ artificial	2-desegregated/ integrated	3-vague/ distinct	4-dim/ bright	5-dull/ catchy	6-tense/ relax	7-harsh/ soft	8-discomfort/comfort	9-imabalanced / uniform	10-Color of light	11-Visual Quality			
3	3	2	3	4	3	1	2	1	2	2	2	1	3	10
6A1	3	5	2	3	5	3	2	5	5	2	3	6	10	11
1A	5	4	5	3	3	2	1	3	4	2	2	4	9	10
1D	4	3	4	2	3	3	2	4	2	4	3	1	6	11
1A	5	2	5	3	4	3	2	3	2	4	2	1	8	10

B PAINTINGS												
	B2 EVALUATION											
	SINGLE SPOT (1,4,7)											
B1	1-des/ integrated	2-distinct/ vague	4-dim/ bright	4-tense/ relax	5-harsh/ soft	6-dis/comfort	7-imabalanced / uniform	8-Color of light	9-Visual Quality	B3	B4	B5
7	2	4	2	3	2	2	5	4	4	6	2	4
4	5	5	5	5	3	5	5	2	3	6	2	8
7	3	4	3	4	3	4	3	4	3	7	3	8
4	2	5	2	3	2	4	4	3	4	4	3	5
7	5	5	2	4	1	5	5	4	4	6	3	8

B PAINTINGS										B PAINTINGS									
	B2 EVALUATION										B2 EVALUATION								
	MULTI SPOT (2,5,8)										AMBIENT (3,6,9)								
B1	1-des/ integrated	2-distinct/ vague	4-dim/ bright	4-tense/ relax	5-harsh/ soft	6-dis/comfort	7-imabalanced / uniform	8-Color of light	9-Visual Quality	B1	1-des/ integrated	2-distinct/ vague	4-dim/ bright	4-tense/ relax	5-harsh/ soft	6-dis/comfort	7-imabalanced / uniform	8-Color of light	9-Visual Quality
5	1	2	1	3	2	1	4	3	1	6	5	5	3	5	5	5	5	2	5
8	5	3	1	1	1	2	3	4	3	6	5	5	1	5	5	5	5	3	4
8	3	3	3	4	4	4	4	4	3	9	3	2	2	4	4	2	4	4	1
5	4	3	1	5	4	3	3	4	3	9	5	2	3	4	4	2	4	5	2
8	4	5	1	2	1	5	5	3	4	3	3	4	2	5	4	4	5	2	4

C SCULPTURE												
	C2 EVALUATION											
	BACKGROUND SPOT (1,4,7)											
C1	1-des/ integrated	2-distinct/ vague	4-dim/ bright	4-tense/ relax	5-harsh/ soft	6-dis/comfort	7-imabalanced / uniform	8-Color of light	9-Visual Quality	C3	C4	C5
7	3	3	2	2	2	3	2	4	3	8	3	7
4	5	5	1	5	5	5	5	4	5	5	3	8
7	2	4	2	4	3	4	3	4	3	8	3	8
4	3	4	4	2	2	3	3	4	4	7	3	7
7	5	5	3	4	1	5	5	4	5	8	3	7

C SCULPTURE										C SCULPTURE									
	C2 EVALUATION										C2 EVALUATION								
	SINGLE SPOT (2,5,8)										AMBIENT (3,6,9)								
C1	1-des/ integrated	2-distinct/ vague	4-dim/ bright	4-tense/ relax	5-harsh/ soft	6-dis/comfort	7-imabalanced / uniform	8-Color of light	9-Visual Quality	C1	1-des/ integrated	2-distinct/ vague	4-dim/ bright	4-tense/ relax	5-harsh/ soft	6-dis/comfort	7-imabalanced / uniform	8-Color of light	9-Visual Quality
5	5	4	3	2	4	4	4	2	4	9	2	1	1	3	2	1	1	4	1
5	5	5	1	3	4	5	5	3	5	9	5	3	1	1	1	2	5	5	5
8	4	4	4	4	2	4	4	4	4	9	3	2	4	4	4	2	4	3	1
2	3	2	4	4	3	3	3	3	2	3	3	1	1	4	4	1	3	4	1
8	5	5	4	4	2	5	5	3	5	3	1	1	1	2	5	1	1	2	1

APPENDIX D

OLS RESULT SAMPLE

```
Call:lm(formula = desegregates ~ warm1 + warm2 + neutral4 +
neutral5 + neutral6 + cold7 + cold8 + cold9)

Residuals:
    Min      1Q  Median      3Q     Max
-2.91837 -0.91837 0.08163 1.07438 2.05263

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.3750    0.3072  10.985  <2e-16 ***
warm1        0.9408    0.4170   2.256  0.0249 *
warm2       -0.4276    0.4170  -1.026  0.3061
neutral4     0.5114    0.3588   1.425  0.1553
neutral5    -0.1192    0.3599  -0.331  0.7408
neutral6     0.5434    0.3539   1.536  0.1259
cold7        0.6991    0.3877   1.803  0.0725 .
cold8       -0.2679    0.3851  -0.695  0.4874
cold9        0.3850    0.3935   0.979  0.3287
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 1.229 on 261 degrees of freedom
Multiple R-squared:  0.1026,    Adjusted R-squared:  0.07514
F-statistic: 3.732 on 8 and 261 DF,  p-value: 0.0003744
> summary(lm(vaguedistinct ~ warm1 + warm2 +neutral4 +neutral5
+neutral6 +cold7 +cold8 +cold9))

Call: lm(formula = vaguedistinct ~ warm1 + warm2 + neutral4 +
neutral5 +  neutral6 + cold7 + cold8 + cold9)

Residuals:
    Min      1Q  Median     3Q    Max
-3.3158 -0.8411 -0.0370 0.9184 2.1053
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.5000    0.3036  11.528  <2e-16 ***
warm1        0.8158    0.4121   1.980  0.0488 *
warm2       -0.6053    0.4121  -1.469  0.1431
neutral4     0.7045    0.3545   1.987  0.0479 *
neutral5    -0.1977    0.3556  -0.556  0.5788
neutral6     0.5816    0.3497   1.663  0.0974 .
cold7        0.5370    0.3831   1.402  0.1622
cold8       -0.2857    0.3806  -0.751  0.4535
cold9        0.1800    0.3888   0.463  0.6438
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.214 on 261 degrees of freedom
Multiple R-squared:  0.1239,    Adjusted R-squared:  0.09708
F-statistic: 4.615 on 8 and 261 DF,  p-value: 2.759e-05
> summary(lm(dimbirght ~ warm1 + warm2 +neutral4 +neutral5
+neutral6 +cold7 +cold8 +cold9))

Call:lm(formula = dimbirght ~ warm1 + warm2 + neutral4 + neutral5
+ neutral6 + cold7 + cold8 + cold9)

Residuals:
    Min      1Q  Median     3Q    Max
-2.6531 -0.7674 0.1429 0.4815 4.1429

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.1875    0.2715  11.741 < 2e-16 ***
warm1       -1.0296    0.3685  -2.794 0.005588 **
warm2       -1.3980    0.3685  -3.794 0.000184 ***
neutral4    -0.4602    0.3170  -1.452 0.147790
neutral5    -1.4201    0.3180  -4.465 1.19e-05 ***
neutral6     0.4656    0.3127   1.489 0.137719
cold7       -0.6690    0.3426  -1.953 0.051937 .
cold8       -1.3304    0.3403  -3.909 0.000118 ***
cold9       -0.1875    0.3477  -0.539 0.590141
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.086 on 261 degrees of freedom
Multiple R-squared:  0.2906,    Adjusted R-squared:  0.2688
F-statistic: 13.36 on 8 and 261 DF,  p-value: 3.514e-16
> summary(lm(tenserelax ~ warm1 + warm2 +neutral4 +neutral5
+neutral6 +cold7 +cold8 +cold9))

Call:lm(formula = tenserelax ~ warm1 + warm2 + neutral4 + neutral5
+  neutral6 + cold7 + cold8 + cold9)

Residuals:
    Min      1Q  Median     3Q    Max
-2.9474 -0.7711 0.1250 1.1020 2.4737

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.87500   0.30063  12.890 < 2e-16 ***
warm1        0.07237   0.40802   0.177 0.85936
warm2       -1.34868   0.40802  -3.305 0.00108 **
neutral4    -0.14773   0.35106  -0.421 0.67424
neutral5    -0.43314   0.35214  -1.230 0.21980
neutral6     0.02296   0.34625   0.066 0.94718
cold7       -0.20833   0.37938  -0.549 0.58338
cold8       -1.08929   0.37685  -2.890 0.00417 **
cold9       -0.19500   0.38499  -0.507 0.61293
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 1.203 on 261 degrees of freedom
Multiple R-squared:  0.1161,    Adjusted R-squared:  0.08897
F-statistic: 4.284 on 8 and 261 DF,  p-value: 7.374e-05
> summary(lm(harshsoft ~ warm1 + warm2 +neutral4 +neutral5
+neutral6 +cold7 +cold8 +cold9))

Call:lm(formula = harshsoft ~ warm1 + warm2 + neutral4 + neutral5
+ neutral6 + cold7 + cold8 + cold9)
Residuals:
    Min      1Q  Median     3Q    Max
-2.7755 -0.7755 0.2245 1.0625 2.4643
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.9375    0.2983  13.201 < 2e-16 ***
warm1        0.5362    0.4048   1.324 0.186498
warm2       -1.1480    0.4048  -2.836 0.004928 **
neutral4    -0.1648    0.3483  -0.473 0.636556
neutral5    -0.7980    0.3494  -2.284 0.023178 *
neutral6    -0.1620    0.3435  -0.472 0.637646
cold7       -0.5671    0.3764  -1.507 0.133100
cold8       -1.4018    0.3739  -3.749 0.000219 ***
cold9       -0.3375    0.3820  -0.884 0.377737
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.193 on 261 degrees of freedom
Multiple R-squared:  0.1583,    Adjusted R-squared:  0.1325
F-statistic: 6.134 on 8 and 261 DF,  p-value: 2.99e-07
> summary(lm(discomfort ~ warm1 + warm2 +neutral4 +neutral5
+neutral6 +cold7 +cold8 +cold9))
```