MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

LED TECHNOLOGY USAGE IN NIGHT LIGHTING IN OPEN AIR MUSEUM

SAFİYE NAZMİYE ÖZTÜRK

MASTER THESIS

Department of Electrical-Electronic Engineering

Thesis Supervisor
Assoc. Prof. Dr. Mustafa Onat

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Dr. Hasan Hüseyin Çelik

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Safiye Nazmiye ÖZTÜRK, a Master of Science student of Marmara University Institute for Graduate Studies in Pure and Applied Sciences, defended her thesis entitled "**Led Technology Usage In Night Lighting In Open Air Museum**", on 25/02/2020 and has been found to be satisfactory by the jury members.

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APPROVAL

Marmara University Institute for Graduate Studies in Pure and Applied Sciences Executive Committee approves that Safiye Nazmiye Öztürk be granted the degree of Master of Science in Department of Electrical and Electronics Engineering, Electrical and Electronics Engineering Program, 04.03.2020 (Resolution no: 2020/08-02).

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Date	**Name/Surname**
20.02.2020	Safiye Nazmiye ÖZTÜRK

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ÖZET

AÇIK HAVA MÜZELERİNDE GECE AYDINLATMASINDA LED TEKNOLOJİSİ KULLANIMI

Türkiye'de son yıllarda müzelerin önemine vurgu yapılırken, açık hava müzeciliği (örenyerleri) ayrı olarak değerlendirilmeye başlanmıştır. Örneğin, Cumhurbaşkanlığı tarafından 2018 yılı "Troia yılı " ilan edilmiştir, ve UNESCO Dünya Kültür Mirası Listesine 1998 yılında girmiştir. Aynı şekilde, Kültür Bakanlığımızın çalışmaları ile 2020 yılı "Patara Antik Kenti" olmuştur ve 2019 yılı "Göbeklitepe Yılı" kabul edilmiş olup, bu yıl UNESCO Dünya Mirası Listesine girmiştir**.** Türkiye'nin çok eski tarihlerden beri süre gelen bir çok medeniyete ev sahipliği yapmış olması "taşı toprağı altın" deyimini doğrulamaktadır. Türkiye'nin farklı bölgelerine geziler yapıldığında, bir çok tarihin saklı olduğunu hem görür, hem de hissedersiniz. Ancak ülkemizde müzeleri özellikle açık hava müzeleri sadece gün ışığında ve bulunduğu yere göre belirli bir zaman diliminde görebilme imkanımız vardır. İngiltere, Almanya, Fransa, Amerika gibi gelişmiş ülkelerde bu tür tarihi önem taşıyan müzeler, açık hava müzelerini, kullanılan LEDler ile hava karardıktan sonrada gezebilme imkanı vardır, çünkü, LEDler sanat dünyasından, eğlence sanayi, cadde ve sokaklara kadar birçok alanda pratik ve verimli kullanım imkanı sunmaktadır. Son yıllarda, ülkemizin sahip olduğu bu zengin ve değerli mirasları, sadece gün ışığında değil, geceleride yerli ve yabancı turistlerin gezebilmeleri ve eserler hakkında bilgilenebilmeleri için gece aydınlatma sistemlerinin olmayanlarda kurulması, ve var olan sistemlerin daha modern hale getirilmesi konuları gündemdeki yerini korumaktadır.

Bu çalışmada, açık hava müzelerinin, dış mekan aydınlatma ile geceleri aktif durumda kalması için doğru ve modern teknoloji donanımlarının kullanımıyla, LED teknolojileri kullanılarak, 3 boyutlu modelleme ve aydınlatma tasarımı yapıldı. Bu çalışma, açık hava müzelerimizden Laodikia ve Afrodisiası konu edinip, var olan aydınlatma sistemleri incelendi. Örnek olarak seçilen LEDler ile geceleyin uygulamalar yapıldı. Müzelerin seçilen bölümlerindeki tarihi eserler ve yolların 3D görünümü oluşturularak aydınlatma sonuçları incelendi. Uygulamaların sonuçlarına göre, müzelerin gece aydınlatılması için LEDler kullanılarak doğru renk sıcaklığı, geri verim indeksi, ışık verimi, yerleşimi ve açık hava müzelerinin yapısı çok iyi analiz edilerek istenilen sonuçlara ulaşılabileceği gözlendi. Elektrik-Elektronik mühendisleri ile farklı alandaki mühendisliklerin bir arada ortak çalışma yapmalarının gerekli olduğu saptandı. Çünkü, ortak olarak yapılacak çalışmadan ortaya çıkacak sonuçlara göre, açık hava müzelerimizin yapısına uygun özel LED tasarımı, ve aydınlatma sistemi kurulması gerektiği sonucuna ulaşılmıştır.

Kelimeler: müze aydınlatma, renk sıcaklığı, aydınlatma tasarımı, renk geri verim indeksi, açık hava müzesi

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ABSTRACT

LED TECHNOLOGY USAGE IN NIGHT LIGHTING IN OPEN-AIR MUSEUM

While emphasizing the importance of museums in Turkey in recent years, the open-air museums (ruins) have begun to be considered separately. For example, the year of 2018 was declared as the “Troia year” by our Presidency, and was included in the UNESCO World Heritage List in 1998. Likewise, with the works of our Ministry of Culture, 2020 became the “Patara Ancient City” and 2019 was accepted as the “Göbeklitepe Year” and was included in the UNESCO World Heritage List this year. Turkey's long history of many civilizations confirms the statement "paved with gold". When you visit different parts of Turkey, you see a lot of history, and you feel it. However, in our country, we have the opportunity to see open-air museums, only in daylight and in a certain time period according to the location. In developed countries such as England, Germany, France, and America, such historical museums have the opportunity to visit open-air museums after the dark with the LEDs used, because LEDs offer many possibilities from the art world to the entertainment industry, and streets. In recent years, to be visited and to be informed of local and foreign tourists about our history, the issues of establishing night lighting systems or the issues to make the existing systems more modern have remained on the agenda.

In this study, both 3D modeling and lighting design were made by using the right and modern technology devices, namely LED technologies, to keep the open air museums active at night with outdoor lighting. This study is based on Leodikeia and Aphrodisias of our open-air museums, and the existing lighting systems were examined, and experiments were made in the dark with selected LEDs as an example. Illumination results were examined by creating a 3D view of historical artifacts and roads in selected sections of the museums. Implementation of it was observed and the desired results could be achieved by analyzing the LEDs having correct color temperature, color rendering index, light efficiency, placement and the structure of the open air museums very well to illuminate the museums at night. It could be determined that electrical and electronic engineers and engineering in different fields should collaborate together. Because,

according to the results to be obtained from the joint work, it has been understood that special LED design, and lighting system and 3D design should be installed in accordance with the structure of our outdoor museums.

Keywords: museum lighting, colour temperature, lighting design, color rendering index, open air museum

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SYMBOLS

λ	:	Wavelength
T	:	Blackbody Temperature
W_λ	:	Spectral Radiant Emittance
R_a	:	General colour rendering index
R_i	:	Special colour rendering indices
L	:	The glow that our eyes perceive
LD	:	Glow of detail
ΔL	:	Absolute glow difference
C	:	Relative Glow
$E(\varepsilon, \eta)$	:	Space angle
$I(\lambda)$	:	Spectral light intensity
A	:	The surface area of the sphere

ABBREVIATIONS

SSL : Solid State Lighting

LED : Light Emitting Diode

HID : High - Intensity Discharge

CCT : Correlated Color Temperature

CRI : Color Rendering Index

IEC : International Electrotechnical Commission

SDCM : Standard Deviation Colour Matching

NIST : The National Institute of Standards and Technology

IES : Illumination Engineering Society

NEMA : National Electrical Manufacturers Association

IESNA : Illuminating Eangineering Society Of North America

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Chapter 1 Introduction And Objective

1.1 History and Background

There are two types of light sources known since the existence of the world and human beings. The first one is the daylight provided by the sun that we all know. And we have the opportunity to benefit from daylight at certain times of the day. However, people is changing their demands and their desires have altered the necessity to benefit from the power of light at night, both in the business world and in areas such as the security, health and entertainment sectors. For this reason, the second source is artificial light, where people still continue their studies by trying various tools and techniques and lighting engineering has been developing on artificial lighting techniques in the current century. Particularly, in the 21st century, studies on LED technologies in the lighting industry continue to increase.

Because light is a concept as old as human history, people began to pay more attention to visit museums to maintain the relationship between past and present. While the illumination of such historical places is coming to the fore, the use of LED technologies has started to spread rapidly all over the world and in all areas because Light Emitting Diodes allows you to control the colors and to make the desired settings. In many European countries abroad, museums meet day and night standards with LED Technologies [5]. Recently, open air museum in Turkey brought the agenda the opening of the domestic and foreign tourists at night. Activities can be expanded with night lighting projects and museums can be visited during the dark hours and made more colorful with LED [1].

As the use of LED continues to become widespread in museums, outdoor and indoor lighting in Europe, the importance of LED technologies in every field is emphasized. Because while providing visual comfort at optic levels with LED technologies, energy use is minimized and CO_2 emission is reduced in terms of environmental safety.

In our country, attaching great importance to night illumination of historical places brings to mind the questions of whether the lighting systems of open air museums are installed adequately and systematically. One of the working stages of this thesis was to visit and to study the museums. After observations and reviews, it was understood those lighting systems in our open-air museums have a limited degree illumination, false illumination and almost no illumination system. In this study, the importance of design for energy saving LED light source models used for outdoor lighting at night in outdoor museums are specified. With the LED sources, the appropriate color temperature (CCT) around the museum, satisfying light tones according to brightness, the color rendering index, and their light efficiency are analyzed. By comparing the results with both application and 3D design, suggestions are offered for the selection of the most suitable lighting system and LED source for historical places [2].

1.2 Important Reasons For Choosing This Thesis Topic

In recent years, the importance of many historical ruins and places hidden in our country has been brought back to the agenda and it has increased my interest in museums. Open air museums have a very different structure than the museum concept we know. Open air museums include the cities established by civilizations and societies that have lived in our country before. In fact, it contains many elements such as lifestyle, street, uilding, and infrastructure, which are very close to today's city concept. While visiting the open-air ruins, I saw that tourists attach great importance to these historical places and the historical ruins and artifacts they contain. Through the Internet, I gained an overview of museums abroad. However, I realized that these places were allowed to be visited with the appropriate lighting systems in the evening, that is, they could be visited in the evening with the most used LED technologies of the 21st century. For this reason, I asked myself the question of why not open to domestic and foreign tourists in the evening. For another reason, I have seen that some of the open-air museums do not have enough lighting, whereas in others, there is a bit lighting. Today, lighting is no longer a simple concept, it is a field that evolves and continues to progress. The developments in lighting engineering, not only electrical-electronic, but also architecture, film industry, advertising, and many other disciplines such as its continuing development, brought to mind the idea of advancing myself by working in this field. For this reason, I decided to do an exemplary thesis study by using application and 3D design for night illumination in open air museums using LED technologies.

1.3 Purpose and Importance

The purpose of this study is to understand the importance of lighting with LED technologies, comparing the old lighting scheme with the new technology. The experimental study needs that electrical energy consumption with its modern design concept minimizes and presents an an exemplary study to keep open air museums open to visitors at night. Because LEDs are economical, sustainable and save energy by consuming less energy. It is to explain that our open-air museums, which exist in many parts of our country, It can be opened to local and foreign tourists at night with the necessary studies and correct lighting systems, as in Europe and other developed countries.

1.4 Methodology

Multiple approaches are used in this study. First, the museum was visited, the existing lighting structure and plan were analyzed and experience gained. Second, a place was determined in the museum area for the application, and lighting measurements were made in the evening with the LEDs selected as an example. The most important point was to present an aesthetic solution for the appropriate lighting technique and design for outdoor artifacts and roads in open air museums without damaging the historical texture [4]. Lighting work at the museum site and simulation were done on the program. As a result of these studies, it was tried to reach the appropriate result by making a comparison between the existing lighting and the designed lighting.

1.5 Methods

The existing lighting in historical places was examined, a general idea was obtained at the study measurement points selected as examples in various open air museums, while collecting information about the historical texture, it was tried to create a floor plan by taking many photos. In order to be able to make outdoor lighting in these open-air museums, some points were applied with different LED models at dark. According to the conclusions; firstly, the 3D image was studied and an appropriate lighting model was created to advance the illumination with almost or almost none.

Before moving to the field view of this study, the settlement plan and satellite images and photos prepared for the area to be applied were examined. The lighting plan or electrical plan was researched as a reference. Due to the sensitive naturalness of these places, information was collected and photographs were taken via the internet.

During our visit to these open air museums, we observed the lighting devices that existed and identified their locations. After examining the area and taking notes about the area, information was obtained on the existing lamp models in external lighting systems, how lighting control was achieved, area plan measurements and discrepancies were noted. Information was obtained about existing lamp models. Later, by designing on the computer, lighting system and design were created on the open air museum. Lamp information was created. The field images of the open air museum and the places of application and the outdoor lighting designed on the computer were compared through photographs. In these measurements, we emphasized that it is necessary to be able to capture the light tone and suitable temperature for the texture of historical places in our country for experimental purposes and the lighting systems that have been made up to now in these places were not made correctly.

Chapter 2 LED Technology And Lighting

2.1 Solid State Lighting (LEDs) From Past To Present

Electrical luminescence is a phenomenon that comes from light in LEDs. It was first studied in about 1907. Commercially, the first LEDs were given to IBM. It was first tried in computers that we use for reasons such as reducing the heat and the required power, allowing the machines to shrink in size and producing more reliable results with the light generated by the LEDs. However, in the beginning, due to the lack of technology and circuits, despite the desired efficiency, the practicality in use and the opportunity to develop as a technology, it contains many different disciplines such as semiconductivity, optics, electromagnetic wave theory, physics, mathematics, especially in the lighting industry. The fact that there are many topics to be researched makes it valuable in terms of technological advances [6]. As a result, LEDs (SSL -Solid State Lighting) have come as a research and technology product century ago. Continuing to work as long as power is applied means that it always produces light in theory [26]. LEDs continue to produce light even when the amount of light drops to the point where the human eye cannot see. So it is not out of use.

Conventional lighting sources use plasma, gas, filament and mercury, harmful toxic substances, while they are not used in LEDs. Besides being environmentally friendly and long-lasting, energy saving, LEDs can be controlled and adjusted. Spread spectrum can be controlled for health and peace due to electronic structure of LEDs in the future. Its application to computer-use technologies such as software shows that the smart technolgy and smart energy usage area will develop further.

2.2 The Importance Of Solid State Lighting (LED)

Solid state lighting has started to be used in many places where incandescent lighting is used because it contains many features such as the quality of halogen lamps and the effectiveness of using fluorescent lamps. In addition, due to the characteristics of its resources, it allows the product designs to be re-imagined, reproduced and to make the lighting equipment smaller and more useful. In addition, it allows the use of more colorful and more dynamic directions. In addition to qualitative and careful work, old lighting systems are left in industrial infrastructures and many places requiring important testing standards and mechanisms and the transition to new technology LEDs continue [6]. With the warning light embedded in LEDs, it was taken into account in the monitoring and analysis of building uses and traffic, in these universities, health institutions, in areas where logistics planning is made, in shopping malls, airports, historical and touristic places, it will increase income, increase safety, and contribute to operational qualifications.

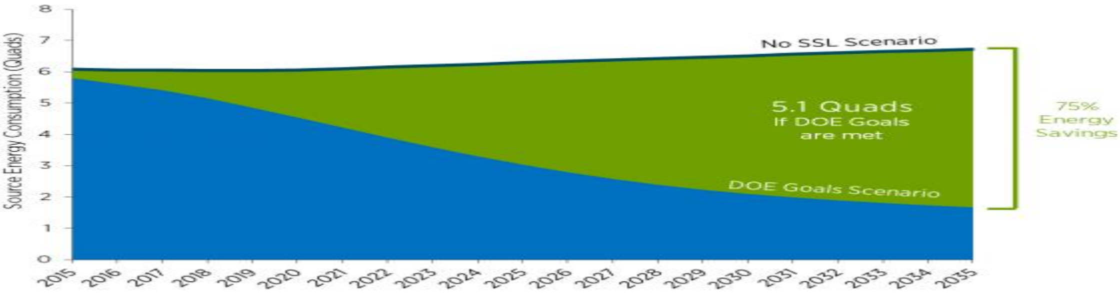


Figure II.1 Energy saving in LED lighting between 2015-2035 [7]

Reference: The United States (U.S.) Department of Energy (DOE)

As shown in Figure II.1, if the LEDs targeted until 2035 are put on the market and offered to consumers, 75% energy consumption will decrease and 5.1 quadrillion. British Thermal Units (quads) indicate that energy savings will be achieved. It is approximately equal to the energy consumed in 45 million U.S houses [7]. In other words, if LEDs are not used, the energy spent in the lighting industry will be 6.7 quads. The most important feature of SSL lamps is their efficiency in energy conversion compared to incandescent and fluorescent lamps. Incandescent lamps consume most of the electrical energy and convert it into heat energy, the amount of visible light is very low and unnecessary energy consumption occurs because the lamp emits heat. So, it converts to about 90% heat energy. Fluorescent lamps consume less energy than incandescent lamps, about 75%. LEDs consumes less energy than fluorescent lamps, incandescent lamps and fluorescence, it is about 80%. In addition, the operating time of LEDs is longer than other lamps [7].

2.3 Working Principle Of LEDs

LEDs consist of N-type and P-type semiconductor material. N-type contains a large number of free electrons. P-type contains holes because the number of electrons is not enough. The electric current moves in one direction through the LED. When current is applied to the electrons, they release energy and go to the hole and merge. They form the light tones. The color of the light changes according to the type of semiconductor material used. Different wavelengths of light can be obtained according to these materials [24]. That is, the wavelength of light depends on the bandwidth of the semiconductor material.

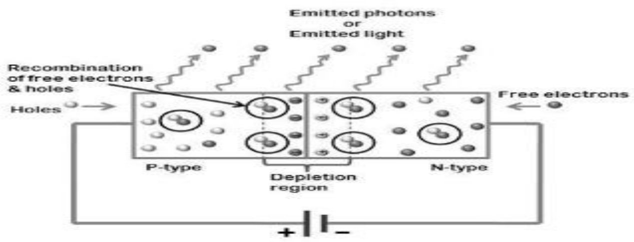


Figure II.2 Working rule of LEDs [24].

Light emission due to the combination of electron-hole pair at forward voltage

In Figure II.2, the working principle of LEDs can be explained by quantum theory. Electrons switch between energy levels. When electrons pass from one energy level to another, they emit energy in the form of photons. This energy is emitted from the photon. Also, this energy of photon is equal to the energy gap between energy levels.

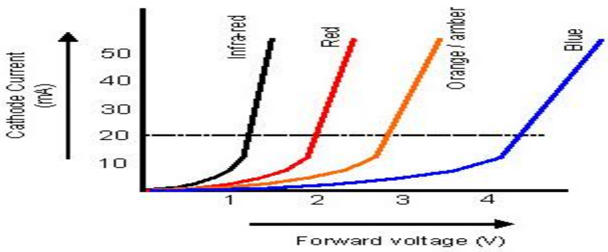


Figure II.3 Display of colors in advanced voltage current [24].

In Figure II.3, LEDs have wavelength, light intensity and distinctive features such as color, radiation. The most important feature is that colors can be created according to the wavelengths and semiconductor materials used [8].

In electromagnetic radiation, the product of plank constant h and frequency is equal to the energy of the photon. In addition, the speed of light is displayed as the connection between speed and frequency, f = c/λ. The wavelength of the light is expressed as λ = c/f. When determining the wavelength, Broglie Wavelength formulas are also used. The Energy of Light Particle is expressed as E and Momentum as p. From the equations between Energy and Momentum [4,24] ;

$E = hc$……………………………………………………………………………(II.1)

$E = mc$……………………………………………………………………………(II.2)

$f = c/\lambda$…………………………………………………………………………...(II.3)

$p = mv$ ………………………………………………………………………...(II.4)

$p = h/\lambda$…..…………………………………………………………………………(II.5)

Denklemler : II.1, II.2, II.3, II.4, II.5

$E = mc * c \qquad mc = E/c$

$p = E/c \quad p = hf/c \qquad p = hc/c\lambda \qquad p = h/\lambda$

$p = mv \qquad p = h/\lambda$

$mv = h/\lambda$

ışığın dalga boyu

$\lambda = \frac{h}{mv}$ olarak bulunur.

As a result, if the electron gains energy, it moves into a high energy level orbit, when it loses energy, it will move into a lower energy orbit and the photon emits, while differences in energy level cause the spectra to appear, energy is taken or emitted. It raises the rule of energy and momentum.

Table II.1 Light colors according to wavelengths [10]

Colour	Wavelength
Infrared	λ >760 nm
Red	620 < λ < 750 nm
Orange	590 < λ < 620 nm
Orange / Amber	590 < λ < 610 nm
Yellow	570 < λ < 590 nm
Green	500 < λ < 570 nm
blue	450 < λ < 500 nm
Violeta	400 < λ < 450 nm
Ultraviolet	λ < 450 nm

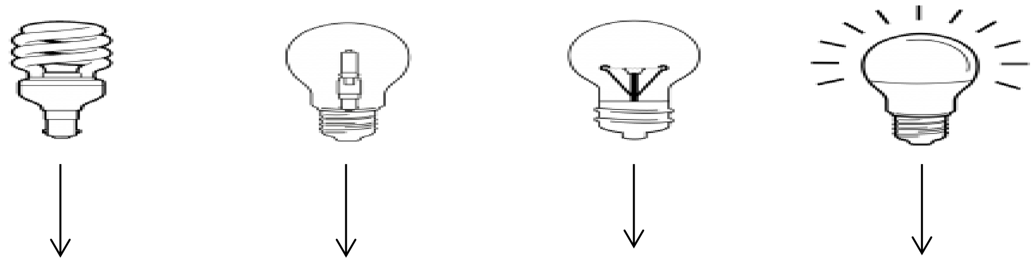
Light Source models used in lighting:

Traditional incandescent bulbs:

Halogen incandescents

Compact fluorescent bulbs

LED bulbs



fluorescent bulb **halogen bulb** **incandescent light bulb** **LED bulb**

Figure II.4 Models of lighting technology used from past to present [26].

LEDs Light Bulbs:

Besides being energy efficient lighting technology, its most important feature is that it consumes very little electricity. While it was expensive at first, its price decreases with technological developments. By adapting to the smart technology, it can be controlled and adjusted remotely. For this reason, it is becoming widespread in homes.

Working principle:

LEDs neither use a filament like incandescent lamps nor use gases like flourescent lamps. It works by conducting electricity through the solid matter. Electric charges stimulate electrons that move quickly through the solid matter and produce light. As a result of these processes, a lot of heat is released and the amount of energy consumed is small. Its usage time is longer than the other three models and it has less cost than others.

2.4 Why LEDs have become crucial

One of the controversial topics of the 20th and 21st century is sustainable energy. Increasing demand for renewable and sustainable resources, the depletion of energy resources, economic concerns around the world, costs on electricity bills, increasing costs from many industries to the health sector, museums were opened or planned to be opened, require innovations in devices to be used in electricity. In many parts of the world, LEDs are the latest technology. For this reason, we can list the reasons for the widespread use of LEDs in many sectors as follows:

- Protect the environment
- Energy-saving
- To reduce operating costs
- To provide better light in terms of vision, safety and security.

Concerns about the rise in energy prices in the world, the availability and control of fossil fuels and the sustainability of the environment was required developments in the lighting industry, and made advances on LED technologies. Due to energy savings in electricity, it continues to be preferred in many historical places such as parking garages, streets, public parks, billboards, museums. Reasons such as long working time, decreasing electricity consumption and the low amount of materials used in its installation and locations bring it to the agenda. In addition, since older model lighting systems contain heavy metals such as mercury and lead, LEDs do not contain these substances, while damaging the environment.

2.5 LEDs are sustainable

1. It reduces energy consumption. It consumes less energy than traditional lighting devices. It reduces the amount consumers spend on electricity bills. It also reduces the amount of energy to be withdrawn from the energy grid, while reducing the demand for natural resources spent to strengthen these grids.
2. It reduces heat. Loss of heat in electricity is a big problem. Most of the energy consumed in traditional lighting types is wasted due to heat loss. Advances in LEDs such as reducing the number of lamp wires used and designing effectively and efficiently greatly reduce the heat loss rate.
3. It does not contain harmful chemicals or substances in its construction. It does not contain substances such as mercury and lead that require many precautions.
4. Reduces the amount of garbage generated. That is, since the LEDs are manufactured to maintain their durability and work for a long time, the amount to go to the garbage will be small
5. One of the most important substances is recycling. In Turkey, now more importance is given to the use of recycled material and wife of our President as well as conducting studies on this subject. LEDs are made of recyclable

materials. For LEDs, it is correct to use the following magic words. “Reusable, recyclable, sustainable, green energy effective”. Because LEDs are now used everywhere, from lifestyle to design, building construction, improvements.

Figure II.5 Difference Between Sodium Vapor Lamp and Color Rendering Values of LED Luminaires [9].

As can be shown in Figure II.5, in traditional lighting, as more materials are used, the desired efficient lighting could not be provided and possible more fees are paid in the electricity bill. However, in the picture where the LEDs are placed, it is seen that there are fewer numbers and higher lighting efficiency. Features such as high efficiency, high quality and high color index (CRI), better user experiences and rising energy prices in the world make it necessary to engage energy efficient technologies, namely LED technology.

2.6 Vision

Human eyes receive the light that emits in visible spectra in the LEDs. The rod cells and cone cells in our eyes are the photosensitive parts of the structure of the retina. Rod cells are the most sensitive to light, and their number is higher than cone cells. They are rod cells that are sensitive to all spectra. It is known that there are 3 types of cones and they are sensitive to red, green, blue colors. 3 different vision patterns are detected with the receptors in the eye.

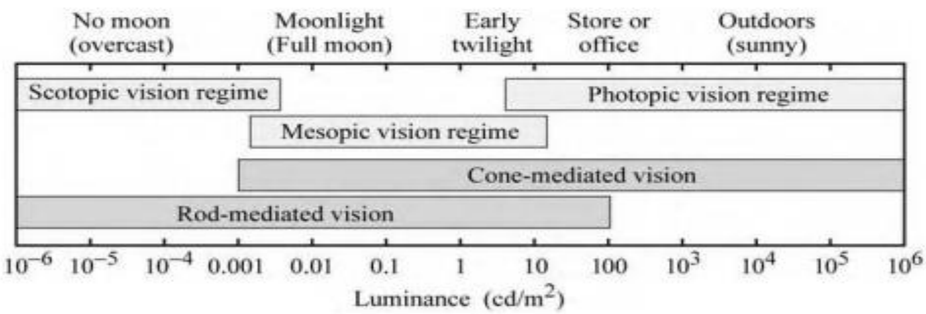


Figure II.6 Rod Cells and Cone Cells [8].

Three main methods explain human vision

2.6.1 Photopic (Day) Vision:

It is the vision under very good lighting conditions that works with the help of cone cells in the eye and provides color perception. Cone cells in the eye are 62% red, 32% green and 2% blue.

2.6.2 Mesopic (Mixed) Vision

It is a combination of day vision and night vision in low light, working with the combination of rod and cone cells in the eye. It takes place under medium lighting conditions. It is the section where both cone and rod cells are used [11,25].

2.6.3 Scotopic Vision:

It is a very low light monochromatic vision with the work of the rod cells in the eye. In low-level lighting, cone cells do not work with rod cells. It is sensitive to light wavelengths on the 498nm electromagnetic spectrum with blue and green color bands [10].

While three methods of vision help us see under different situations, night time vision is explained by scotopic or mesopic systems. While the scotopic mechanism is valid in the absence of ambient light or in very dark conditions, the mesopic mechanism continues to function as full moon light, full moon and intensely lit commercial highways. Almost all photometric tests carried out to determine the light results obtained from street, street light sources are based on photometric vision, which cannot present human response to the light in the night time when the light is very low [25].

Photopic measurements show warmer light and colors, such as street lamp sources and orange light produced by high pressure sodium lamps.

Scotopic and Mesopic measurements contain cooler light and show a wider light spectrum, which is preferred in street lighting applications and mostly produced from LEDs [25].

Based on these differences, photopic measurement is mentioned in daylight, and it is said by lighting experts that night time lighting measurements should be used with scotopic or mesopic measurement.

IESNA (The Illuminating Engineering Society of North America) is currently using photopic measurements in street lighting, but it is still working on mesopic and scotopic measurements against photopic measurements, and it is expected that regulations on street lighting standards will be evaluated in the near future.

2.6.4 Threshold Value:

The threshold value capability of our visual system depends on time, place and color classes.

Visual Threshold:

The most important factor affecting our visual system is brightness and the position of our visual system in the target area. If the brightness is low, our system will be easier to adapt. For the target to be seen, color difference with the environment, contrast in brightness and size are important. The lower threshold value will be measured as the area of the object or it has a similar brightness and it is neutral in color. The threshold value of the eye is expressed as measurement (cd/m^2)

The background glow of an object is expressed as follows:

L: the glow that our eyes perceive

LD: the gleam of detail

ΔL: absolute glow difference

L: relative glow difference

Since the glow level is directly proportional to the luminance (brightness), the contrast does not depend on the luminance level of the objects, so C (relative luster) is constant for the background color and object.

Color Threshold:

In the CIE (1931) chromatic diagram, each of the MacAdam ellipses shows the standard deviations between the chromaticity at the center point and the chromatic coordinates in the two sides of the 2° degree double-sided area to match the color.

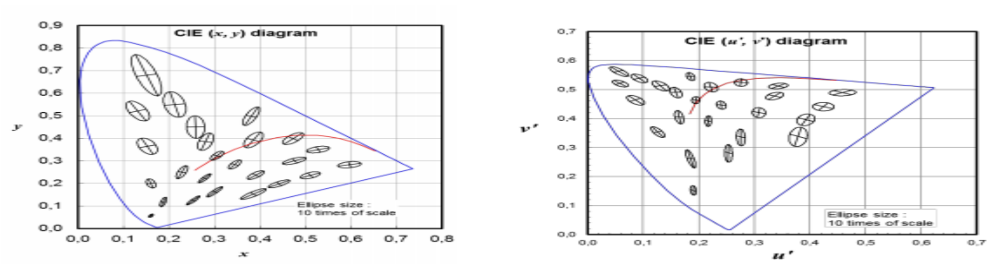


Figure II.7 MacAdam ellipse CIE 1931 (x, y) and 1976 (u ', v') chromatic diagram [12].

As can be seen from the Figure II.7**,** Planckian locus approached the circle more in CIE 1976 diagram.

2.7 MacAdam Ellipse:

The SDCM abbreviation comes to mind when MacAdam is called ellipse. The SDCM stands for "Standard Deviation Color Matching". In the CIE (1931) (x, y) diagram, it defines a region of color differences that cannot be detected by the human eye in a two-degree color space [12]. He found that in areas where the color match belongs to standard deviations, the color fields are elliptical. It was noticed that the size and directions of the ellipses changed depending on their location in the color space or chromatic diagram. While these regions were large in green areas, they were small in red and blue areas. For this reason, MacAdams Ellipse is still used today to determine the harmony between colors from the human eye's perception.

Significant Of MacAdam Ellipse

This diagram has had little practical use until the time LEDs came to the fore. Because light sources were mass production, color tolerance was considered sufficient at that time, or very few people complained due to incompatibility between colors.

The production method of light changed with the transition to LEDs. In the initial production of LEDs, the quality of the products was determined by the accuracy of the microcircuits. LEDs are divided into groups according to the performances in color outputs. However, these methods were both expensive and wasted time. Therefore, advances in the design of LED chip circuits have brought up the process of controlling colors and increased the importance of MacAdam Ellips [12].

The light color of each LED chip individually is different from each other. The performance range of LEDs guarantees uniform light distribution. Manufacturers determine the color characteristics of the LEDs using the MacAdam ellipse system. Most manufacturers classify their products in LEDs, paying attention to brightness (Lumen), color temperature (Kelvin), voltage (Volts), color placement.

MacAdam Ellipse Steps (SDCM- Standard Deviation of Color Matching)

Step 1: It's almost impossible to see the differences

Step 2: Differences can be seen with measuring instruments

Step 3: Color differences are less common

Step 4: Color differences are visible

Step 5: Clear distinctive differences are visible

2.8 The Commission Internationale de l'Eclairage (CIE):

According to The Commission Internationale de l'Eclairage (CIE), the visual system of human cannot react to all wavelengths in the visible spectrum. In the middle of the spectrum, it responds most to wavelengths, while blue and red light responds least to wavelengths. They are classified as photoreceptors (rods and cones) in our eyes, and they have different spectral response graphs. The situation where the rods are saturated and only the cones produce visual signals are called photopic situations. Even when the light levels are too low to revive cones, situations where rods continue to respond are known as scotopic situations. Situations where both rods and cones are active are known as mesopic states. The peak of the 555 nm photopic curve is the peak point of 505 nm for the scotopic curve.

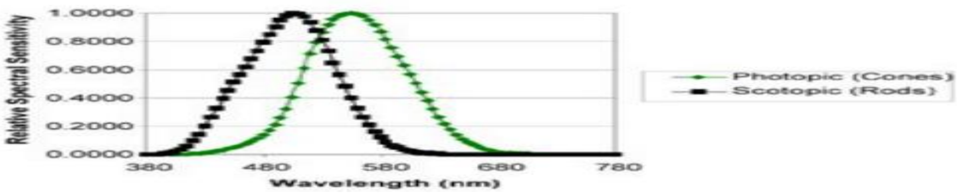


Figure II.8 CIE Standard [10].

Figure II.8 CIE Standard Photopic Response V(λ) and Scotopic V′(λ) Response [10].

2.9 Lighting

Light is a type of electromagnetic energy and extends from radio waves to gamma rays. The area between 380 nm and 750 nm is perceived by the human eye. The energy between these wavelengths is absorbed through the photoreceptors in the human eye and the vision process is performed by our eyes.

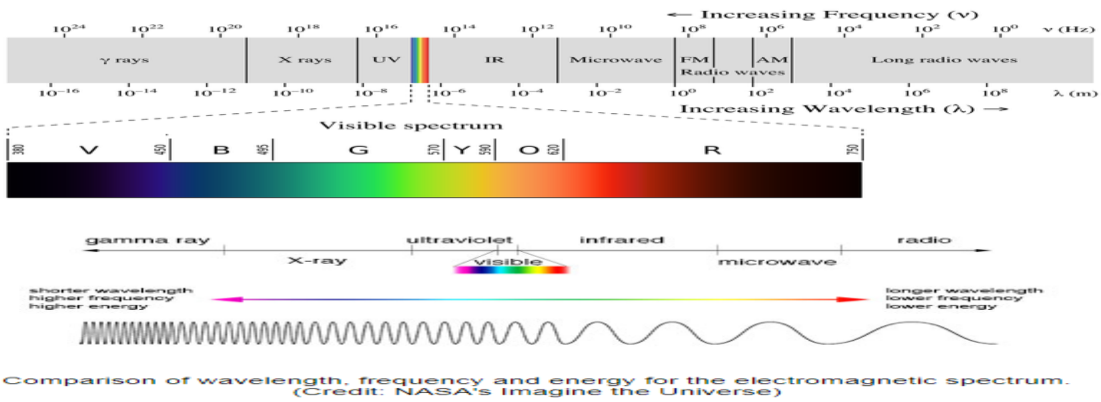


Figure II.9 Comparison of the electromagnetic spectrum by frequency and wavelength

Reference: https://commons.wikimedia.org/wiki/File:EM_spectrumrevised.png, February 19, 2013

In Figure II.9, light is produced in two ways. The first is the diffusion of light from hot matter. This is called incandescence and the temperature is higher than 800 Kelvins (K). The second is the emission of light as the excited electrons descend to lower energy levels. This is called luminescence.

2.9.1 Features of Light

The intensity of the light waves express its amplitude.

Intensity: absolute measurement of the power intensity of the light wave.

Brightness: relative violence perceived by our eyes.

The color of light depends on the frequency of the light waves. It is divided into Monochromatic and Polychromatic.

Monochromatic Light: It is the representation of light based on a single frequency. Laser lights are examples. Simple colors combined with six frequency bands are monochromatic light. These are listed as follows with frequencies decreasing from high to low. Red, Orange, Yellow, Green, Blue, Purple. Its sum is white light. The human eye detects light wavelengths between 380nm and 780nm

$$\lambda_{KIRMIZI} > \lambda_{TURUNCU} > \lambda_{SARI} > \lambda_{YEŞİL} > \lambda_{MAVİ} > \lambda_{MOR}$$

$$f_{MOR} > f_{MAVİ} > f_{YEŞİL} > f_{SARI} > f_{TURUNCU} > f_{KIRMIZI}$$

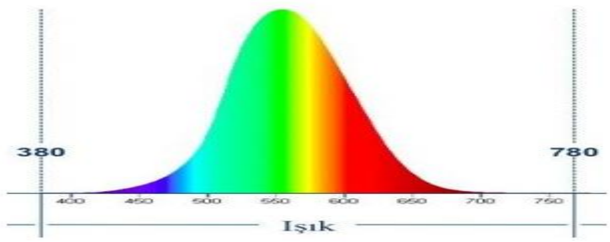


Figure II.10 Sorting Monochromatic Light by Wavelength [17].

Multi-colored (Polychromatic) Light: It contains different frequencies of light and white light belongs to this group. Many light sources polychromatic.

2.9.2 Photometry

There are four concepts in Photometry, which are luminous flux, luminous intensity, luminance and illuminance.

Luminous Flux :

It is the measurement of the current of light energy taken from a surface or emitted from a source. The luminous flux is called light power. In other words, it is a measurement of the perceived power of the scattered light emitted by a light source in all directions per unit time.

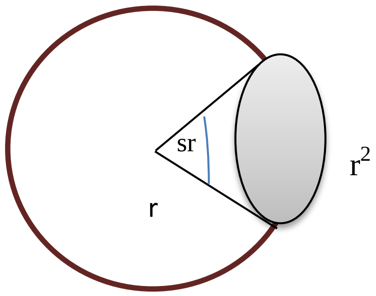


Figure II.11 Sphere's center streadian (solid angle) [27].

In Figure II.11**,** Surface area r^2 and 1 steradian = r^2, surface area of the sphere $4\pi r^2$ = 4π steradian. Total luminous flux = 4π. The sphere and the small surface are integrated.

A total lumen is measured by placing a photometer at the output of the combined sphere. This device is used to measure resources such as LED.

Luminance intensity:

In most applications, the point source is directional, but it does not radiate from a center, nor does it emit rays. It is a source of candle power. It is the light flux of the full angle in each unit emitted from the constant point source of light. That is, the luminous flux emitted by a light source in certain directions. It is used to measure the output of LEDs and very small light sources. Its unit is candela. Candle power is measured in a certain direction at small angles along the radial axes [18]. LEDs are measured with this technique in milicandelas. LEDs have receivers and tubes made up of compartments with special geometry. LED receivers are tubes with two ends. The first end is connected to the light measuring device and the second end is connected to the LED. These receivers are calibrated using luminous intensity.

Luminance:

It is the photometric amount used to measure the brightness of an object, or the measurement of flux reflected or radiated from the flat or the same surface or object in the specified direction. Also, it is known as photometric brightness. It shows the luminous intensity of the light source in the unit area. It is a convenient and useful measurement and method for defining sources that produce glare. Its unit is known as cd/m^2 or nit [18]. If the distance between the detector and the source is ignored, the luminance measurement is fixed. The violence determined by the detector decreases with distance. The human eye is the best illuminance meter.

Illuminance :

It is defined as the total light flux event in lumens per square meter on a surface. It is examined how much the incoming light illuminates the surface. Lighting is closely related to two rules in physics. These are known as inverse law and cosine law. Inverse law; The square of the distance between the light source and the detector is inversely proportional to the intensity intensity that occurs in the unit area of the surface. The Cosine rule, on the other hand, shines on the unit surface, decreases as a function of the coming angle of illumination. The angle of illumination moves from vertical to surface, moving away. As the illuminated area increases, the flux intensity per area decreases. Its unit is expressed as l m/m^2 or lx. It is the most commonly used technique in electrical designs of surface lighting condition [18].

Table II.2 Lighting and values in different environments [15]

ILLUMINATION SITUATION	ILLUMINANCE
Fullmoon	1 lux
Street Lighting	10 lux
House Lighting	30 – 300 lux
Office Desk Lighting	100 – 1000 lux
Operating Room Lighting	10000 lux
Direct Sunlight	100000 lux

Table II.3 Lighting Units [15]

Quantity	Radiometric	Photometric
Power	W	Lumen(lm)=cd.sr
Power per unit area	W/m^2	Lux(lx)=cd.sr/m^2=lm/m^2
Power per unit solid angle	W/sr	Candela (cd)
Power per unit area perunit solid angle	W/m^2 - sr	cd/ $m^{2=lm/}$ m^2.sr=nit

The power of light sources perceived by the human eye is the luminous flux, but also the photometric amount. The Lumen (lm) unit is the unit of the light flux. 1 lumens (lm) light flux is obtained from 555nm, 1/683 watt monochrome light emitting optical power supply.

Reflectance :

It is known as the relationship between the light coming to the surface and the light reflected from the surface. It is the ratio of the light coming to the surface to the light

reflected from the surface. It is the luminance coefficient. The ratio of the light flux reflected to the surface to the light flux coming to the surface describes the reflectance value of the light. If the luminance is isotropic, the light is best distributed from the surface, it is reflected. That is, light, surface, geometry between the observer and the purity of the surface are effective in determining the luminance coefficient. For this reason, the relation between luminance and illuminance is expressed as follows [15]:
diffusing surface (area);

$$L = \frac{(E \times R)}{\pi} \longrightarrow \text{luminance} = \frac{(\text{illuminace} \times \text{reflectance})}{\pi}$$

non diffusing area:

$$L = \frac{(E \times K)}{\pi} \longrightarrow \text{luminance} = \frac{(\text{illuminace} \times \text{luminance factor})}{\pi}$$

Luminance birimi cd/m^2

Illuminance birimi lux = lm/m^2 [18]

2.9.3 Colorimetry

Since photometry does not take into account the wavelength combinations of light, two surfaces with the same illumination as the reflected beam can be mentioned consists entirely of different wavelength combinations. If there is enough light for color perception, the two surfaces will appear in different colors. Colorimetry created by CIE is the perception of colors by the human eye. The Tristimulus XYZ system describes color quantitatively and qualitatively [19]. This system was defined and established by the CIE (International Lighting Commission) in 1931. Each color consists of a combination of red, blue, green primary colors, and this topic is described as the tristimulus system. x (λ), y (λ), z (λ) are color matching functions [13,15]. The colors of the light source defined in the XYZ coordinate system are found by multiplying this function by the spectral power distribution of the light source. CIE (1931) 2D and Color Matching Diagram 3D diagrams are widely used in LED industry.

Color matching System:

To make quantitative analysis in colors and use a color matching system to examine colors quantitatively is described as colorimetry. The rule here is the three main colors, red, blue, green, flawlessly. Spectrum compositions or wavelength compositions of light are described as numerical investigation of colors [15].

SPD (Spectral Power Distrubition):

It is defined as the radiation power of each wavelength in the visible areas to identify the light

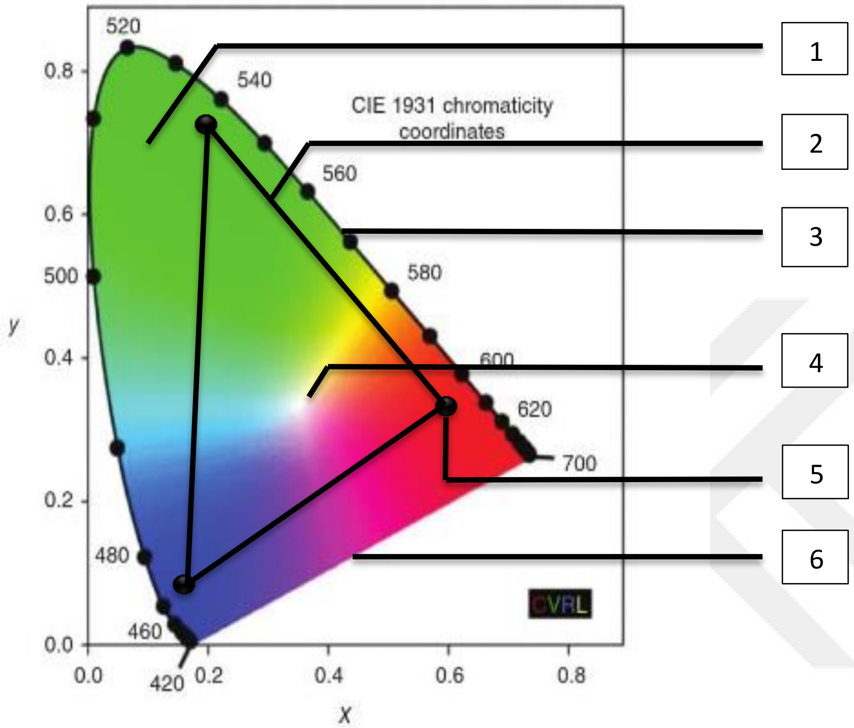


Figure II.12 CIE 1931 (x,y) Chromatic Diagram [12]

As shown in Figure II.12:

1. As it is in the diagram, all colors are visible.
2. Colors extending between the two points on each line are created by mixing them to the end points.
3. The edges of the diagram show the pure monochromatic light obtained by measuring wavelengths in the nanometer.
4. The least saturated colors are in the center. It spreads from white.
5. Subsets of the presented colors are created by mixing the colors at the corners.
6. Colors are completely saturated. It shows purple colors. It is made by mixing two colors. These are red and blue [12.14].

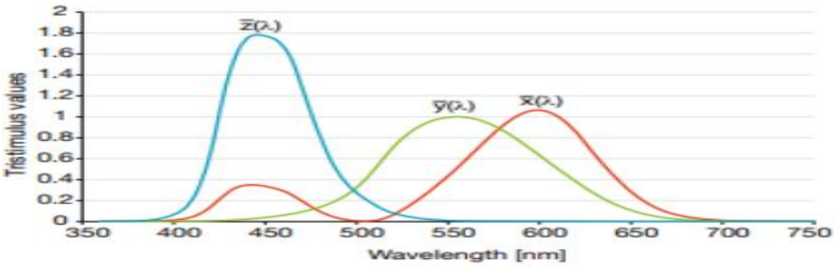


Figure II.13 Normal Spectral Simulaion Curves [17]

2.10 CCT (Correlated Color Temperature)

It is called in the ambience of the light color that the light creates in the environment. The ratio of colored lights in the total light created by the light source determines the color temperature. Color temperature in desired Kelvin degree is obtained mostly in LEDs among artificial light sources.

Table II.4 Relative Color Temperature [19]

Temperature (K)	Colour
2200	Flame
2700	Warm white
3000	White(neutral)
5000	Cool white
6500	Daylight

In the Table II.4, the color temperature is mostly measured between 2200 K and 6500 K. Red, orange, yellow color ratios are between low color temperature, namely between 2200 K and 3000 K. Blue color ratios are seen at high color temperature > 4000K. Relative Color Temperature started to be used because white light does not have chromaticity coordinates falling on Planckian neighborhoods [35]. In the light source, CCT is expressed in Kelvin and it is defined as the temperature of the blackbody section approaching the chromaticity of the source in the coordinate system (u ', v'). In other words, the appearance color of the light from the light source is CCT. Simply it is the spectral power distribution Planks (Planckian loci.) In the black body section is defined as Radiation Law [27,31].

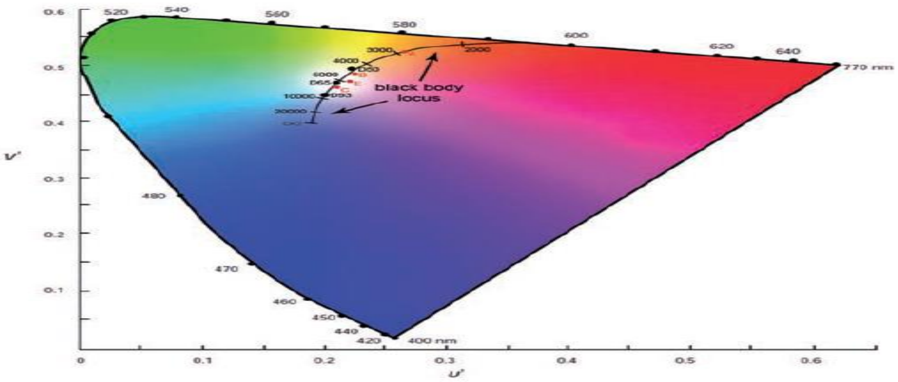


Figure II.14 CIE (1976) (u' – v') chromaticity diagram [19]

2.11 IEC (International Electrotechnical Commission)

According to the CIE UCS (diagram) made in 1976: In the chromaticity diagram produced in u '- v' coordinates:[13]

$$u' = \frac{4X}{X+15Y+3Z} \rightarrow \frac{4x}{-2x+12y+3} \qquad v' = \frac{9Y}{X+15Y+3Z} \rightarrow \frac{9y}{-2x+12y+3}$$

X, Y, Z are triple stimulus colors (tristumulus colors). x, y is the diagram prepared in CIE 1931 for the color excitations considered [19].

Blackbody radiation curve is represented by the formula:

$W_\lambda = C_A / [\lambda^5 (e^{(C_B/\lambda T)} - 1)]$

λ = Wavelength

T = Blackbody Temperature

W_λ = Spectral Radiant Emittance

e = Natural Logarithm (2.718)

C_A = 37,418

C_B = 14,388

Blackbody: It is an absorber that absorbs radiation on the blackbody.

Blackbody 3000K, 4000K and 4999K are seen. Daylight 5000K, 6000K, 7000K are also seen.

2.12 CRI (Color Rendering Index)

The importance of CRI was discovered in the 1950s, modern calorimetric studies were carried out in 1999 and they have been used universally in the lighting industry. CRI index is a measurement of the ability of the light source to show the colors of objects, unlike natural light sources. One of the most important features of light sources is to show the colors of objects under artificial light source. It shows how accurate the light source is when it reflects colors. CIE (International Commission on Illumination) designed it to show how effective and accurate the light source offers colors between R1-R14. As a result, when the CRI value is low, more colors are observed in the lighting by the light sources [12,13].

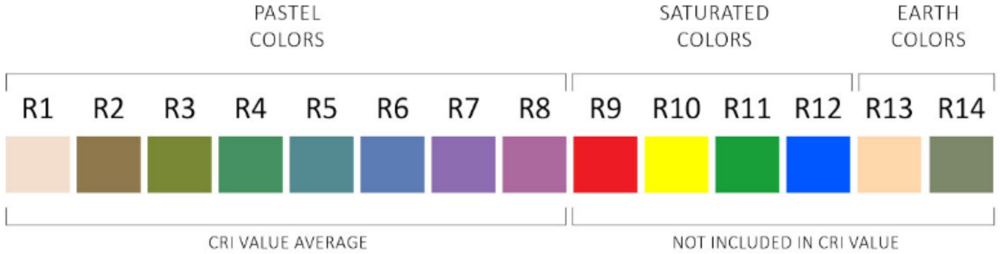


Figure II.15 Ra values in the light spectrum (R1-R14) [12].

As can be seen Figure II.15, the R value measures the concentration of 14 colors within the light spectrum, capable of presenting or returning its own color. The first eight of the above colors are made up of pastel colors, taking into account the hues, the next six are the representation of specially important colors, such as leather tones, vegetation tones, art and retail outlets. The average of the color rendering indexes for the first eight colors forms the overall color rendering index (Ra). CRI is rated from 0 to 100.

Table II.5 Grading of colors between 0-100 [19]

0-55 POOR	55 WARM WHITE	60 COOL WHITE	75 DAYLIGHT	60-85 GOOD	90-100 EXCELLENT

In the Table II.5, CRI has a value between 0-100 and has no unit. For natural light (natural light), CRI is 100. Studies on CRI are ongoing because the colors of sunlight or the proportion of visible lights still have not been captured [25].

2.13 Concepts to Be Known In Applications Using LED

When it comes to LED, it is necessary to know the concepts of brightness, the appearance of light and color formation.

Brightness:

One of the most incorrect information known is the idea that the amount of power is equal to the brightness. The concepts of amount of power and brightness can be connected with incandescent lamps. However, it does not apply to LED products, the minimum power in watts is consumed by LEDs. Therefore, the brightness of traditional lamps and LEDs cannot be compared over watts. The only factor that can be considered for the brightness of the LEDs is Lumendir, because the unit of measure of the brightness is lumen. Also, with lumen, it can be understood how much light products can emit [26].

Color Accuracy:

It differs in light sources accurately displaying the color of objects, that is, acquiring a color close to natural light. Color rendering is expressed as color rendering index (CRI). Over 80 values can be achieved with LED technologies, which is considered to be a good CRI [31].

Appearance of Light:

Color temperature (CCT) or color appearance can be measured in Kelvin (K). It is necessary to know whether the lighting devices produce warm, sharp light or cold light. In this case, we look at the numbers in Kelvin. Warm light is obtained when the number is low, and cold light is obtained when the number is high.[26,31]

Measurement of the LEDs:

In general lighting and applications, different models of LEDs were introduced and used with developing technology. More accurate measurement results are tried to be obtained with various optical parameters. LEDs differ from traditional models in subjects such as physical dimensions, flux levels, spectrum, density distributions, so the calibration needs of conventional standard lamps do not seem to be used in LEDs [18]. For example, differences in optical designs, color temperature, etc. cause difficulties in both measurements and production. Some optical and physical concepts continue to work on improving LED calibrations on photometric, calorimetric, and radiometric units, such as NIST (The National Institute of Standards and Technology) [21].

Chapter 3 Different Lighting Function

3.1 Choosing the right light techniques according to the Lighting Areas

1. Functions of Light: we can classify the light as decorative, homework, emphasis, environment. In this classification, each feature has different purposes. When we plan light for an area and sources of different light levels are used, it is important that they complement each other or match the colors.
2. Ambient lighting: It is general lighting. It provides homogeneous light distribution throughout the fields in general view and orientation. Arch shelter, cove lighting, recessed lights are examples.
3. Task lighting: It is for actively used areas. It is used especially in areas where it is desired to be illuminated. Like a reading lamp [33].
4. Accent lighting: Brightness is used to illuminate places with artistic, architectural and historical features and objects such as artworks by creating contrast. Examples include wall washing, recessed and surface mounted adjustable lamps.
5. Decorative Lighting: The purpose of this lighting is to create a comfortable and well-balanced environment. Chandeliers in different models and wall applications are among the examples. This model is used to illuminate many areas and items in homes. Color temperature is important here. Personal preferences and options are thought out [33].
6. Color temperature for ambient lighting: When it is used in homes, a warm white light source is preferred for a comfortable, balanced environment. The number of Kelvin for LEDs is 2700-3000 K because it is preferred to capture world

tones. 3500-4000K is also considered to emphasize lighter colors and to capture neutral light. Neutral and cool white light make people more energetic. Also, neutral, cold light sources create good contrast with warm light sources.

7. Color temperature for task lighting: It is used task lighting to meet the need for high and excessive light levels in the surrounding areas where there is a visual task. It is important to achieve good contrast, which is important here. This can be achieved from 3500K to 5000K because both neutral and cool white are the most suitable color temperatures and shades. In task lighting, color temperature, color rendering index (CRI) and brightness are important points to be considered. In color rendering, the index (CRI) value of 80 and above is considered sufficient for ambienet lighting, while the CRI value of 90 and above is considered suitable for task lighting.
8. Dimming: The most important feature in ambient and task lighting is dimming because it ensures that the brightness approaches the ideal in task lighting, it helps us to adjust the light levels in the ambient lighting to create the desired atmosphere in the area. In addition, lighting equipment saves energy by reducing the electrical load. An important point is that all LED products do not provide this feature. For this reason, both process, environment and properties should be examined when LEDs are opted. In fact, the emergence of dimmers is for incandescent lamps. LEDs continue to develop around different technologies. LEDs and dimmers should be suitable, if compliance is not achieved, poor dimming levels, or flashing lights may result in a similar appearance.
9. The items that we should pay attention to for the LEDs in the areas where we will be lighting are:
    - Light Output (Lumens))
    - Power Consumption (Watt)
    - Lumens per Watt (Efficacy)
    - Color Accuracy (CRI> 80)
    - Temperature Color Temperature (Kelvin)

3.2 Researches On The Lighting Industry

Researches on lighting techniques are divided into two sections as basic and applied research. They are basic research that is based on light science in the field of lighting. The developments in the lighting sector from the 19th century to the 21st century are based on the production of new lamp sources, electricity and photometry. Concepts such as performance, daylight and sustainability and environmental friendliness cover applied research. Fundamental researches are leaned on color, flickering light, dimming, brightness, dazzling light (glare), optics and control, lighting measurement science, performance. It is about the plan and design of the places to be illuminated. R&D studies are carried out on LEDs.

Some of the research topics identified by the CIE are listed as follows:

1. Color quality of light sources: perception and preference
2. Glare metrics for various lighting techniques
3. Dynamic, smart and applicable lighting techniques
4. Subjects such as perception, measurement, metric, ie visual appearance
5. Measurement science for photometric and radiometric devices

3.3 Open Air Museum Lighting and LEDs Development

The institutions that is responsible for museums all over the world have accelerated the conversion to LEDs in museum lighting. In this study, night illumination of open air museums was studied. With the scientific explanation of the subject, it was extended to the planned work of the architecture of this area. The purpose of this thesis is to discover the use of new possibilities proposed with the use of light sources in the new generation, youth, and to get acquainted with the LEDs closely and to provide a view to the lighting of open air museums at night. Turkey is a country that reflects itself on the best way in terms of historical geography because it still has unseen open-air museums. Hovever, it is extremely strength and diffucult to illuminate these places. These places visited in daylight should be open to people from all over the world at night because the curiosity of people's past is always increasing, this system is well established abroad and many countries contribute greatly to its economy in this field. In fact, it can also be considered as know-how. It is a know-how system, both architecture and lighting allow us to closely follow developments in electrical and electronic engineering in our country, and allow these systems to be developed not only in historical areas, but also in many areas such as galleries, construction and health sectors. It covers a wide range of technologies from image processing to control systems, network systems, photonic engineering. Without lighting systems, only a certain part of the day is used and other productive hours are wasted.

According to most of geographic location of the open-air museum in Turkey, namely mathematical location, they can be visited only during the day [2]. In addition, some of the lighting systems need to be renewed since they are almost non existent. In those with lighting systems, color temperature and color rendering are not good.

LEDs have been an important issue for a long time. Incandescent lamps were phased out in the European Union in 2009 [5]. Discussions about the LEDs used in museums have started again. Museum lighting manufacturers started to work more actively on this subject. The first discomfort expressed in this technology was related to the use of LEDs in museums due to their harmful wavelengths. So it was about ultraviolet (UV) and infrared (IR) lights. With the advancement of LED technologies, UV and IR radiation causing harmful light wavelengths are designed for museums and removed from light sources [20].

The most important issue here is how to understand or to choose good and bad LEDs. The quality of light in LEDs is important [8]. This means: light source, color rendering index, relative color temperature, light output should be considered together [7]. Also, when LED source is opted, latitude and longitude of open air museums should be taken into consideration.

Modern lighting technologies began to dominate the nights. Unlike the decoration purposes, smartly designed lighting increases the understanding of safety in open air museums. Well-planned lighting and detailed illumination of the roads in these places increase the perception of security, and this is also effective not only in open air museums but also in places where the public is located in the evening, i.e. public meeting places, bus stops, public spaces, public gardens, parks, etc. With a good night illumination system and design to be applied in open air museums, both the perception of safety is raised and emphasis is placed on historical sites and ruins.

The Importance Of Lighting The Environment Of The Open Air Museums In The Evening

In such historical places, local and foreign tourists can travel safely so that people can easily walk around in the evenings, witness the historical monuments and ruins on the road. They can see and examine them easily. These can be provided with sufficient and appropriate lighting to capture their atmosphere.

With the right and sufficient lighting:

- It will reduce the risk of accidents in historical open air museums for evening sightseeing.
- It will help protect valuable objects and ruins.
- It will help to create a safe environment.
- Road plays a major role in environmental lighting in open air museums. For this reason, it needs to look at the general features of road lighting fixtures:
- It is placed vertically and mounted horizontally
- On the long and narrow roads, road lighting fixtures have more intensive light distribution on one side of the luminaire while the intensity is reduced on the other side.
- The variable light intensity on narrow roads is generally the same.
- Fixed luminaires without being the same light intensity should be considered as area luminaires.

Considerations for Lighting Planning in Open Air Museums:

1. To determine the areas where lighting is needed: Areas planned to open tourists open-air museums in the evening should be determined in advance. These places are illuminated during the evening, ensuring the safety and security of both tourists and historical monuments. After these hours, outdoor lighting systems can be reduced or dimmed.
2. According to the IES (Illuminating Engineering Society), light pollution should be prevented by reducing direct light delivery by using full-cutoff equipment or protected equipment.
3. The best light source should be chosen. However, the motion sensor of the model to be used for evening lighting in open air museums should also be added. For this reason, IOT (Internet of Things) LEDs are the ideal light source as they

can be applied to network systems and computer programs. When it is thought in other lamp options, for example, Metal Halide, high cost and energy usage, environmental damage are higher. Color temperature values are limited in fluorescent lamps or high pressure sodium lamps.

4. Lamp models allowing the use of electronic devices such as motion sensors and meters should be selected. Automatic control systems can be installed with LEDs, and openings and closing can be made on the lighting areas needed.
5. The length of the lighting equipment should be determined according to the historical texture and location of outdoor museums.
6. Light transitions should be limited.
7. Appropriate amount of light should be used with the correct light source.

Main Purpose of the Lighting Design Plan for Night Lighting Of Open Air Museums:

The main purpose is to increase visual perception, vision, safety and security.

- In Open Air Museums, roads are for the common use of people and vehicles waiting for sightseeing or emergency situations. Increasing the perception of people and creating an enlightened environment will allow fast movements.
- In night museums, local and foreign tourists provide a better view field by walking around, they can move more easily and feel the historical ruins, objects and mystical atmosphere.

According to Luxembourg: Publications Office of the European Union, 2019, “the concept of "Street Lighting" is now emphasized the concept of "Road lighting" and important points are determined by the EN13201 standard”. In addition, the CIE 12 standard was examined. Spreading over a large area of open air museum in Turkey, and opening to domestic and foreign tourists in the evenings, besides a good lighting system and design is important for live security, these standards should be investigated, assessed and identified which are appropriate to the nature and location of our this museum.

3.4 Standards

3.4.1 Considerations in the EN 13201 Standard:

Classification of roads according to their characteristics:

1. M-class roads: It is the road reserved for motor vehicles. Medium speed and high speed are the allowed ways.
2. C-class roads: it is especially for motor vehicles, traffic is continuous. Roads intersect with pedestrians, cyclists roads. Contraction in the width of the main road, changes in the road geometry caused by decreases in the number of lanes and increases confusion.
3. P-class roads: Roads are used by low speed motor vehicles, pedestrians and cyclists.

3.4.2 CIE Standard:

Paths are classified as A, B, C, D, E.

1. Class A roads: Roads are with heavy and fast traffic. It is controlled accesses. Roads are separated, crossings are not allowed.
2. Class B roads: There is heavy and fast traffic. Roads are for slow traffic or they are reserved for pedestrians.
3. Class C roads: These are the traffic areas that are progressed at medium speed. Roads are belonging to village areas in city.
4. Class D roads: Traffic is slow or roads are made for pedestrians. These are the roads in the places where the city center or shopping centers are located.
5. Class E roads: These are mixed roads with speed limits. It connects to the road between the settlements.

In Open Air Museums, P class roads in EN 13201 Standard and D class roads in CIE Standard can be taken as examples.

Optical Or Photometric Distribution Models of LEDs According To The Areas For Lighting Design Defined By IESNA And NEMA.

IES (Illumination Engineering Society) was classified by light distribution models IESNA (Illuminating Eangineering Society Of North America). It consists of 5 different models. Light distribution is also defined as NEMA (National Electrical Manufacturers

Association) [22]. There is a difference between the two. IESNA defines the shaping of the area illuminated with the help of a fixture. NEMA examines light angles (Beam Angles) [22]. That is, it classifies the light distribution of vertical and horizontal rays emitted by lighting fixtures. It can be used for projectors and sports lighting [9]. The amount of light coming at vertical angles and the horizontal models are explained the light distribution. In fact, each lighting application provides a unique lighting model in itself. Having knowledge about lighting projects, the best distribution model can be chosen. Space geometry plays an important role in our design to select the best luminaire distribution. For example, better spill light control is important in residential areas, while wide light distribution is more important in shopping centers. If we cannot make these distributions correctly, we will have to use more lamps [18]. In outdoor lighting, how far the lamps illuminate and how effective they are is determined by the distribution type model. When choosing LED lighting equipment, many factors such as lumens and color temperatures are considered. However, light is important in distribution because it is the model of light that is distributed on the surface by a fixture.

In museums, it is necessary to have enough light to reduce brightness in outdoor lighting, to keep the contrast at appropriate levels, to ensure the homogeneity of the light, to minimize the amount of light pollution, i.e the amount of light that is wasted, to optimize the light by controlling the light distribution, to easily notice people, objects and vehicles. While illuminating the roads in open air museums, depending on the applications and the structure and location of the place, it can be placed in the center of the road, either side of the road or on one side of the road because the width of the road, the distance between the lighting lamps, the height of the poles from the ground, the model of the lighting are determined by considering and measuring.

3.4.3 Distribution model types according to IES

Type 1:

It provides wide and symmetrical light from the lamps placed in the middle of the walking path. The height of the equipment is approximately equal to the width of the model created. This model is good for border lighting, sidewalks, one or two lane roads, pathways, narrow walkways. It is used to illuminate places that are twice the height of the installation and lateral width is determined as 15 degrees. It shows a bi-directional lateral distribution because it has two focused beams to illuminate in opposite directions. If it is necessary to illuminate both sides of the road in traffic, it is used to illuminate the middle of the road [17].

Type 2

In Type 2, lane roads, narrow passages and wide roads are also designed for the installation of equipment, and there is a wider distribution. The lighting area of these lamps is 1.5 times the mounting height of the lamps. Therefore, it is suitable for wide roads, narrow passages, side streets. It is considered for wider walking paths with long and narrow lighting. However, it is suitable for wider roads than type 1. It is used in small side streets and jogging tracks. It consists of two principal light collectors with a 25 degree side width and facing different directions. Applications are valid when lights are placed on one side or near the road [16].

Type 3:

It is planned to be mounted on the edge of a medium-sized highway with a lateral width of 40 degrees. The installation height of the LED distributions should be 2.75 times the width of the highway. It is ideal for lighting larger areas, parking areas and highways. Lamps should be placed outside the designated area. Type 3 is similar to the distribution in Type 2 because it is used in the wider area of the spot source outwards [16]. This light model is considered for illuminating the driving paths of the park areas and surroundings including the large and wide roads, the edges of the open areas, sports field garage, tennis. It is designed for the illumination of pedestrian roads and roads and car parks, rather than being placed inside the square..

Type 4:

It is known as the forward distribution, and it has a lateral width of 60 degrees. This distribution type should be used if we plan to illuminate building facades and lateral surfaces, parking areas and walls, courtyards. It is suitable for areas up to 2.75 times the mounting height [12]. Semi-circular light is produced, so parking areas are installed next to buildings and businesses to illuminate the surrounding of the building. It illuminates the point farther than Type III, however, side-by-side light distribution is shorter [30]. Compared to the original three models, this light scatter pattern is more rounded. In this model, it is placed along the edges and perimeter of buildings where safety lighting is required, and it is applied for outdoor activities. For example, it is suitable for outdoor sports lighting and outdoor museums. It is the best choice for LED distribution, suspension bridges, highways, panel lighting and outdoor building lighting.

Type V:

This model can be observed for circular and versatile LED distributions. The road center is suitable for the intersection. It has the same distribution in all lateral angles and it is recommended for general area lighting. It produces a circular 360-degree distribution and even light distribution in all positions of light. This distribution has the same foot candle symmetry at apparent angles. 1ft ≅ 1 lumen/ft^2. Luminaire assembly is suitable at intersections, in the center of the park roads. This model allows it to extend up to the parking areas and the large area in front of the armature. It is the most widely used distribution model today. It has the same distribution in all lateral angles and it is recommended for general area lighting. It is designed to be installed at the center of the parking lots, at the intersection points, and near the highways. It provides center circular or square models that pass equally from all angles through a central point. Since the light is transmitted from the center in all directions, the most appropriate distribution of light is obtained. In this model, light distributions are directed the light in a circular or square model in all directions around the luminaire. It is designed for large open areas such as intersections, large car parks, road medians where the light pattern of light is distributed equally. This distribution is the largest and flatest pattern.

Type VS:

This model has a square distribution and the same density at all angles. Intersections are intended to install in the center of the park roads, in the center of large roads. It is used for places where large areas, commercial parking areas, evenly distributed light is required. It is allowed to use in more defined areas where certain limits should not be exceeded [30]. This model produces a square 360 degree distribution with the same density at all angles. It has a square symmetry of the same candle power at all lateral angles. Intersections are designed for armature assembly so that the center of the park roads are close to the center of the roads [12]. It is suitable for the use of large commercial parking areas, with areas where distribution is required evenly enough. It is used areas where a more precise definition of the light pattern is needed.

Note:

The difference between Type V and Type VS: one includes a regular distribution and the other is a square distribution. Type VS is used for areas that require more precise definition with square light distribution, planned lighting areas. The main difference in Type VS lighting is that it has a more defined or distinct angle fiting lighting projects. It needs special attention.

3.4.4 NEMA (National Electrical Manufacturers Association)

Beam Angle is a concept used by NEMA. It is the radiating of the beams horizontally and vertically by the luminaire. It is the luminaire's light distribution classification system. Classifying light distribution is possible in a universal way. It is especially important in outdoor lighting because it is necessary to know what is the light distribution in the light produced by a luminaire in projects designed for outdoor lighting. Everything can be calculated from the number of luminaires required in the projects to the space between them because a standard has been created with the NEMA beam angle classification [22]. To emphasize an architectural feature, while a narrow-angle luminaire is required, we have to adhere to a wider angle if we want to reveal the features of a large stone wall. Lighting engineers, project engineers, design engineers can safely choose the best luminaire for memberships using the NEMA Beam Angle classification. NEMA identifies seven light model examples with this classification. These seven light patterns show asymmetrically two light planes where the light intensities are 10% of the nearest central beam of light or the maximum candle power emitted in terms of area [22].

Table III.1 NEMA Beam Angle Classification [22]

Beam Spread	NEMA Type	Description
10˚- 18˚	1	Very Narrow Spot
18˚- 29˚	2	Narrow Spot
29˚- 46˚	3	Medium Narrow Spot
46˚ - 70˚	4	Medium Flood
70˚ – 100˚	5	Medium Wide Flood
100˚ – 130˚	6	Wide Flood
130˚ +	7	Very Wide Flood

3.5 Examples from the Open Air Museums in Turkey

3.5.1 Laodikeia Ancient City:

It has a history of 5500 BC. This historical open-air museum with first settlements from the Chalcolithic period was established in the south of the Lycos river. The open-air museum joined Rome in 130/129 BC. It was used as a religious center in the early periods of Byzantium. Leodikya is one of the historical ruins that experienced many earthquakes and saw war. It revealed the concept of urbanism by reconstructing it during the roman period because the road, sewage, water network system were used as it is today and even the system was separated as hot water and cold water. Later, as a result of the wars under the Byzantine rule, this city was surrounded by walls, it lost its defense and fell under the control of the Turks. It was won by the Seljuk Ruler, Gıyaseddin Keyhüsrev as a result of conquest, and it was named Ladik in both Seljuk and Ottoman times [23].

An important point is neither the Roman nor the Greek city of Leodikya because it was founded by people living in Anatolia. Here, Hellenistic period from the historical remains comes from the Roman Kingdom, and from the early Byzantine Empire. As a result of the studies carried out here, it shows that Denizli city is an industrial city and a commercial city, it dates back to very old times with the historical remains [23].

It entered the UNESCO World Heritage Temporary List, Leodikya has an important place in the textile field because the textile at this center was used as an indicator of nobility at that time [32].

3.5.2 Aphrodisias Ancient City

This open-air museum in our province of Aydın was included in the World Heritage List by UNESCO in 2017. Its history dates back to mid 5000 BC. It increased the importance of their shopping from the late Hellenistic period to the Roman and Byzantine periods because the works were made of marble that revealed their ideas, reliefs and views. The marbles had white, blue, gray tones. The greatest wealth of Aphrodisias was due to its proximity to marble quarries. For this reason, it was effective in the art of sculpture and the creation of high quality works. Sculpture school was established. In addition, the Roman Empire's architectural understanding at that time and its contribution to reaching information about marble art were great [23]. It has historical buildings such as theater, sebasteion, agora, Hadrian Baths, Aphrodite Tuna, odeon.

Location: Aegean Region, Aydın

Longitude: 37 ° 42 '30 ”East

Latitude: 28 ° 43 '25 ”North

Category: Cultural

3.6 Technical Applications In Open Air Museums

The practices and explanations we made in Ephesus, Pamukkale, Leodikya are important places in our country.

3.6.1 Purpose:

In this section, it is to present a case study in our open air museums by bringing the day into the night, that is, it opens museums to domestic and foreign tourists after dark. If the lighting is insufficient and wrong, it will cause not only aesthetically but also a large amount of energy loss. This study aims to limit the effects of excessive and unnecessary light, to make our design by finding the most useful way by using the standards and to keep such museums safe for visitors at night. At the end of the application studies with the most used light source LEDs today, it is our goal to obtain both a three-dimensional image in the virtual environment using the Dialux program and to demonstrate a sample study by making lighting design.

3.6.2 Scope:

The lighting model according to the accepted standards for the selected outdoor museums is the basis of the lighting in this thesis. Pedestrian and landscape lighting, safety lighting, monumental and decorative lighting, lighting in historical areas are models explaining by this study.

Factors To Be Considered In The Installation Of Lighting Systems:

Visual threshold and Visual disturbance:

Examples and explanations

There are three important factors for visual threshold:

1. Characteristics of the place to be illuminated,

2. Background of the target

3. Visual system factors such as luminance.

Visual Discomfort

Four factors are mentioned for visual discomfort.

1) In one case, selecting the information needed in the illuminated area makes it difficult. It causes difficulties to perceive the visual assignment.

(a)

(b)

Figure III.1 (a) Part of the City Ruins at the Ephesus Open Air Museum in daylight (b) Part of the City Ruins at the Ephesus Open Air Museum in night light

Visual Disturbance - the area in front of the wall is not visible, it is unlikely to walk safely.

2) In the second case, it is the situation where the visual environment presents too much or too little information, but the illumination is either more or less.

Figure III.2 Example of Ephesus Open Air Museum Columns - Walking path and artifacts not noticed - low illumination level

(a)

(b)

Figure III.3 (a) Ephesus Open Air Museum Celsius Library in day light (b) Efes Open Air Museum Celsius Library in night light

In Figure III.3**,** (a) Ephesus Open Air Museum Celsius Library in day light (b) Efes Open Air Museum Celsius Library in night light Illumination light value is too high, Contents need to be checked and brightness, reflection, decorative light etc. all seem to be together.

3) In the third case, the attention is distracted, the important thing is drawn the attention of the observers to the objects that do not contain the information, that is, the interest of tourists is drawn to places that are not considered necessary.

Figure III.4 Section from Ephesus Open Air Museum

In Figure III.4, Section from Ephesus Open Air Museum. Lamps positioned on the ground are very bright. The walking path and the surrounding area are too dark to feel safe. It is very difficult to see and perceive walking paths, local and foreign tourists visiting the museum, the cars used in the museum and historical monuments.

4) The fourth case is that the lighting arrangement causes confusion with the pattern reflected in the visual environment.

Figure III.5 Distribution of different light sources

In Figure III.5, brightness,distribution of different light sources, different design, different light sources incur confusion. It causes visual disturbances, flickering of light, brightness, obstacles in the reflection of light, changes in lighting between work surfaces or transitions, insufficient light.

3.7 Lighting Pollution

Misuse of light causes light pollution. Light pollution occurs due to sky glow, excessive illumination, light transitions (trespass), brightness.

3.7.1 Brightness (Glare)

Glare is a condition that prevents the eyes from seeing and the perception of the hidden parts of the objects in the field of vision due to high light. It creates visual discomfort or night blindness that reduces visual acuity and creates a problem of adaptation to the stability for about 30 minutes when exposed to glare. The open air museums are one of the most important problems in the night visit. It is a very large area because it will reduce the ability to see properly. In these places, the roads can be straight or bumpy, which creates problems for safety. It is caused by the misdirection of light.

(a)

(b)

Figure III.6 (a) and (b) show Hierapolis Open Air Museum Part

In Figure III.6, Hierapolis Open Air Museum Part. (a) Glare originates from horizontally directed light (b) Glare remove light sources. The glare from the light sources cannot be blocked. However, when strategic settlements are made by considering light barriers such as bushes and trees, the glare effect can be reduced, both the area is better illuminated and better vision is provided.

3.7.2 Light Transitions (Light Trespas)

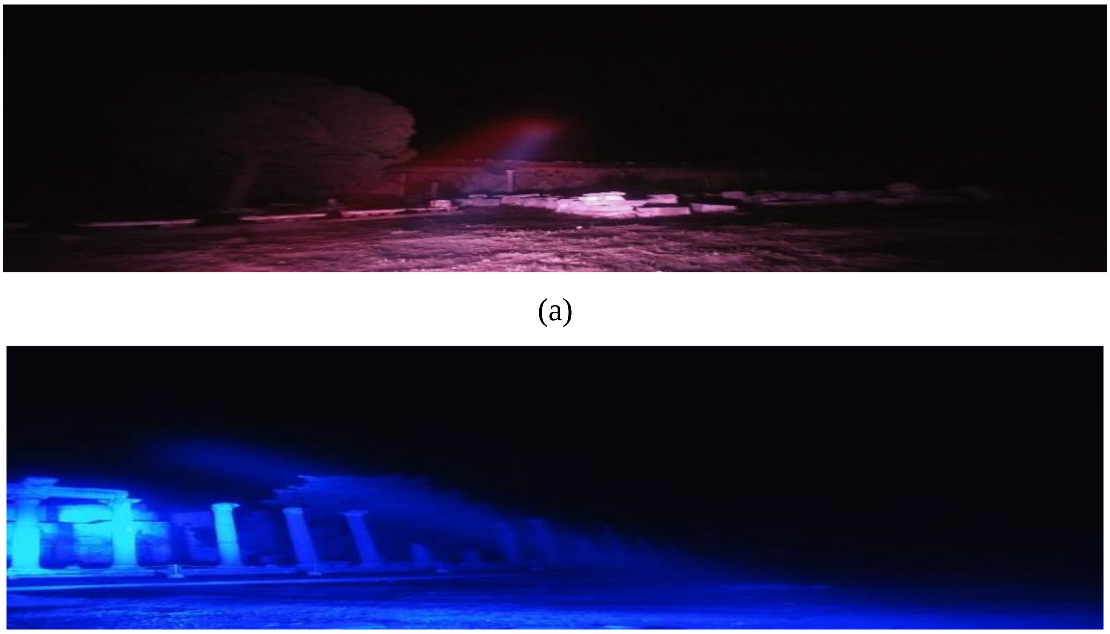
It is known as the shedding of light, the light coming out of the lighting source illuminates the unwanted or unnecessary places.

Figure III.7 Ephesus Open Air Museum

InFigure III.7, Ephesus Open Air Museum Section - Light Trespass- While lighting is planned to illuminate the columns, unwanted illumination emerged by illuminating its historical walls.

3.7.3 Sky Glow

It is light pollution caused by light that creates orange brightness in the night sky, scattered with the help of particles such as gas molecules and dust and spread directly to the sky. It causes unnecessary energy consumption.



(a)

(b)

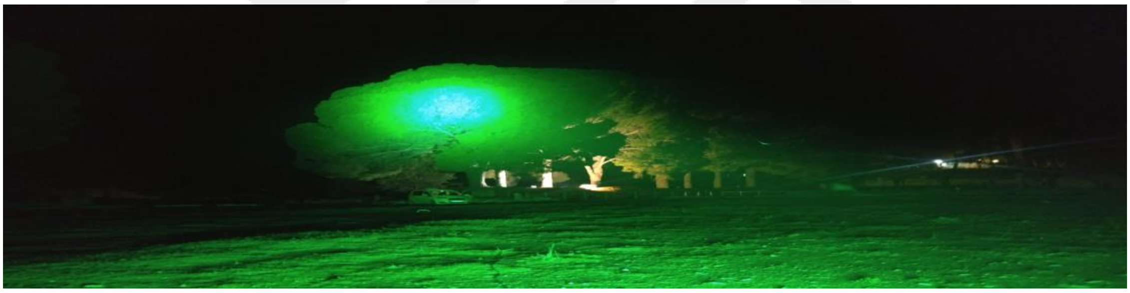
Figure III.8 (a) and (b) illustrate Ephesus Open Air Museum

In Figure III.8, (a) and (b) show Ephesus Open Air Museum Section - Sky Glow Examples

3.7.4 Clutter

It is an excessive collection of bright lights. It causes discomfort and confusion. Other light sources such as clutter, other light transitions (light trespass), brightness (glare), sky glow (over glow), and overlit cause pollution.

Figure III.9 Hierapolis - Clutter, Sky Glow, Glare, Trespass



(a)

(b)

Figure III.10 (a) and (b) show Ephesus Open Air Museum

In Figure III.10, (a) and (b) show Ephesus Open Air Museum Clutter

As seen from Figure III.6, Figure III.7, Figure III.8, Figure III.9, Figure III.10, while we show examples of light pollution, it is understood that very careful measurements and adjustments should be made in our open-air museums because many of our open-air museums either do not have enough lighting or cause unwanted light pollution that will disturb visitors in different ways. This gives rise to evaluate the security and safety problem in such museums, and the fact that the lighting is insufficient and inefficient lighting systems cause unnecessary energy consumption. On the other hand, it put forward an obstacle to create the historical and mystical atmosphere here.

Discussion On Existing Lighting Design In Sample Museums

Figure III.11 Ephesus Antique City, Izmir

The Figure III.11 illustrates that it has the appearance of resembling car headlights. It is not safe due to its excessive brightness and low illumination areas, it decreases visual acuity and increases visual impairment. The view of the spotlight is considered that the tourists may be careless, they can be attached to the lighting sources and they fall on ground at night. Shadow formation is very high. This light source model is good for border lighting, pavement, one or two-lane roads, pathways, narrow walkways. According to IES, the field enters Type I, which is one of the light distribution model types. In the Nema Beam Angle classification, it is narrow light or medium narrow light and it is not suitable. Color rendering index is CRI <80.

Figure III.12 Ancient City of Ephesus, Izmir

In Figure III.12, Ancient City of Ephesus, Izmir. Lighting is insufficient.

Figure III.13 Ancient City of Ephesus, Izmir. Lighting

Figure III.12 and Figure III.12 show that there is insufficient, irregular light distribution, incompatibility in color temperature, vertical light, ie sky lighting, not ground. Historical ruins cannot be selected. Color rendering of the lamps used is not suitable.

Figure III.14 Ancient City of Ephesus

In Figure III.14, the lighting degree of the lamp is very low. Color Temperature is suitable. The lamps illuminate in the background, so they cause insufficient light to fall on the floor. Since the distance between the lamps is very high, the area where light does not fall on the floor is a lot. It shows that the design was made without the necessary measurements.

The road or historical walls are intended to be illuminated, but it is unclear to be illuminate which of them or if the stones on the floor are intented and the wall is aimed to illuminate. There is ambiguity in purpose.

(a)

(b)

Figure III.15 (a) and (b) show Ancient City of Ephesus

In Figure III.15, (a) Ancient City of Ephesus in daylight (b) Ancient City of Ephesus in in night light

Figure III.15 represents that it is not suitable for color temperature in amber shade because the columns here are marble and generally white, gray or light gray. The floor is light gray. Materials and colors are important in determining the color temperature of the lighting sources.

Figure III.16 Ancient City of Ephesus- Celcius Library

In Figure III.16, the most important point that causes light pollution is the use of many colors in lamp sources, disproportionate lamps. It will also distract tourists and prevent them from feeling the mystical atmosphere. The interference of light distributions is another problem. Lamp placement distances are incorrect. Visual discomfort is another problem.

Figure III.17 Hierapolis Ancient City, Denizli

In Figure III.17, Hierapolis Ancient City, Denizli - Normally no Lighting in many historical ruins

Note: Night lighting in the Ancient City of Leodikya is almost negligible. Only certain points have insufficient light source on the poles, the room is old model. LED is not a light source.

3.8 Result

Conclusions can be drawn from the existing lighting systems in Open Air Museums:

1. There is not enough lighting or too little.
2. Lighting was not designed without being researched and measured.
3. We can see every model of light pollution.
4. It is not possible to talk about energy efficiency since it has wrong lighting design.
5. Historical artefacts and road lighting were not evaluated separately, they were all made using the different model light source.
6. Criteria such as CCT, CRI, and light efficiency are not considered.
7. Standards such as NEMA, IESNA are not considered.

Technical Discussion On Application Results:

We used 3000K, 4000K, 5000K,6000K and RGB LEDs in our applications in the ruins.

Figure III.18 Hierapolis Antique City, Denizli

In Figure III.18, Hierapolis Antique City, Denizli - Normally there is no Lighting.

Figure III.19 Hierapolis Ancient City, Denizli

In Figure III.19, Hierapolis Ancient City, Denizli. NEMA Standard must considered.

Figure III.20 Hierapolis Ancient City, Denizli

In Figures III.20, Wallwasher and the light-emitting sources at a certain angle were tried. The large walls and columns were investigated which would work better.

Figure III.21 Ephesus Antique City, Izmir

The use of more amber colors and light sources in different colors in the existing lighting is far from reflecting the historical texture of the Celsius Library. When it is considered the architectural texture of this historical residue, it is used a light source tone close to one color and material color should be used.

Figure III.22 Laodikeia, Aydın CCT Evaluation

In Figure III.22, there is no lighting at all. It is our application on historical texture. CCT determination is done

Figure III.23 Laodikeia, Aydın

Figure III.23 Laodikeia, Aydın. According to the historical texture, application is made to determine the color temperature of the light source and the appropriate lumen value.

Figure III. 24 Laodikeia, Aydın

Figure III.25 Ephesus Antique City, Izmir

In Figure III.24 and Figure III.25, it is an important situation that shows that the same objects will give different results with similar light sources according to the location of the museums. Here, it was understood that the geographical structure of the region and the factors such as ground texture, climate characteristics and moonlight are effective.

Figure III.26 Ephesus Antique City, Izmir

In Figure III.26, Ephesus Antique City, Izmir - Historical Art Accent Lighting

Figure III.27 Ephesus Antique City ,İzmir

In Figure III.27, Ephesus Antique City ,İzmir Historical Artifact CCT Analysis

In Figure III.26 and Figure III.27, it was determined with which light source would be more appropriate to emphasize important historical monuments. It is applied a wide angle to reveal the stone wall and its features such as shape and writing. It is experimented with the wall washer.

Figure III.28 Ephesus Antique City, Izmir

In Figure III.28, Ephesus Antique City, Izmir - Historical Monument Lighting

As can be shown Figure III.28, it is examined the image that appeared when the material the works were made was illuminated by the light source, that is, it is researched from aesthetic point of view. Here, it is used the narrow-angle light source LED because it is wanted to emphasize its architectural feature. NEMA Standard was taken as an example.

3.9 Experimental Results

The results of the application studies in Open Air Museums:

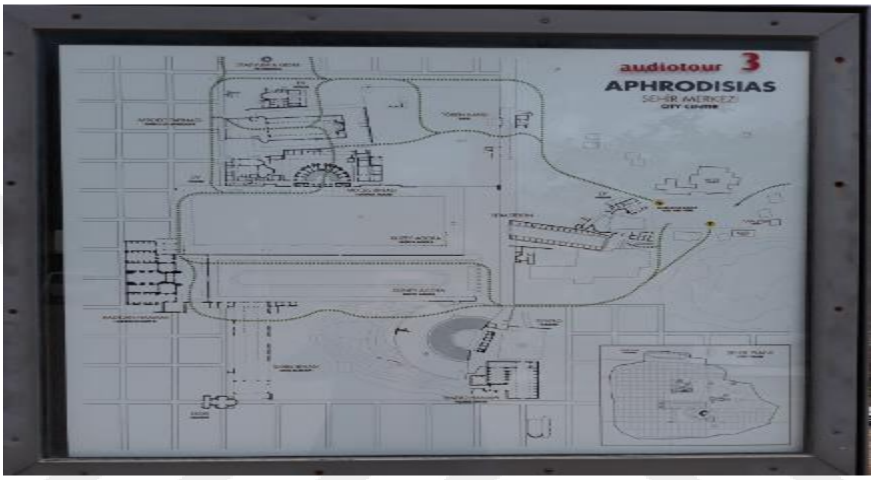
1. Before starting the measurement, it is explored open air museums one by one. It is examined the historical texture, geographical structure and what materials are used.
2. Since open air museums spread over a wide area, road lengths and widths were measured. It is valued the works according to their environment.
3. It was revealed that light sources should be selected and designed by emphasizing the importance of concepts.
4. Since open air museums is a developing concept in our country in recent years, it has emerged that lighting devices, methods, applications and light sources in other developed countries should be followed.
5. The most important result of our open air museums in the region where they are located should be thoroughly investigated, in the same historical ruins and similar environmental environments, the materials of the ground texture of these

regions, the reflection of the moonlight on the museums in the night applications. Different results arise due to its geographical issues.

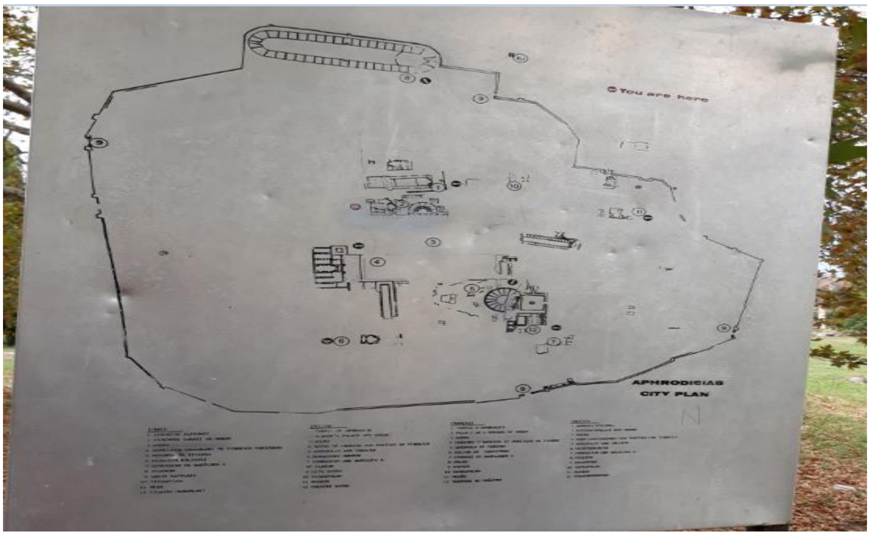
6. The lens structures of the LEDs to be used should be designed after these detailed investigations because even if strategic positioning is made, unwanted reflections, diffractions and dispersions can be seen due to the characteristics of the materials and the ground. Adjustment can be made by adding a special fixture to the light source or by dimming.
7. While it is necessary to use a wide-angle LED source for historical artifacts consisting of large stone walls, it is decided that a narrow angle luminaire should be chosen if it is wanted to emphasize the architectural feature.

Chapter 4 3D Design And Results

4.1 Aphrodisias Historic Relic Lighting



(a)



(b)

Figure IV.1 Aphrodisias Plan

In Figure IV.1, (a) and (b) show Aphrodisias Plan

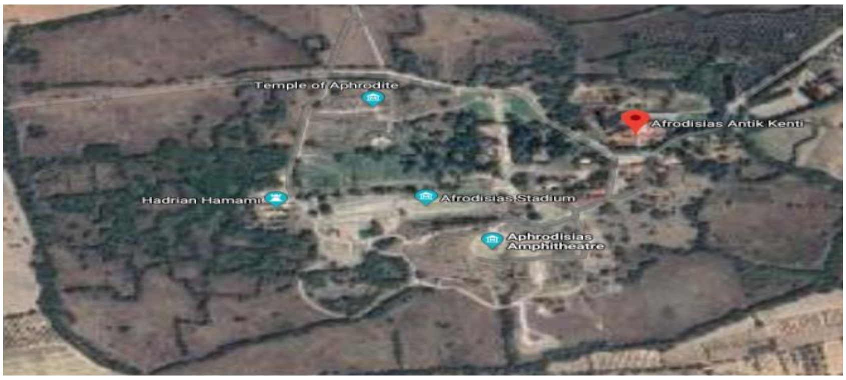


Figure IV.2 Aphrodisias Google Map Plan

Reference:https://www.google.com/maps/place/Afrodisias+Antik+Kenti/@37.7077305,28.7214277,988m/data=!3m1!1e3!4m12!1m6!3m5!1s0x14c756fe

4.2 Sample Places Selected For 3D Design

Figure IV.3 Aphrodisias Stadium

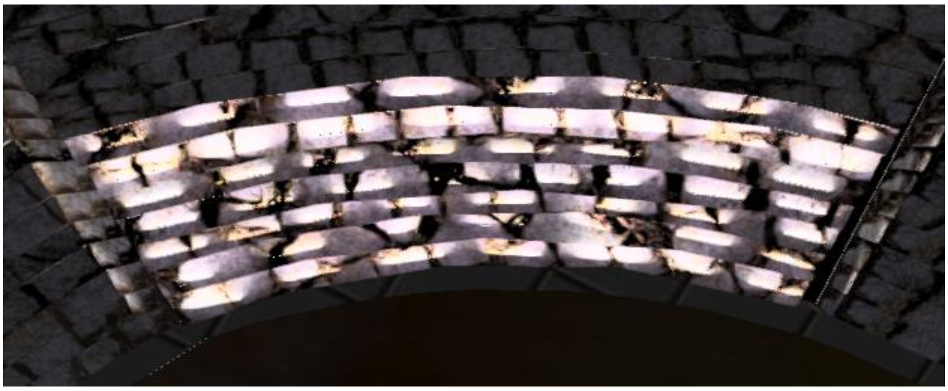


Figure IV.4 Aphrodisias Stadyum 3D Design

In Figure IV.4, the location, structure, texture cleaning and dirty, color temperature (CCT) and color rendering index (CRI) of historical residues have a significant effect.

Here, the marble stones lined up in a semicircle shape by being whole or broken and clean or dirty. This makes it difficult to place the lamps at appropriate angles according to their placement in the x, y, and z axes. The different position and height in each upper step from the previous one creates difficulties in determining of placement of the angles because sufficient power, CCT and CRI are selected, it causes insufficient luminous efficacy and unwanted light distributions such as glare and trespass. The refraction and reflection of light from historical materials causes undesirable results in faulty settlements. Since our materials in this example are close to white marble, it is chosen to keep the CRI value above 80+. Although it is specified as a good qualification for CRI 90 and above, when it was looked at the characteristics of the materials, it did not provide suitable lighting for the historical stadium in this example because it caused excessive brightness and reflections. One of the important points should be placed on every rising staircase in the stadium by measuring the lamp gaps. Thus, the lights emitting from the lamps should be interlocked and excessive brightness may occur at some points or the formation of a non-illuminated area, that is, shadow formation should be prevented. In terms of safety issues in night illumination of museums, shaded areas or lighting system that can create dim light should be avoided because this causes situations such as dazzling in visitors and increases the risk of accident or injury. In our three-dimensional application, it is determined the appropriate height and angles for positioning on x, y, z axes. In addition, by experimenting with various wallwashers, it is determined the most appropriate CCT and CRI value for the historical ruins and textures in the Aphrodisias ruins.

Figure IV.5 Different results of the same LED light source

In Figure IV.5, it is observed that the same light sources exhibit different color tones due to the diffraction, reflection and distribution of light and the structure of the historical textures and materials. For this reason, it is seen that the same light sources cannot be used when there are different floors due to the different color tone. When the same CRI and CCT is wanted to select, it is understood that the lumen values should be selected with lower or higher experiments. When it is considered night lighting in the summer period, it is assumed that there will be various grasses and lawns in the soil areas, it is more convenient to use a different light source with a high lumen value when it is opted over 6500 K and CRI 80+ because the color integrity in the environment must be preserved.

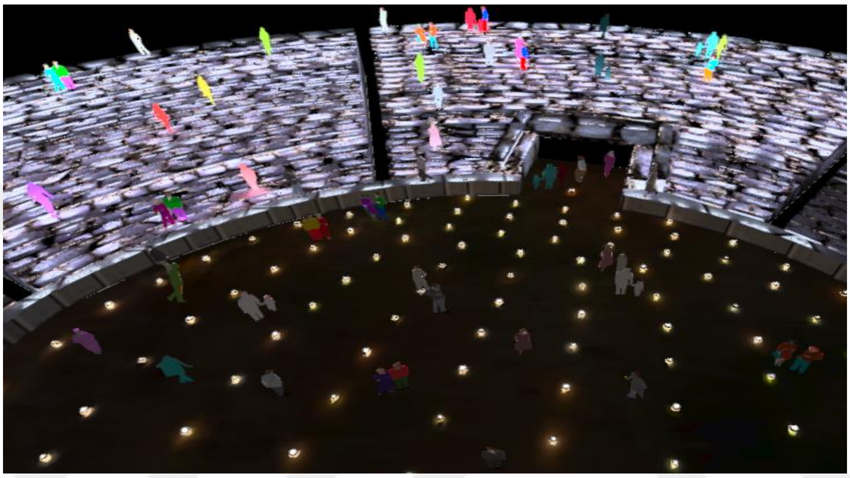


Figure IV.6 Aphrodisias Stadium 3D Design Result

In Figure IV.6, the illuminated area is in the shape of a semicircle. Lamp spacing was determined by placing it between 2 and 3.2 m. The stadium consists of two large semicircles and a rectangular area in the middle. Since the steps are formed by rising upwards, that is, It is rising with a certain slope, if the projector is used from up to down, while tourists are going up, they suffer from glare effects because light comes directly to their eyes and it can cause loss of vision and cause injuries. In addition, because the effect areas and lighting levels of LED light sources are strong, the interference of rays emitted from light sources causes different light colors with irregular reflections, or excessive glare with unnecessary light distributions, and illumination of unnecessary places cause excessive energy consumption. It can make it difficult for tourists to focus, which can lead to negative impressions in the illumination of such historical sites at night. Here it is chosen to illuminate the steps with strip LEDs, and it was provided spot-style ground lighting in the middle area, while visiting these historical places at night, it is set the spotlights in the form of a strip because it is important to determine the route and to choose suitable CCT and CRI values for the ground. It is aimed to keep them focused on the space because it is found that light sources with the same CCT and CRI values produce very different light colors by depending on the texture of the historical remains and the ground. Here it is seen that the light source affects lumen, lumen values, CCT and CRI values. It was determined that the same light source did not provide the same light efficiency in different parts of the historical place where lighting is desired.

Figure IV.7 Aphrodisias Tetrapilo

Reference : https://www.kulturportali.gov.tr/medya/fotograf/fotodokuman/6667

Figure IV.8 Aphrodisias Tetrapilo 3D Design

Figure IV.9 3000K CRI> = 80+ of light sources, but wattage, lumen values are the results in different examples.

In Figure IV.9, the texture material of the historical ruins and theater have a dirty yellow appearance. The value of 3000 K CCT is suitable for this historical residue. However, it should be noted that there are many LED light sources with the same CCT value, and all of them have different lens structures, angles, as well as their power and lumen values and light efficiencies are very different and they can demonstrate undesirable results.

Figure IV.10 Results based on the placement of LED light sources

As can be shown on Figure IV.10, light sources will cause excessive glare, trespass in our 4000K CRI> = 80 + and after the diffraction and reflections, illumination in unnecessary places will lead to increase shadow areas and energy consumption. In addition, it is not suitable for safety because it causes bright formation in certain points of historical buildings and shadow formation in certain points, which will cause glare in the eyes of tourist.

(a)

(b)

Figure IV.11 Results based on the placement of LED light sources

In Figure IV.11, (a) and (b) shows results based on the placement of LED light sources

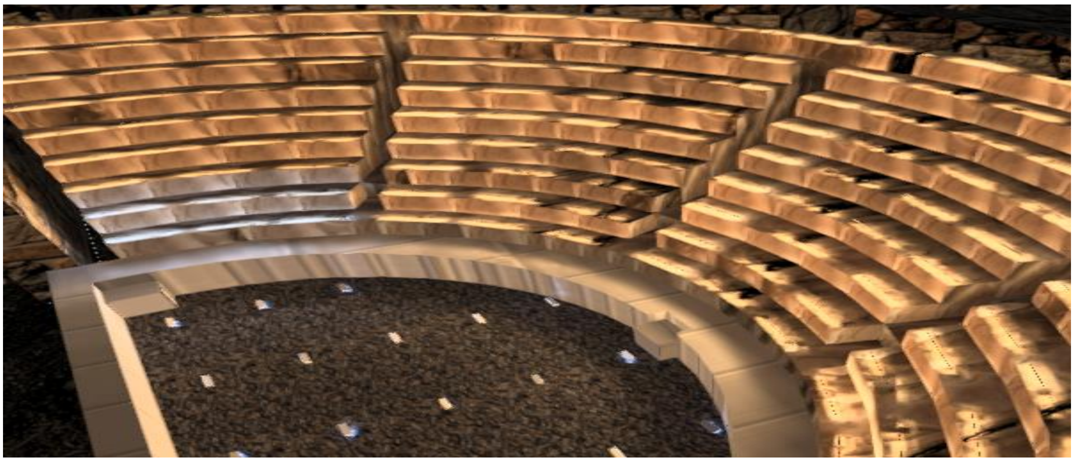


Figure IV.12 Light sources selected according to historical texture and evaluations

In Figure IV.12, Mistakes in the placement of the light sources cause reflection and refraction from the surfaces or diffusion of the rays on each other, causing different light colors to appear on the undesired surfaces. The blue colored light source suitable for pebbles reflected from the ground and marble surfaces, causing the blue color to drop on the stairs. For this reason, knowing the coordinates in lighting is very important in the placement of light sources. Although CCT and CRI are appropriate here, the placement of the light sources has affected the color distribution and reflected in different places. This is one of the mistakes seen in our open air museums. In addition, 3000K, CRI> = 80 +, 8.3 W, 54 lm / W Blue Light is obtained while 3000K, CRI> = 80 +, 24W, 149 lm/W is obtained. Watt and lumen values appear to produce different colors at the same CCT and CRI values for Luminous efficiency lm/W. For this reason, one of the biggest mistakes when installing the lighting system in Open Air Museums is to consider either the wattage only or only the temperature value of Kelvin. When choosing the appropriate LED, all features and lens structures must be taken into account, because the lens structure will determine how the light will break and scatter.

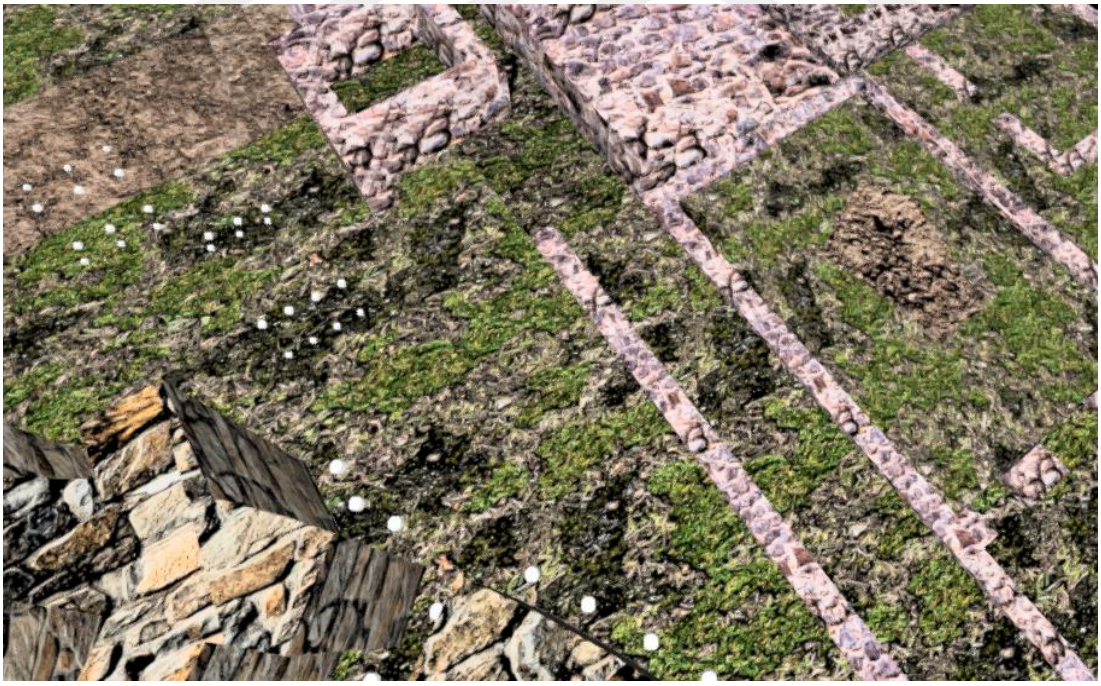


Figure IV.13 3D design cross section

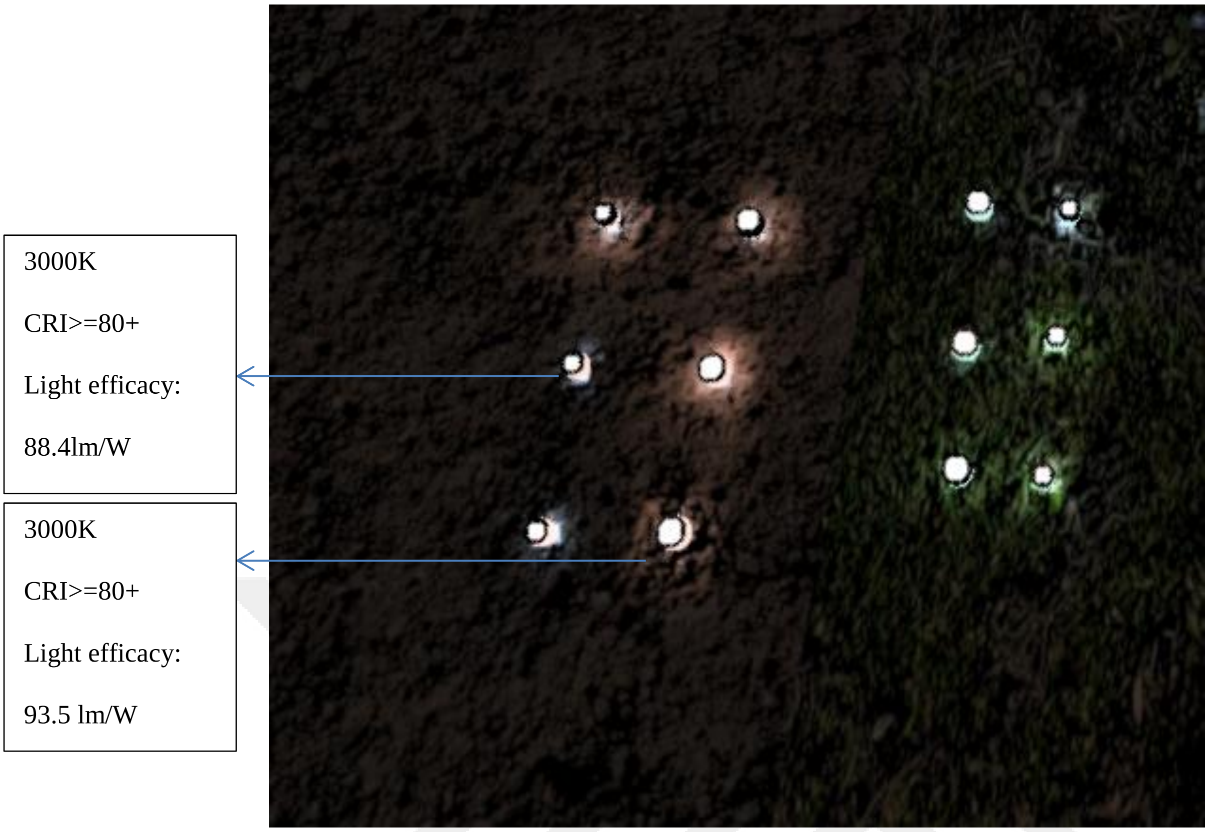


Figure IV.14 Evaluation of light efficiency

In Figure IV.14, The same light source, but the evaluation of light efficiency using different models

The above example is the same CCT (3000K), CRI (> = 80 +) in 3D design, but Watt and lm/W are different. Reflections on different grounds are light blue, close to white, and green. It is obvious that the selected LED light sources can present very different colors on different grounds and the illumination of the light source is more in some places and less in some places because the coordinates of the place to settle LEDs are important, it is concluded that, different light point heights are required for LED light sources. When it is considered the structure of our open-air museums, the dirtier or darker areas reflect the light less and strategic placement has a great importance in terms of energy saving and more efficient use of LED light channels.

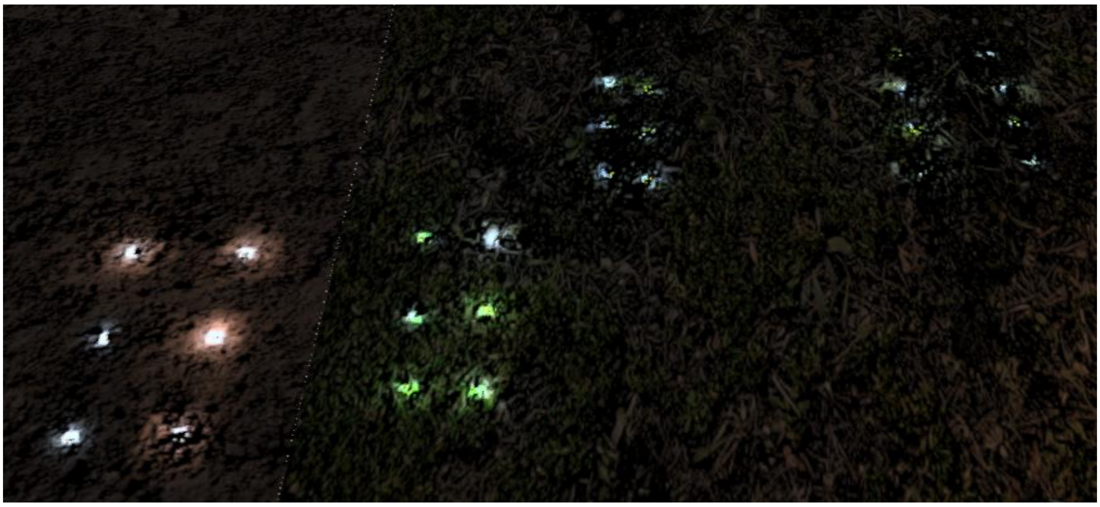


Figure IV.15 Appearance of LED light sources on different grounds

In Figure IV.15, it is suitable to use LED sources with lower luminous efficiency as the reflection will be more for places with grass. In this study, 3000K and CRI> = 80 + are suitable for this site. Light yields of 88.4 lm/W and 93.5 lm/W were considered sufficient for light colored areas such as grass because light rays were observed to reflect more on the environment. It was aimed to prevent unnecessary situations such as unnecessary brightness and light pollution, trespass, clutter and dazzling by reflecting on the eyes of tourists visiting the open air museum at night. It was observed that a higher light source, such as 93.5 lm / W, was suitable because light was kept in dark colored areas such as soil.

Figure IV.16 Appearance of different LED light sources on different grounds

In Figure IV.16, Appearance of different LED light sources on different grounds In Figure IV.16, the purpose of the 3D lighting design above is the fact that open air museums that will be illuminated at night have factors such as altitude, slope, latitude and longitude in the geographical regions where they are located because it is seen that the light rays emitted from the LED light sources with the same features are not of the same brightness. Although CCT, CRI, Luminous efficiency (lm/W), watts are suitable, shadow formation cannot be prevented if the positioning of light sources is not correct. This is undesirable.

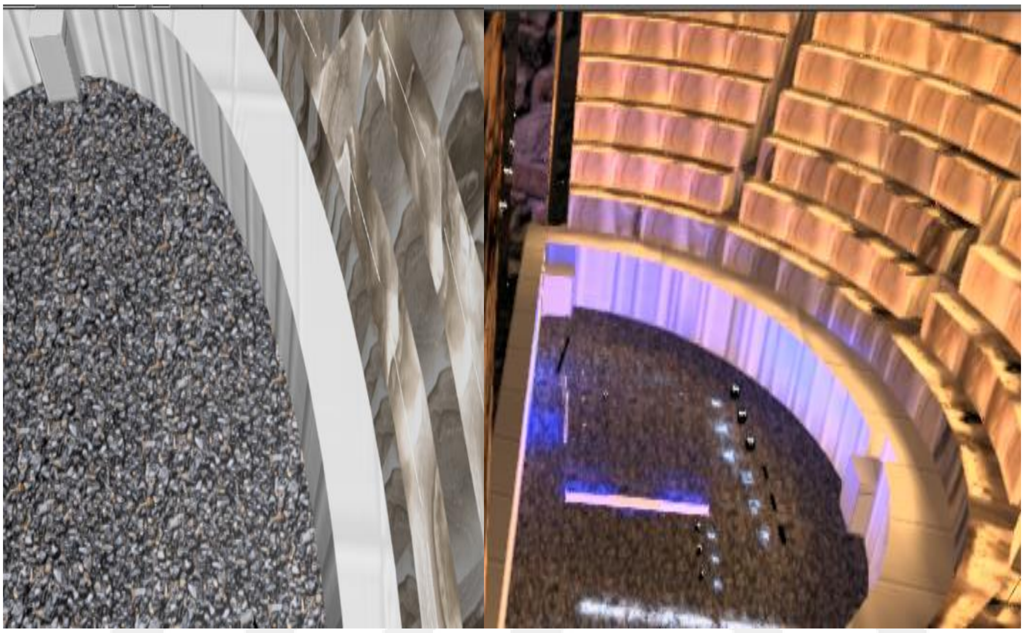


Figure IV.17 LED Light source evaluation

As can be illustrate on Figure IV.17, since the floor is pebbles, it is convenient to use an LED source that dominates the blue tones. However, since our open air museum is mostly made of marble material, the reflection of the light from the light sources will be more. In other words, marbles acts as a mirror. While choosing CCT, CRI value, it is important to keep minimum reflection effects on the surfaces while there is reflection. The passage of lights should be prevented. When two different color formations occur, it will destroy the importance and mystical atmosphere of historical places. While the same CCT and CRI values are preferred, the color tones should be kept close by thinking the lumen and wattage slightly higher.

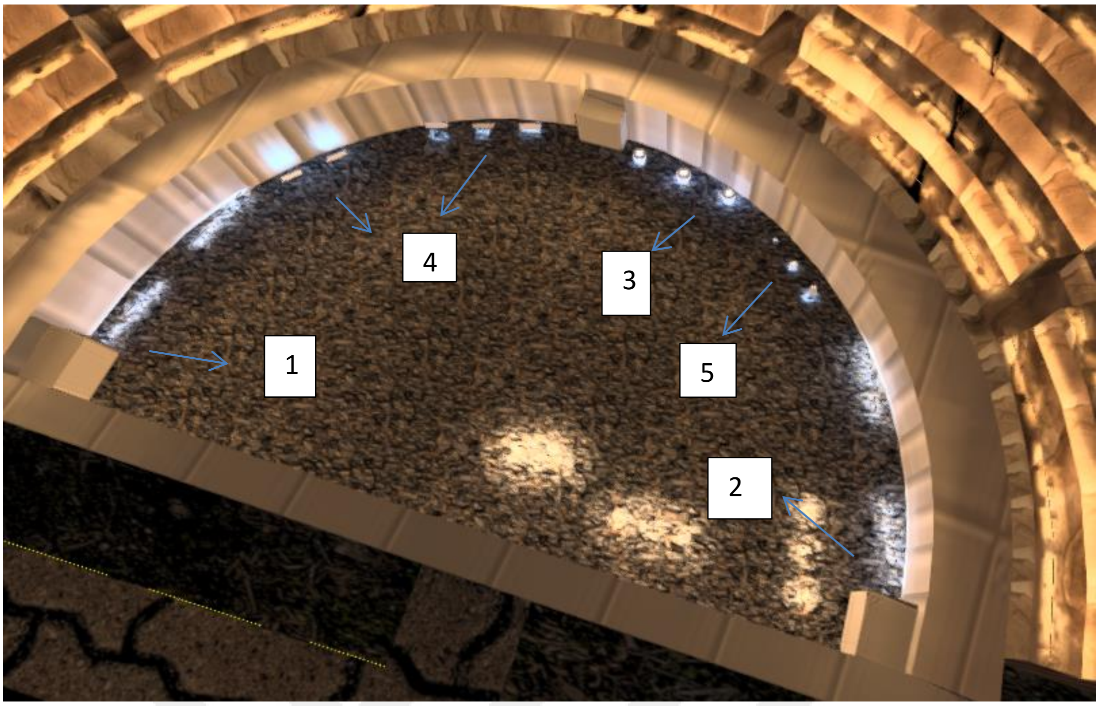


Figure IV.18 Experiments with sample LED models

1. 6500 K, 3053 lm, 127.3 lm/W
2. 5700 K, 3670 lm, 153.0 lm/W
3. 6000 K, 3000 lm, 88.4 lm/W
4. 3000 K, 505 lm, 53.4 lm/W
5. 6000 K, 420 lm, 55.6 lm/W

In Figure IV.18, the yellow light color creates extreme brightness on the 3300-4000 K, CRI> = 90 + ground. It does not give suitable color to floor texture. Although the background color is dark, it almost reflects the yellow light color to the outside. When it is looked at the blue color distribution, although the number 1 and 2, 6500 K and 5700 K CRI>80+ are close to daylight, it is not aesthetically appropriate because they create a mismatch in yellow and blue color texture and the luminous efficiency is high for this material texture. The light source number 4 and 5 are 3000K 6000 K and it is not possible to provide sufficient illumination because the light efficiency is very low. Another important point here is 3000 K warm white, but it reflects the blue color tone with reflections and refractions in the ground texture, although it is yellow light. Here, when lighting the stairs, it is chosen 3000 K and CRI>=80+, it is chosen the light efficiency 149.2 lm/W. While CRI>=90+ is selected on dirty surfaces, the light efficiency is chosen as 124.4 lm/W because it is necessary to prevent unnecessary glare on the surface and to prevent further reflection on the clean parts. That is, while increasing my CRI value, my power rating should be lowered, and my luminous efficiency should be reduced. In our applications, it is observed that CCT determines the color tone of different light sources in night lighting in our open air museums, it should be used only by considering the material texture and color. However, CCT and CRI values, light efficiency, lumen and wattage values should be analyzed and the location of historical monuments should be taken into consideration.

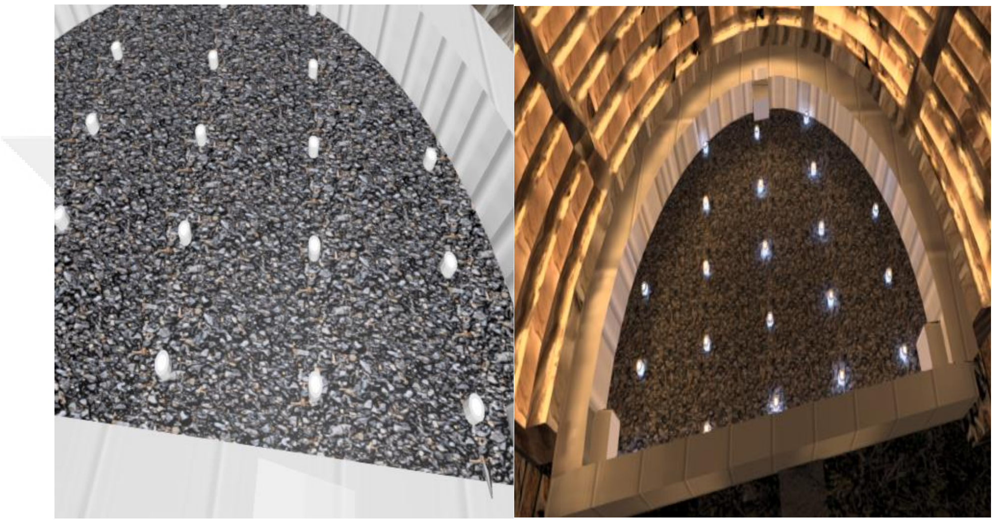


Figure IV.19 Using different light sources together on different floors

In Figure IV.19, when installing LED light sources on the floor, the mounting depth, fastening height and light point height for all lamps are not the same. Geographical conditions, latitude, longitude, and coordinate systems are important when open air museums are illuminated. In other words, if the correct light source is not selected, if the measurements are not taken correctly, the illumination systems cannot be positioned correctly, so unwanted results are obtained and electrical energy is wasted. The desired efficiency can not be obtained in terms of energy saving. In addition, when outdoor museums are illuminated at night, safety and security problems also come up. Our aim here is to prevent my blue light source from intermingling with the yellow light source after reflections because this is a problem of light pollution. It is kept the light efficiency of the 3000 K LED light source high and the light efficiency of the 6000 K LED light source is kept low to prevent contrasting color tones. It is achieved the aesthetically appropriate appearance by trying to equalize the vitality level of these two

LED light sources in the environment. The aim is to live the historical atmosphere by preventing tourists from focusing on light sources in night light.

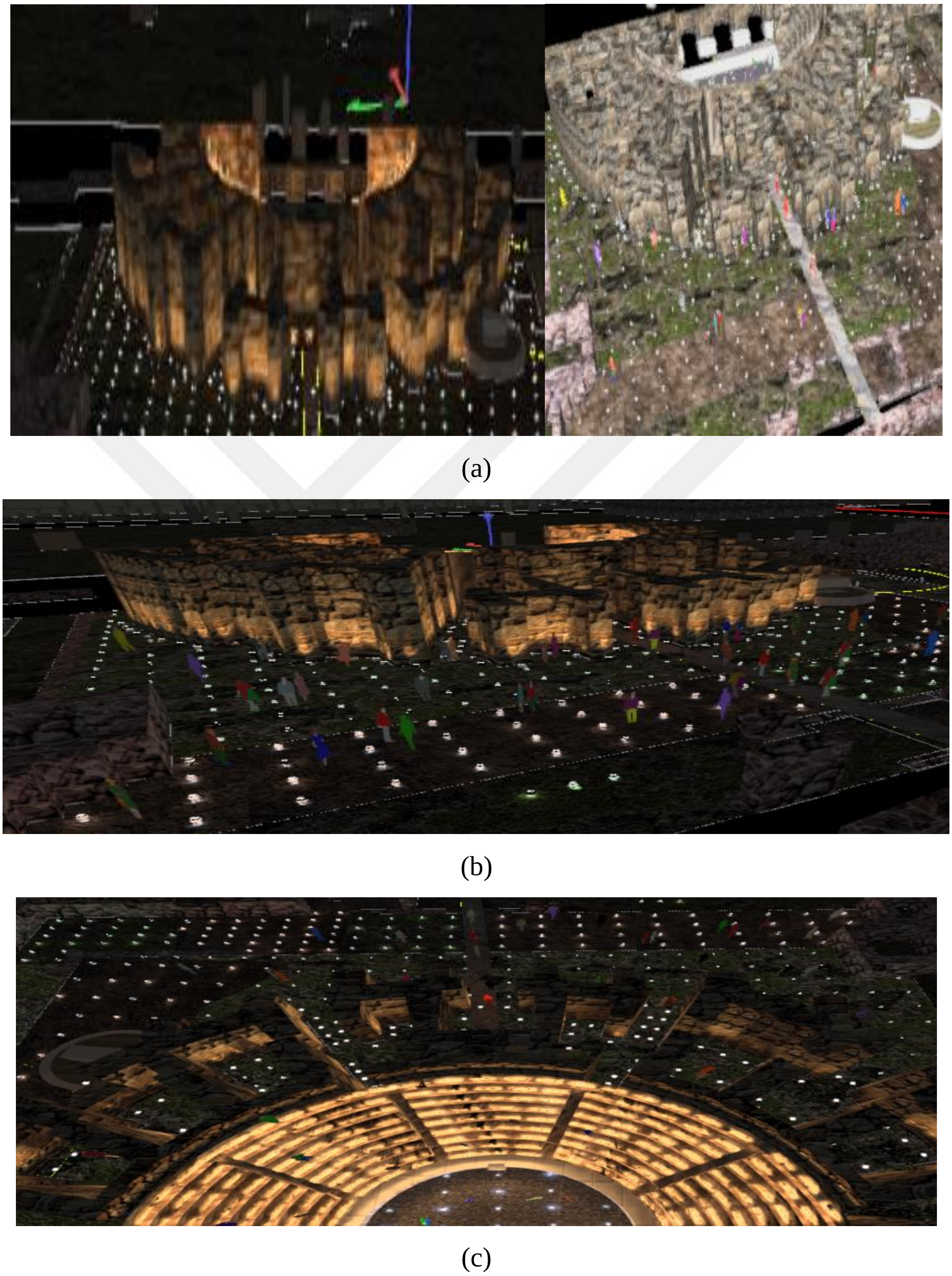
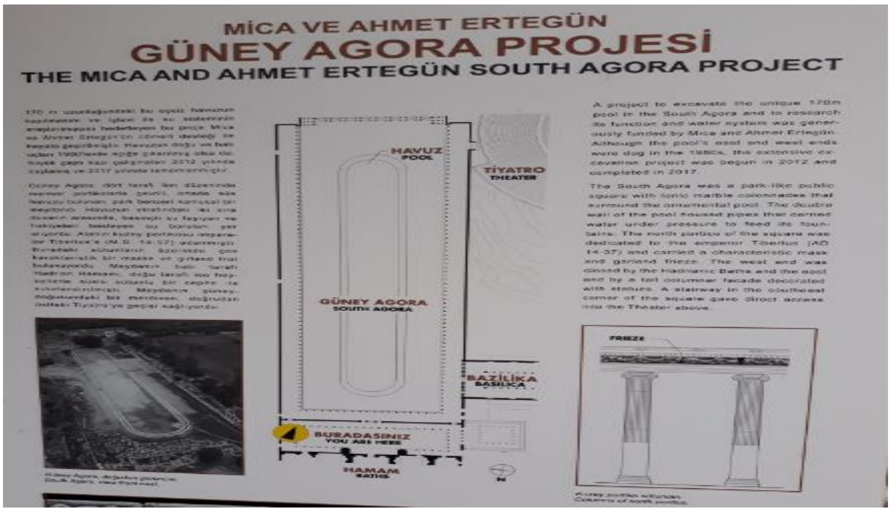


Figure IV.20 Aphrodisias Tetrapilo 3D Design And Lighting System

In Figure IV.20, (a), (b) and (c) show that Aphrodisias Tetrapilo 3D Design And Lighting System.



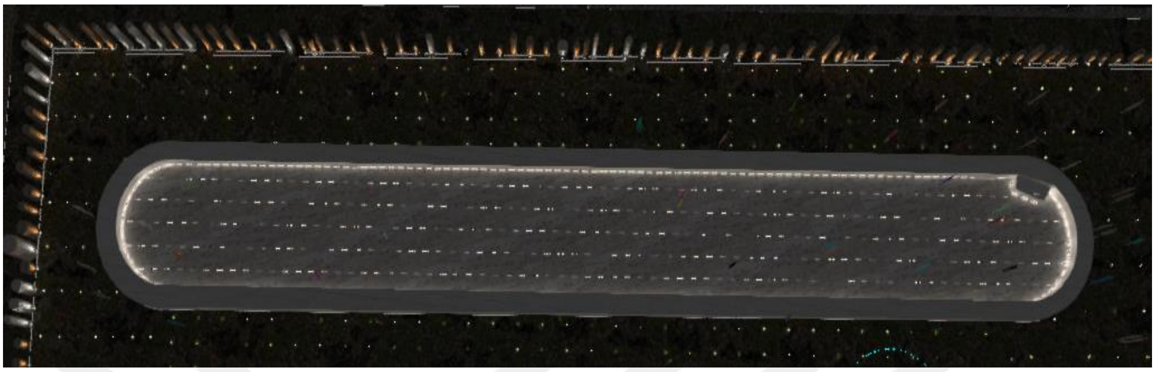
(a)

(b)

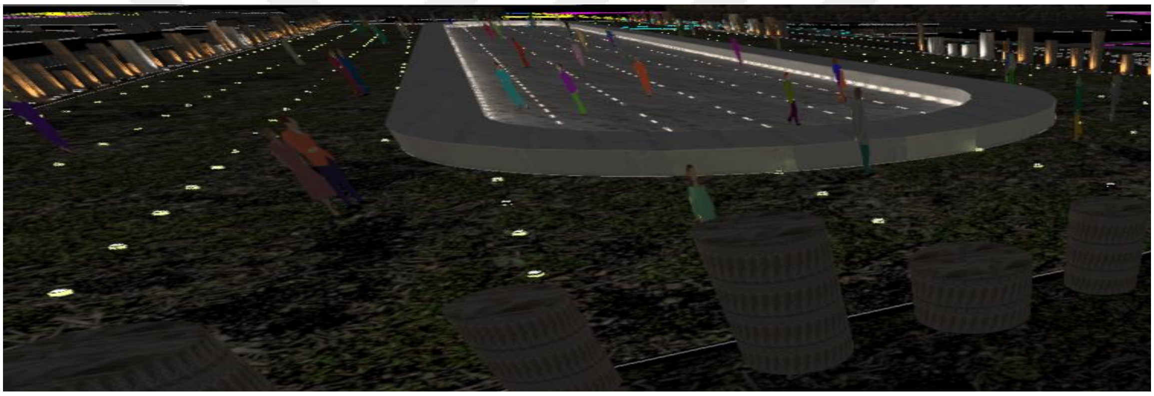
Figure IV.21 (a) and (b) display South Agora

Figure IV.22 Appropriate LED selection

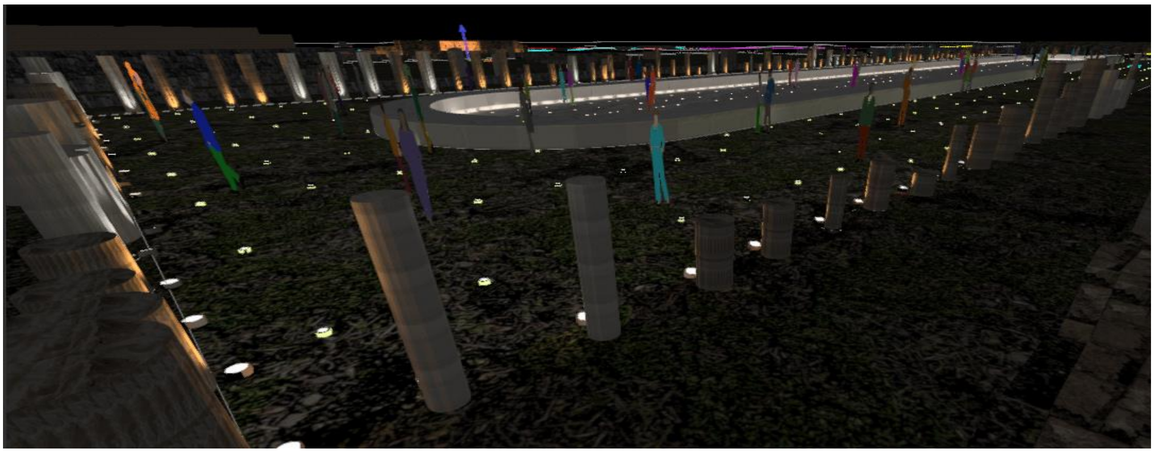
In Figure IV.22, besides the texture material and color, although the properties of CCT and CRI values of the lighting source to be used are suitable, its reflection from the surface is different. 5500 K and 5700 K are suitable as the material is dominated by white color. However, it is obvious that the lumen and power values affect the light efficiency of the light sources. In other words, it seems that it diffuses perception by reflecting very bright and diffused. This poses a risk to safety and security in illuminating open air museums at night. Although the first light source has very low lumen, power and light efficiency, it provides more regular and visible light. Shadow formation is lower than the other two light sources. The most important mistake made in the lighting systems, it is to choose the light source according to the power values or CCT values. It is possible to notice these mistakes in many illuminated areas around us. Although CRI: 90 and above is accepted as the best color rendering index, 70≪ CRI ≪80+ is suitable for our outdoor museums because the textures and material structures of the historical remains found in our open air museums are almost the same. For CCT, although there are many light sources with the same Kelvin value, their outward reflection may be very different or the desired result may not be obtained. For this reason, the lumen value and luminous efficiency are particularly important points. When a very planned and careful lighting design is made, very good lighting can be obtained from low power LED light sources. So, it is possible to save electricity.



(a)



(b)



(c)

Figure IV.23 South Agora 3D Design And Lighting System

In Figure IV.23, (a), (b) and (c) Show that South Agora 3D Design And Lighting System

4.3 Road Lighting

(a)

(b)

Figure IV.24 Road View Example

In Figure IV.24, (a) and (b) show Road View Example

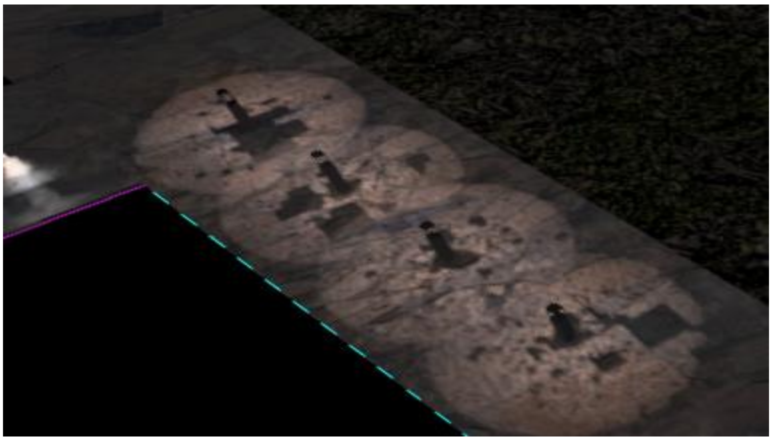


Figure IV.25 TYPE V: 360 degree lighting

In Figure IV.25, TYPE V: 360 degree lighting is not suitable for road lighting. It is suitable to be used in large areas such as a park.

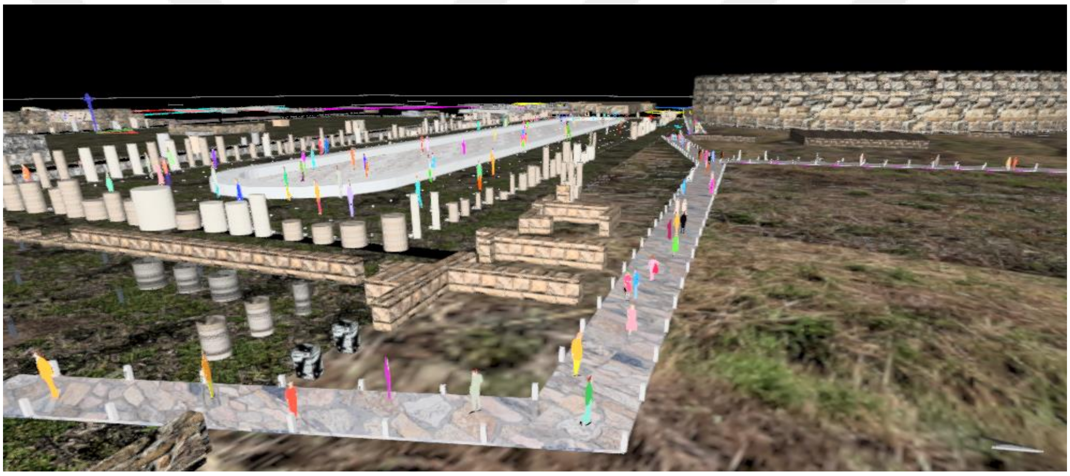
Figure IV.26 Type 2, Type 3 and Type V situations and NEMA angle standarts

Figure IV.27 TYPE V

In Figure IV.27, TYPE V is suitable, wide grass soil mix area. MacEllipse must be at least SDCM 3 and 4.

In Figure IV.26 and Figure IV.27, the bollard mushroom-style lighting model should never be used in road lighting in open air museums. However, it is suitable to be used in our open-air museums to illuminate large areas with the appearance of land. In the above examples, instead of illuminating the road in a circular (360°) manner or below a certain degree, i.e. at a narrow angle ($\theta < 45°$), at least $60° \leq \theta < 90°$ light source should be used because our material texture is composed of white blue stones, the lighting will make full reflection and cause reflection in different places. If CCT and CRI values are chosen appropriately, the light efficiency lm/W value does not determine the quality of the light source, as can be seen from these sample trials. In other words, even if the lumen value is high and the power value is low, the luminous efficiency will be high, so the desired result can be achieved.

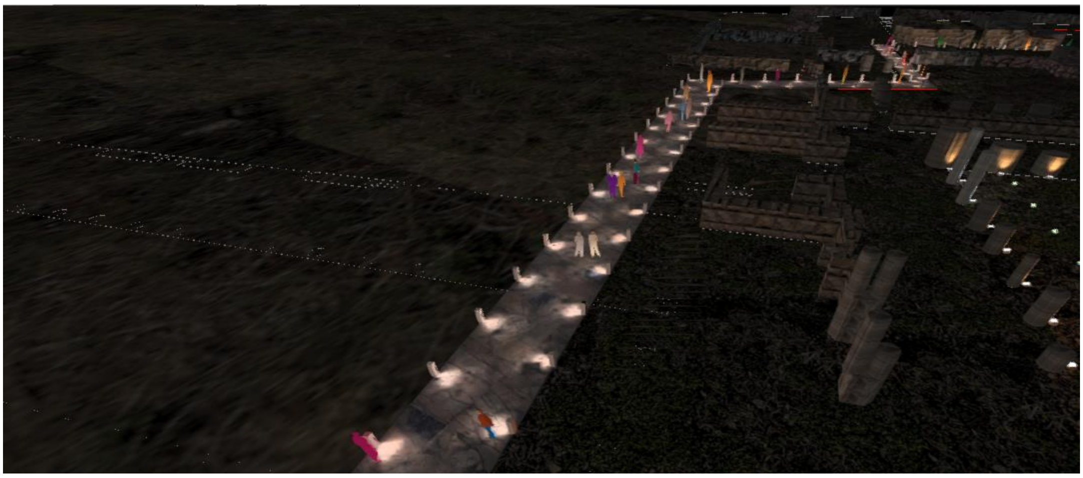
(a)



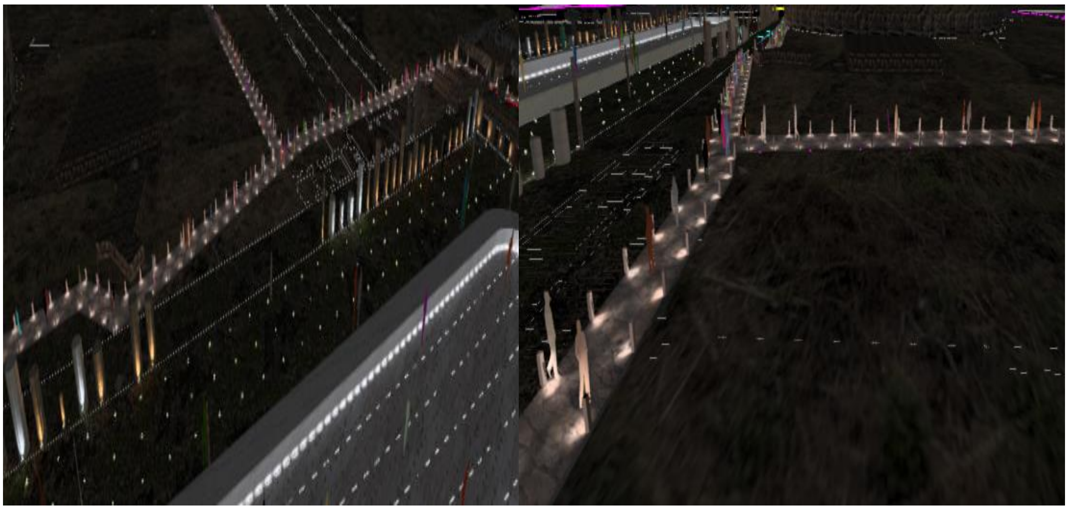
(b)

Figure IV.28 3D Design Daylight View

In Figure IV.28, (a) and (b) show 3D Design Daylight View



(a)



(b)

Figure IV.29 3D Design And Lighting System

In Figure IV.29, (a) and (b) illustrate 3D Design And Lighting System

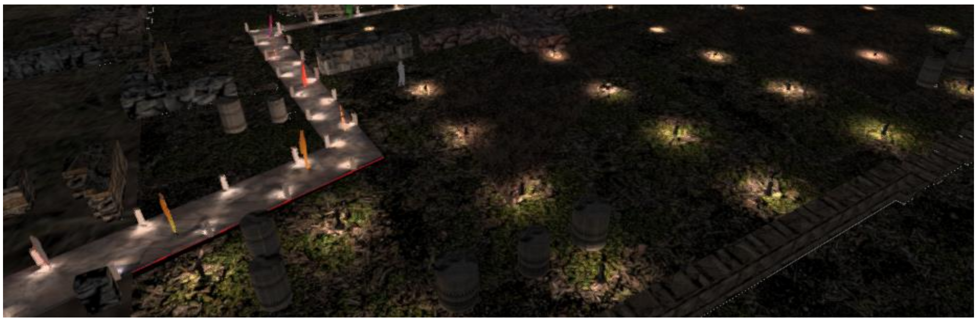
4.4 Road Lighting Results

The open-air museums in our country are very wide and scattered and they consist of old centers of life. For this reason, each process must be done in order and design and lighting must be created. In this study, it is followed the steps below and presented examples of lighting design with 3D designs.

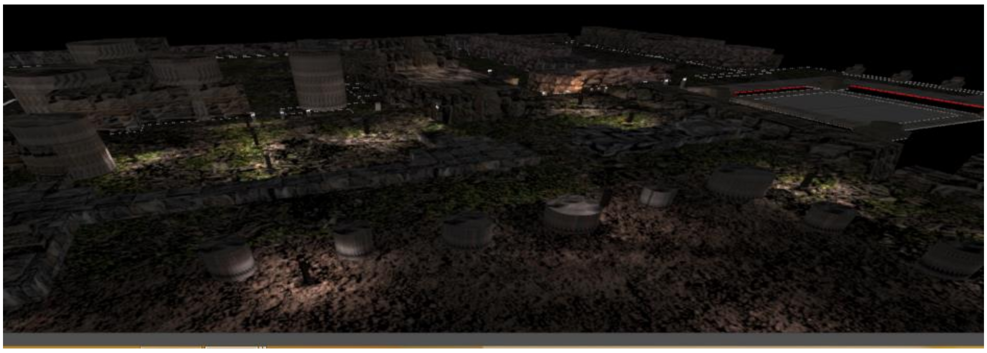
1. Road structure was examined. Material texture was detected. Stone structure belonging to white color and blue color was seen.
2. Due to the geographical structure, there are elevation differences, that is, there are many places with elevation difference. It is understood that when the light source was placed, the height of the lighting section in the source changes from one source to another. It also prevents placing a light source of the same size and height in each section or location because while it causes an increase in the electricity consumed, sufficient light efficiency from the light source will be prevented. Formation of shadow areas is increased or it creates excessive glare.
3. The width of the roads was measured because there is no road width that is seperated equally like highways. This measurement should be done to accurately determine the distance between the light sources. In addition, since there are many crossing paths in open air museums and the width of each is different, the distance between the sources determined everywhere cannot be the same. In our

model, our road width has varying values such as 2.0 m, 3.9 m, 4.1m, 8.1m. The distance between the light sources was determined according to these distances. Example: road width: 4.02 m; one side of the road: 160.5m, the other side of the road: 156.4 m. When the light center height is selected as 0.5 m, the distance between poles should be 3.4 m. It is suitable for our minimum 5 lx in open air museums. The E_m value is especially necessary in highway lighting and varies depending on the length of the pole. However, it is sufficient to provide the value of E_{min} since it is necessary to choose smaller size light sources in open air museum in accordance with the historical texture.

4. Since there are road turns, road lengths were measured mutually. The placement model and number of the light source were determined according to these lengths.
5. According to the results, it is obtained from the ruins, suitable CCT and CRI values were chosen for 3D design and lighting design. In 3D model, it was tried to approach the material texture of the ruins.
6. It is suitable to be between 0.5m≤x<1m beause the height of the mast in the outdoor lighting museums is important for both its aesthetic aspect and the walking path of tourists.



(a)



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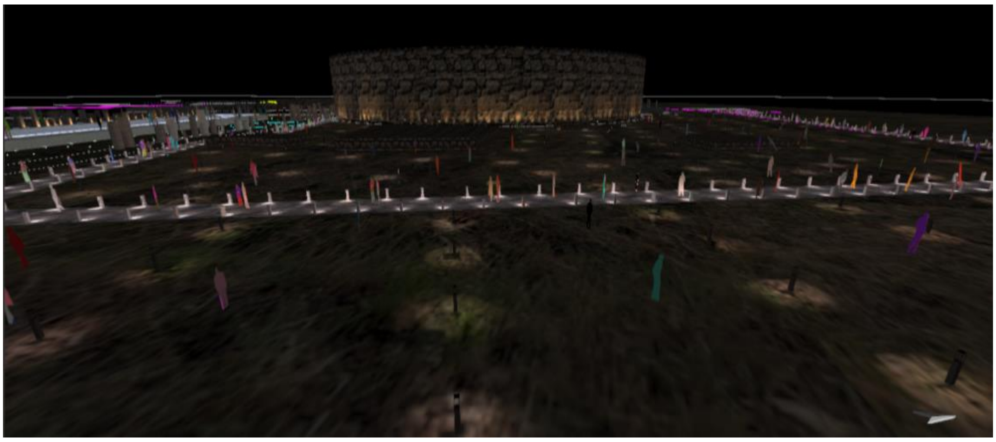

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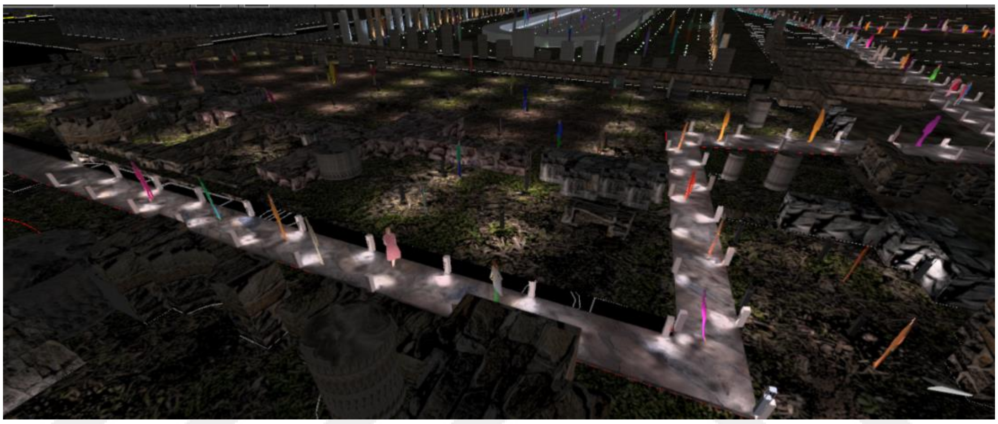
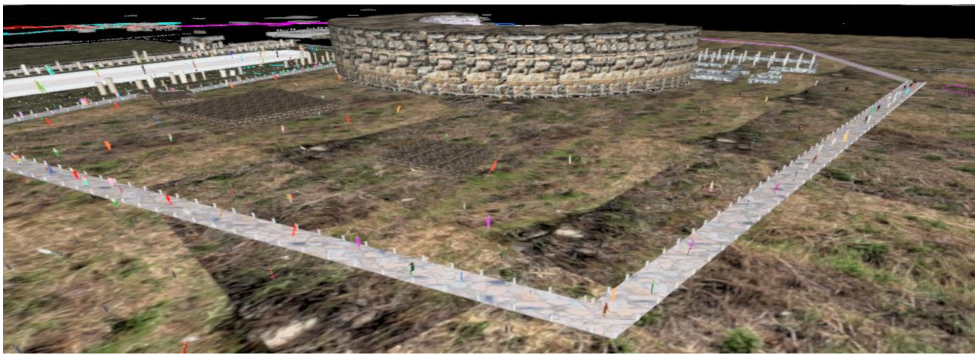


(d)

Figure IV.30 3D Design and Lighting System at night

In Figure IV.30, (a), (b), (c) and (d) show 3D Design and Lighting System at night

(a)



(b)

In Figure IV.31, (a) and (b) show 3D Daylight Views

4.5 Laodikeia -Work And Road Lighting And Evaluation

When it is the illumination of outdoor museums at night, it cannot be considered primarily road structure such as the highway is smooth because there are many road intersections and the indentations of the roads are high, the use of materials belonging to their periods and the regions are evaluated. They increase the importance of examining the places to be illuminated very well and to make measurements. The most accurate placement of the lamps in the places affects the desired light efficiency because it is directly related to energy efficiency. The location of the light placing on the ground will be different from each other. To be able to place them all in the same way, in a regular order, the project must be determined with the coordinate system. In the lighting system, properties such as ground, materials used, geographical structure in the region, etc. must be determined in terms of CCT and CRI values.

In this open-air museum, since the materials with marble texture are intense, light rays will be refracted, reflected, and dispersed by hitting the surfaces, and almost no lighting system has been observed. As can be seen from the applications, since white marble texture is dominant here, bright white is suitable as CCT value between 4000 K - 4500 K, because the walkways consist of white and clean stones, therefore CRI>=80+ is sufficient, higher values because of the clean surfaces will cause brightness to increase at certain points due to excessive reflection. Roads must be measured in both directions in length and width. Path widths vary. This causes problems in the placement of light sources. The Dialux program allows illumination of roads such as plain and highway. While obtaining the 3D look, and planning the illumination of the roads on the tour routes for the tourists, it is evaluated the dialux program according to each measurement result by making individual road measurements and using the map on the internet. It is realized at least 1500 lm and light efficiency 55 lm/W. It is convenient to have the lamp height between 0.5 m-1m. However, positioning the light sources closing to the ground increases the amount of light falling on the road and prevents directly glare from the tourists who visit the museum at night. Lens structures are suitable to emit light between 60° and 75°. Since dirty white, yellow and gray colors are dominant in the walls and columns, 3000K, 6000 K, 6500 K values for CCT and CRI> = 80 + are suitable

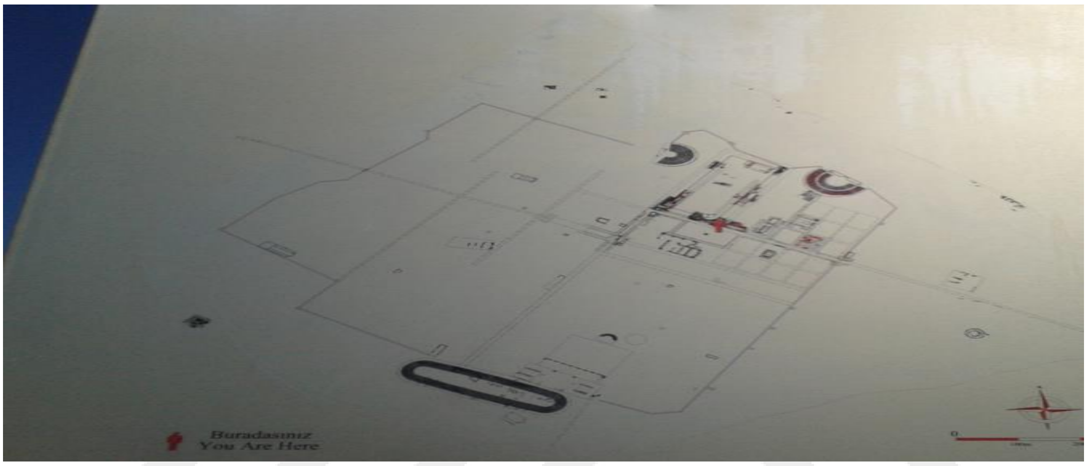


Figure IV. 32 Laodikeia Plan

Photos:

(a)

(b)

(c)

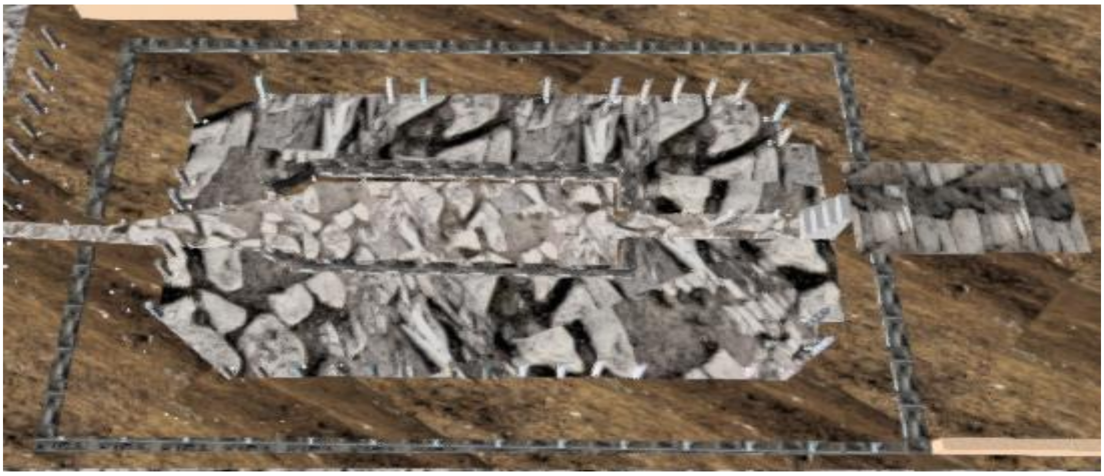
(d)

(e)

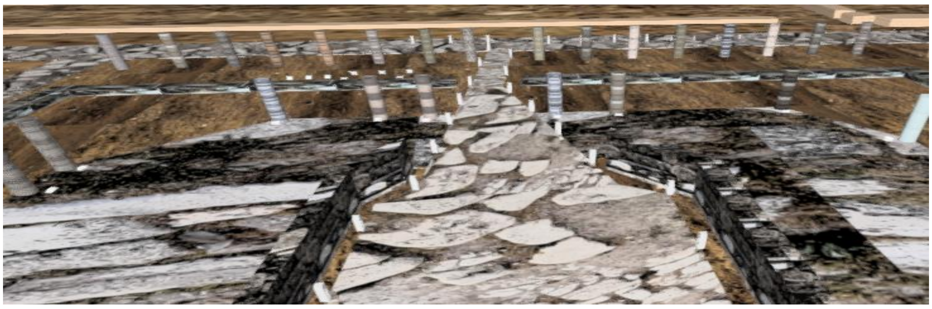
Figure IV.33 Laodikeia Photos in daylight

In Figure IV.33, (a), (b), (c), (d) and (e) show Laodikeia Photos in daylight

(a)



(b)



(c)

Figure IV.34 Laodikeia 3D Design in daylight

In Figure IV.34, (a), (b) and (c) display Laodikeia 3D Design in daylight

Figure IV.35 Laodikeia 3D Design and Lighting Design

As seen in the Figure IV.34, the smoothness, cleaning, light or dark color of the material texture affects the illumination rate of the light coming out of the lamps. In darker colored textures, the area where light falls on the surface is restricted and reflection is prevented.

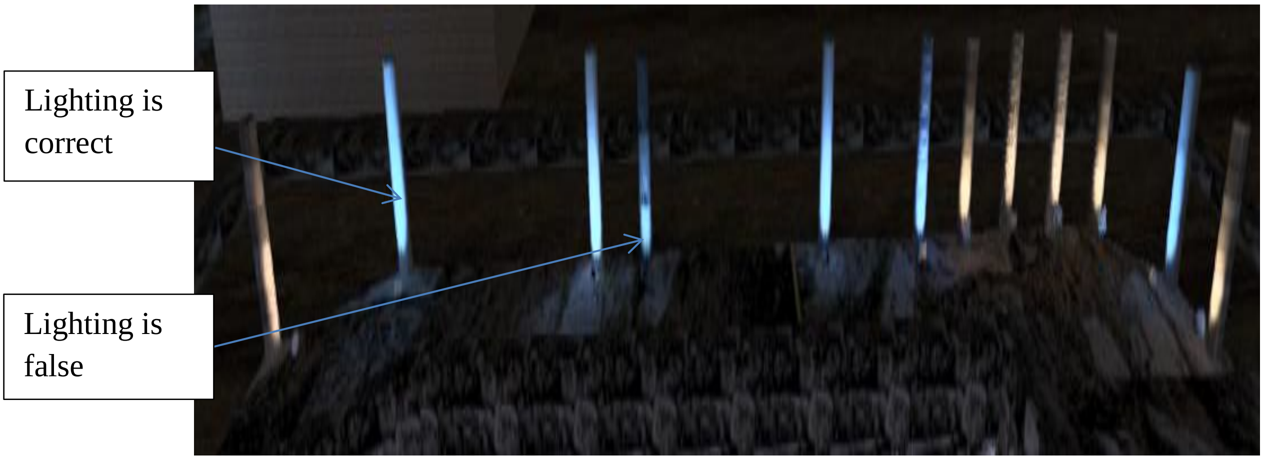


Figure IV.36 3D Design and Monument Lighting

Historical artifacts have an important place in our open-air museums. As you can see from the Figure IV.35, while some of them are fully illuminated, some of them are left in half. Here, the shades and materials of these columns should be determined first. The columns consist of white, gray and yellow colors. Although the CCT and CRI values seem the right and wrong parts of lighting, energy efficiency cannot be mentioned when the lamp layouts and angles are wrong. Since there is light distribution in other parts, the desired area cannot be illuminated, the geographical location where the museums are located is very important. In this 3D design, the LED lamps were taken at equal height from the floor and the angle values were close to each other, it was seen from the results that the ground elevation changes. For this reason, in order to get the best light efficiency, surfaces should be examined while positioning the LED lamps. 3000 K and 6500 K are suitable for historical artifacts in Laodikeia open air museum. However, 4000K should be used in white works. Since the reflection event for historical textures is very high in 6000 K and 6500 K, it shows close to blue features.

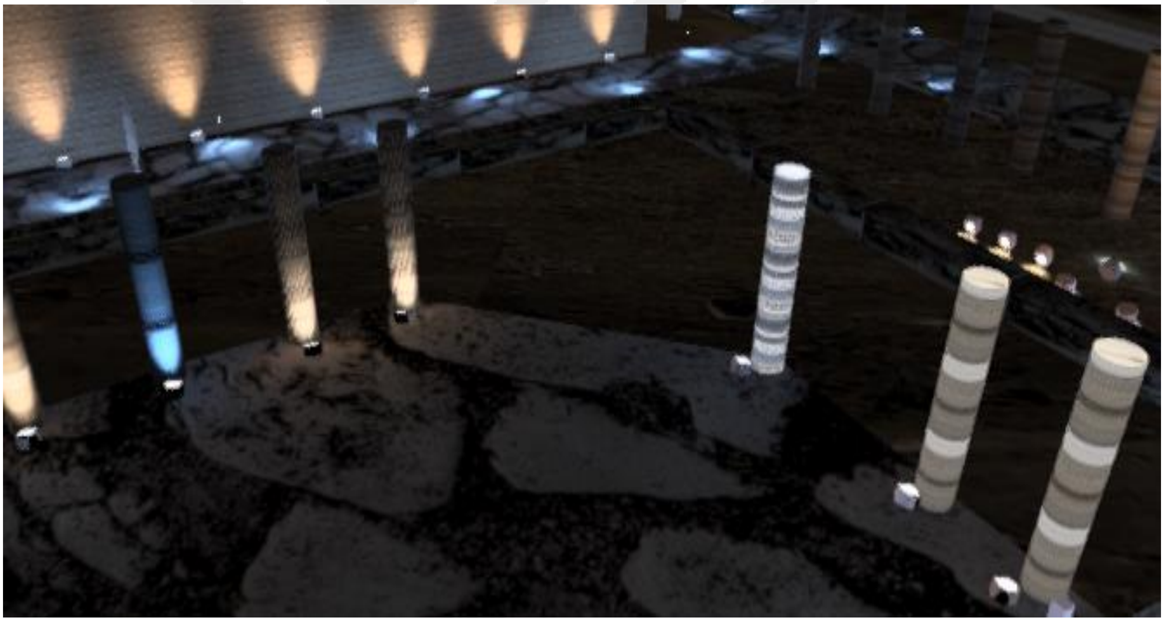


Figure IV.37 Lighting at night

In Figure IV.37, here, the reflection of light from the surfaces varies according to the clean and pollution rates.

Figure IV.38 Different LEDs sources are qualified on the ground

Table IV.1 LED Light Sources

LED Light Sources			
Power	Luminous Efficiency (lm/W)	CCT (K)	CRI
9.2 W	36.1	2700	80
15.5 W	76.5	2700	80
28 W	91.1	2700	80
20 W	91.5	2700	80

In Table IV.1, for the CRI value, 80≤CRI value<90 was determined and the material texture in this museum was determined to be CRI: 80 appropriate. Although CRI≥90 + is considered to be good, it is observed that when CCT is of appropriate value, color perception causes difficulty in detecting and focusing the historical tissues as a whole, as it causes excessive brightness due to the surfaces. Likewise, the CCT and CRI values, power and lumen values, as well as the differences in elevation, material texture and colors in the open air museums are important problems to be faced in night illumination.

Only if the appropriate CCT and CRI or power are determined, where the LED is to be used, the illumination will be bad if the other features are not considered.

NOTE: Therefore, when evaluating light sources, it is necessary to take into account the electrical power of the source together with its luminous power. Energy saving and lighting saving differences should be perceived well. It is our aim to reflect the color tone close to daylight while doing night lighting in our open air museums. 5000 K and over are the color tones approaching daylight. However, the historical texture in our museums where it is worked is mostly in the style of white marble

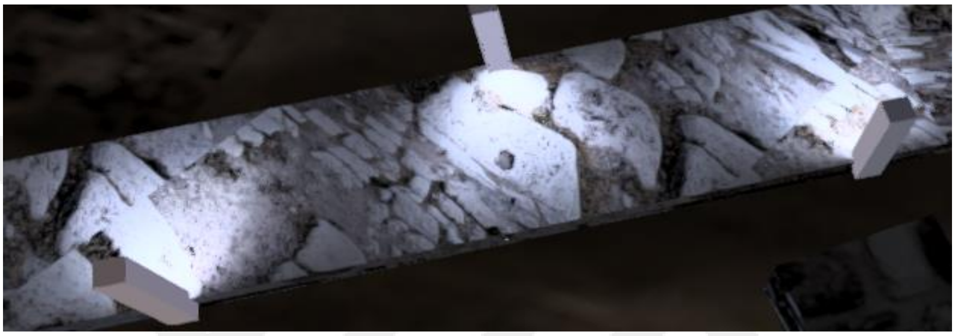


Figure IV.39 4000 K road analysis

In Figure IV.39, 4000 K road analysis with different CRI values

As can be shown in Figure IV.38, on the road: 4000 K, CRI:80, if we do not consider the power and light efficiency in this comparison: in one, the texture of this historical place is white stones, people can perceive the right color. it was able to capture the color of 5000 K and above. However, when it is wanted to capture the color of daylight, CCT: 5000 K and above is not suitable for the safety and security of tourists because it will cause shade and dim environment and it reflects blue color in road lighting.

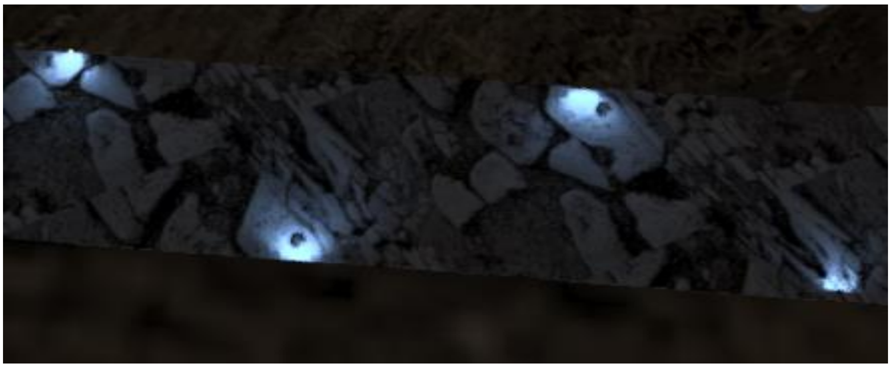


Figure IV.40 CCT 5000 K road analysis

In Figure IV.38, CCT 5000K and blue colour were obtained

In Figure IV.39, it is crucial an integrity in lighting in the space, that is, different color tones causes aesthetic complexity. In this illumination design, the places and historical ruins visited by the open-air museum of Laodikeia are made up of marble and stone textures, while other parts consist of soil and grass. With the CCT: 4000 K, CRI: 80, it is obtained the white light in the tone wanted. It was seen that 5500 K is ideal for catching this in soil and grass. However, its reflection from the ground may be different.

Figure IV.41 LED Light Sources Evaluation

All CCT: 5500 K, CRI: 80. However, lumen, power and light efficiency are different.

Table IV. 2 Evaluating the characteristics of LEDs sources

LED LIGHT SOURCES					
Number	CCT (K)	CRI	Lümen(lm)	Power (W)	Light Efficacy (lm/W)
1	5500	80	4000	49.1	84.2
2	5500	80	1790	27	66.3
3	5500	80	300	4.1	73.1
4	5500	80	520	7.4	70.2
5	5500	80	428	14	30.6
6	5500	70	70	3.5	20

In Figure IV.41, although it is obtained white light from the first LED, 4000 lm, luminous efficiency: 84.2 lm /W, the reflection of the light from the ground causes the brightness level of the light to be high and the dispersion of the light rays gives a mixed image. This will make it difficult for the eye to perceive. It will prevent tourists from traveling the environment easily. The second and fifth LEDs produce close to red and yellow tones as the light efficiency decreases. The third and fourth LEDs create a perception of blue color, although lumen values are low and light efficiency values are suitable. Although the sixth light source has low CRI, power, and luminous efficiency, it shows a more uniform and collective light distribution. Although 80 and above are shown as the best light return for CRI values. For lower power, CRI and light efficiency, light sources should be preferred to prevent the interference from the light rays coming out of them since there will be dominant light sources in the places used.

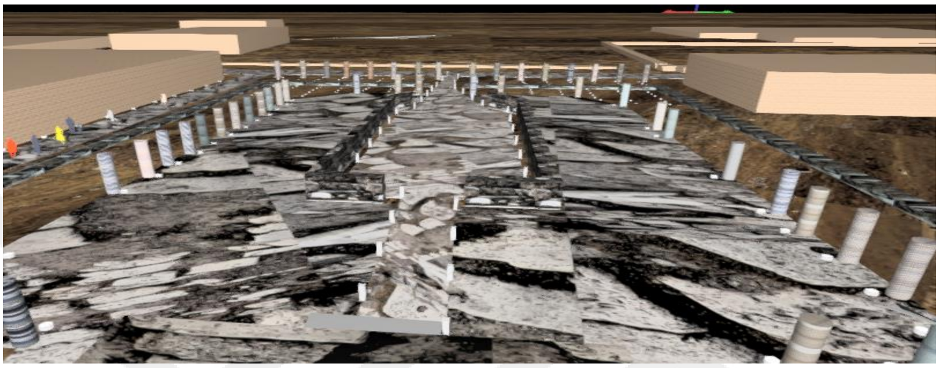


Figure IV.42 Laodikeia 3D Design in daylight

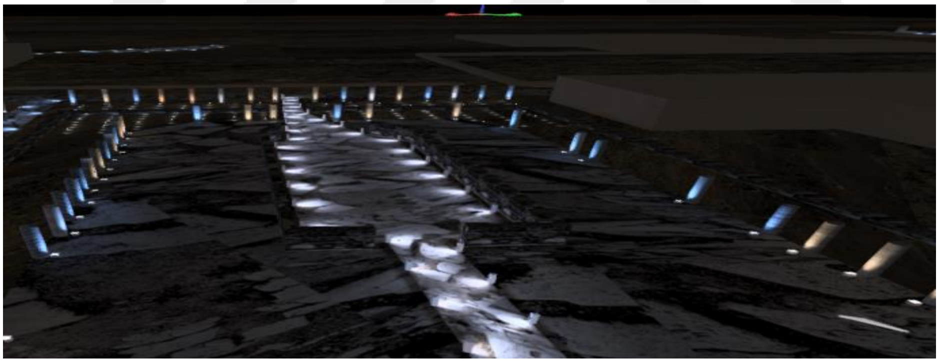
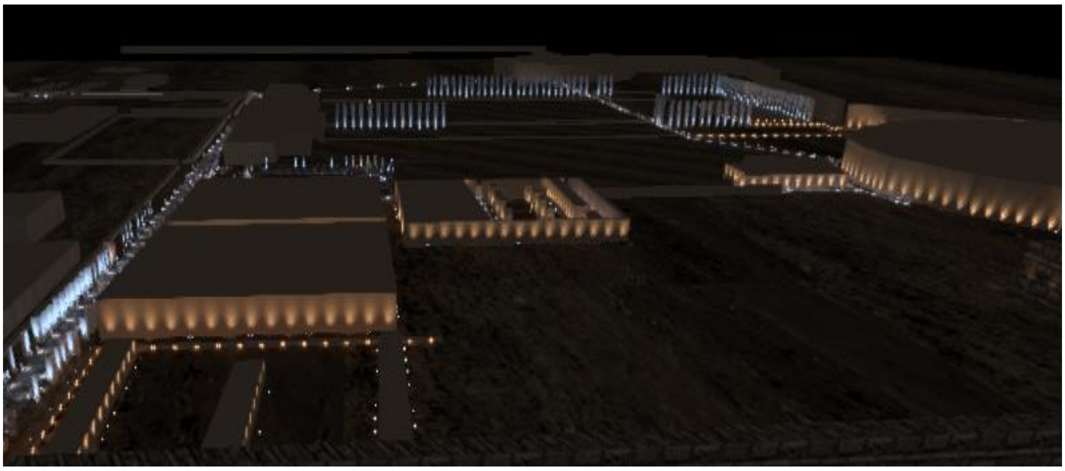
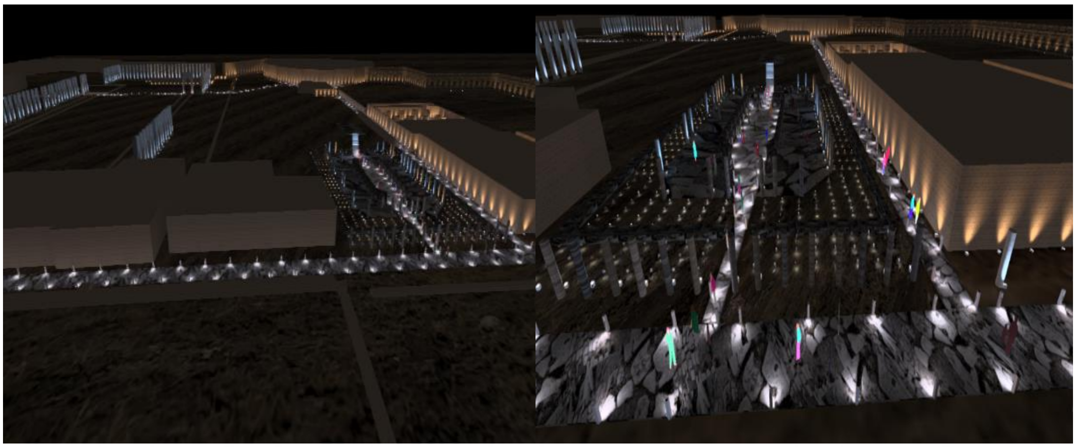


Figure IV.43 Laodikeia 3D Design and Lighting in night light

(a)



(b)

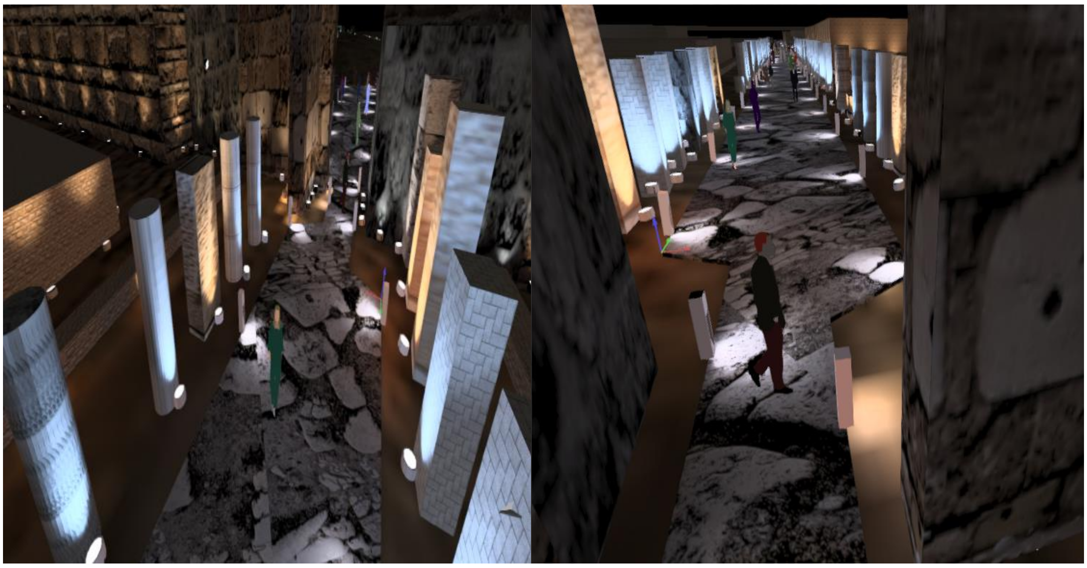


(c)

(d)

(e)

(f)



(g)

(h)

Figure IV.44 Laodikeia 3D Design And Lighting Design at night

In Figure IV.44, (a), (b), (c), (d), (e), (f), (g), (h) display Laodikeia 3D Design And Lighting Design at night

LED lamps used and their features:

Lighting of the column:

1. 6500 K CRI: 98 Luminous efficacy: 119.2 lm/W
2. 3000 K CRI: 80 Luminous efficacy: 94.8 lm/W

Large land consisting of soil and grass:

1. 6000 K CRI: 80 Luminous efficacy: 88.4 lm/W (White light of red, blue and green colors)
2. 6000 K CRI: 60 Luminous efficacy: 93.5 lm/W (White light with red, blue and green colors theatre steps:

1. Strip LED 6500 KCRI: 80 Luminous efficacy: 93.5 lm/W
2. Strip LED 6500 K CRI: 80 Luminous efficacy: 146.5 lm/W
3. Strip LED 5500 K CRI: 70 Luminous efficacy: 80.6 lm/W
4. Strip LED 3000 K CRI: 80 Luminous efficacy: 149.2 lm/W

Bollards:

1. CCT: 4032 K CRI: 80 Luminous efficacy: 57.5 lm/W
2. CCT: 4000 K CRI: 80 Luminous efficacy: 85.0 lm/W

The lamps were selected according to MacAdam Ellipse 4 SDCM.

Chapter 5 Discussion and Conclusion

5.1 Result

Using LED technologies, our open-air museums in our country can be opened to domestic and foreign tourists at night. However, very good measurements, reviews are required. Since there is not any study on night museum in our country, it is tried to present a sample study in this thesis because there is no sample research. In some countries in Europe, open air museums are offered to local and foreign museum lovers by continuing with high standards of lighting work in the evening. The aim of lighting designs is to reflect the historical texture correctly, to provide safety and security of living things, and to provide ideas about history in the minds of museum lovers. For this purpose, studies are carried out to obtain the best quality lighting close to daylight by using LEDs. In our country, as in other European countries, not only electrical, electrical-electronic engineering, but also map engineering, photon engineering, optical design experts, software engineering should work together. Because the museum layout plan to be issued is prepared depending on the features such as latitude, longitude, and elevation. In the historical places, it is designed according to the materials used in its own period. While CCT, CRI are chosen, it is not forgotten that they are relationship in the field of photon and optics for LEDs, the coordinate system that comes out of the layout plan, and software for the lighting system, electricity, electrical and electronic engineers are needed. If all these departments work in coordination, real and correct lighting systems and designs are achieved and efficient results are obtained. Basic research is based on light science. The section up to 21st is about photometry. Concepts such as 21st century performance, sustainability, environmentally friendly approach and products are included in the applied research section. Due to the studies on LEDs in the 21st century, fundamental studies includes topics such as color, flickering light, dimming, brightness, dazzling light (glare), optics and control, in practice, such as lighting measurement science, performance, plan and design of places to be illuminated matters. In this thesis, it is applied lighting techniques, fundamental research and implemented them as basic researches.

5.2 Discussion

Our open-air museums do not have any illumination, or existing projects cause to think away from any research, or to be chosen light sources with only stereotyped ideas, and our open-air museums need to illuminate. Of course, it is necessary to take into account the difference between the period in which our country made old illumination and today's illumination. From now on, it will be possible for our country to keep up with technological developments if it is given importance to R&D studies and it is achieved the most appropriate lighting system, design, and to produce LEDs with the features wanted. However, it is acquired necessary studies, trials and tests and their results is collected the best methods. It is important to provide the necessary training and to follow the studies abroad. In this thesis, it is tried to look through different perspective the illumination studies in our country. Because it is emphasized that LEDs are suitable, lighting is used in every area, and it helps the promotion of the country. Many illumination examples made around us, use of faulty light sources reveal that our project engineers should renew themselves. Many areas work together in the lighting works of historical places abroad, and applications are carried out with the values obtained as a result of the joint work of these areas.

5.3 Proposal

If placed with these applications, new technology "Dynamic Projection Mapping Project" can follows. the historical places in their own times through visual animations can reflect to tourists.

LDT files used:

1. Ligman Lighting USA - LBX Bollard
https://www.ligman.com/lbx-7-lb-10861/
2. Bocaro – RZB Lighting
https://www.rzb.de/en/products/catalogue/bocaro/
3. **LUG** Light factory- RUNA 3 LED
https://archiup.com/en/products/recessed-lamps/lug-light-factory-runa-3-led_9737
4. **LUG** Light factory- RUNA 3 LED
https://archiup.com/en/products/recessed-lamps/lug-light-factory-runa-4-led_9738

RESUME

I graduated from METU Northern Cyprus Campus, at Electrical and Electronics Engineering in June 2016. In February 2017, I started master's degree in Marmara University at Electrical-Electronics Engineering. At the same time, I worked as a Technical Product Engineer in a private company. Then, I have continued my career life in a different company as a Project Engineer.

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