



THE ANGULAR USE OF LIGHT IN ARCHITECTURE AND THE CONCEPT OF SPACE

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Abstract: In this study, the analysis of the understanding of space under the influence of light was made. The content of the study touched on the effect of light and space on human perception, both architecturally and computationally. The identity that the light adds to the space, the interaction of the material with the light, and the illusory properties of the light are explained. While examining these abstract concepts, the illumination area of the light was calculated with a computational application. The fact that light is one of the most effective elements used in space has revealed the necessity of designing form, material, and lighting together. It is understood that the effect of basic elements that make up space, such as form and material color, can be increased with angular lighting. It has been understood that if a textured surface is illuminated with a directional light, the visual effect of the surface will increase. However, it has been understood that a material with a smooth structure and a material with a rough structure cannot be illuminated with the same lighting method, and this visual effect will create negativity. For original lighting designs, it is necessary to make accented or homogeneous lighting according to the need, and it is possible to provide this with designed-planned lighting.

Keywords: Architectural lighting, Artificial lighting, Daylight, Lighting engineering

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1. Introduction

People look at the world from the perspective of their cultural repertoire. Thus, it distinguishes the inner space from the outer space, and the light from the dark, and chooses its boundaries. Human first considers visual stimuli in their relationship with their environment, and these visual stimuli contribute to the person's recognition of their location, boundaries, and all other features. As a result, the person perceives the space or the object with the help of these physical and visual elements. How the space or object is perceived by the users and then the reactions to the space or object are related to how the space is visually presented to the user. Space is a suitable space for people to continue their activities by separating them from the physical environment in which they live at a certain rate. The materials with different properties and the lighting design used by the function and aesthetics of the space on all surfaces of the space are among the most important factors that make the space different from other spaces (Göler, 2009; Turgay and Altuncu, 2011; Esen et al., 2020). Surfaces play an essential role in spaces where a large part of human life passes. The surfaces, which have the characteristics of the materials used in its construction, make the space comfortable and give that space an identity. It is the material of the surface that provides the shape of a surface and gives its texture and color. It is the visual characteristics of the materials

used on the surfaces, such as the form, texture, and color that give the space its identity. Light is also accepted as a building material like concrete or steel materials in space design. Despite the need for all materials that provide the physical definition of space, light is distinguished from other building materials with a feature it has, because light gains its physical existence only if it is seen by the human eye. The ability of the eye to see the light occurs as a result of the contact of the light with a surface (Göler, 2009; Innes, 2012; Cengiz and Cengiz, 2018; Çağal, 2020; Duman et al., 2023). Thus, it is understood that there is an inevitable relationship between surfaces and light. In the 1st picture the light was applied from the top and in the 2nd picture the light was applied from the bottom. In Figure 1, the same shape creates the perception that the pictures are different with the effect of light in different directions.

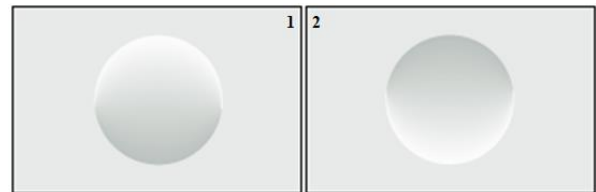


Figure 1. Light effect of the same shape in a different direction (Ganslandt and Hoffman, 1992).

Just as the form, texture, and color of surfaces can be seen by users, depending on the presence of light, light



finds value and is shaped in space only as a result of its relationship with surfaces. In space design, successful results can be obtained if the mutual relationship between the surfaces that make up the space and the light is correctly established. This situation highlights the need for lighting design in space design. In architectural lighting design, lighting design principles should be followed. Knowing the material properties of the surfaces in the space in terms of light (such as reflection or absorption) plays an active role in achieving the purpose of the design. A successful lighting design increases the functionality, reliability, and aesthetic value of the space.

2. Interaction of Visuality and Light

Spaces gain an identity as a result of the combination of human perception ability with light. Because most of the spaces designed with the right lighting are not the spaces seen with the designed light unless there is light. In the absence of light, the colors and forms of the materials in the space lose all their impressiveness. It is possible to design in a wide variety of spaces, from provocative effects to creating a religious environment with light. With the shadow effect created by the light, visual effects such as size changes and expression differences can be obtained in three-dimensional forms. The interaction between light and surfaces visually defines the material properties of the objects and surfaces that make up the space. Light appears as a result of contact with a surface

that will reflect or transmit it. Surfaces have some form, texture, and reflective properties depending on their visual structure. The surfaces can be in various textures such as patterned, matte, glossy, rough, and smooth. In addition, there are various shape features such as concave, convex, pointed, oval, bumpy, and flat. All these visual features are directly effective in the way surfaces reflect light (Unver, 1985; Turgay and Altuncu, 2011; Yumurtaci, 2013; Esen, 2020). A simple change in the wall covering of a space or the addition of a mirror or a polished painting can dramatically change the illuminated appearance of a space. If it is effective on the visibility of the materials with its features such as the visual properties of the surfaces have a great effect on the lighting of the space due to light. From this point of view, it is possible to say that light is a design element that has a passive structure as well as an active one. Although lighting is included in the building after the formation of form and material in space designs, it is an element designed together with other elements beforehand. The fact that light is one of the most effective elements used in the interior reveals the necessity of designing form, material, and lighting together. The effect of the designed lighting on the basic elements that make up the space, such as form and material color, shows how important lighting is. The use of lighting in different designs in the space is seen in Figure 2.

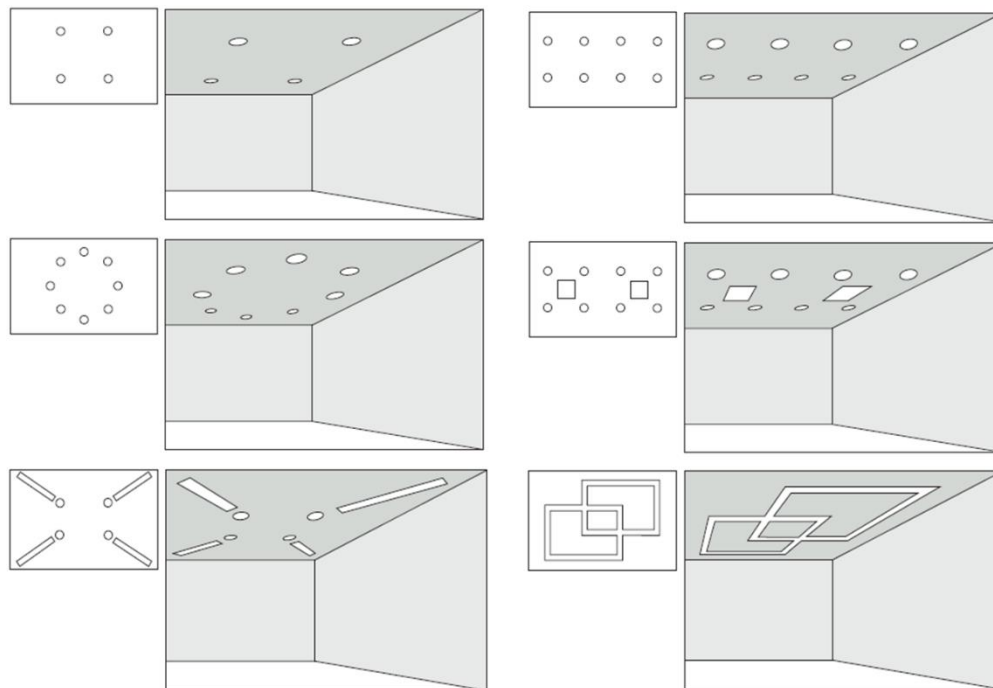


Figure 2. The use of lighting in different designs in the space (Ganslandt and Hoffman, 1992).

2.1. Formalism and Light Influence

Light is an indispensable element in the design of space in terms of facilitating our acquisition of knowledge of the forms around us. The use of light in three different ways directional, diffuse, and dominant direction determines the visibility of the form, its quality, and the

structure of the shadows. In Figure 3, the effects on the shape and shadow structure as a result of the application of light on a shape in different directions are seen. Directed light (left column) produces distinctive shadows and strong effects. The form is emphasized while the details on the surface are hidden by the shadow.

Dominant lighting (middle column) creates soft shadows. The shape is recognizable and there are no disturbing shadows. Diffused lighting (right column) almost does not create shadows but does not sufficiently introduce the form. In Figure 3, some forms and surface structures can be seen at different lighting angles.

Sometimes, it is desired that the shape of a wall or any object that makes up the space is unimportant, creates an uncomfortable image, or is imperfect so that it cannot be noticed by users (Göler, 2009; Çağal, 2020). In such a case, it shows that it would be beneficial to use diffused lighting as needed. Conversely, when the shape is expected to attract extra attention by creating sharp shadows, the emphasis on form can be increased by applying directional lighting. It is necessary to ensure the

harmony between the number and location of the light sources to be used, the direction and direction of the light is applied. Otherwise, light effects that are incompatible with the form will occur. For example, Figure 4 shows the wall surface with curvilinear shape and texture. For this wall lighting, angled lighting suitable for the purpose is used. In the first angle lighting, the light angle was applied as 62%. In the second-angle wall lighting, the light angle was applied to 75%, creating a targeted space perception. In this way, the shape of the wall draws extra attention by creating sharp shadows with angled lighting in Figure 4, and the emphasis on form is increased by applying directional lighting. Figure 4 shows examples of angled lighting suitable for the purpose.

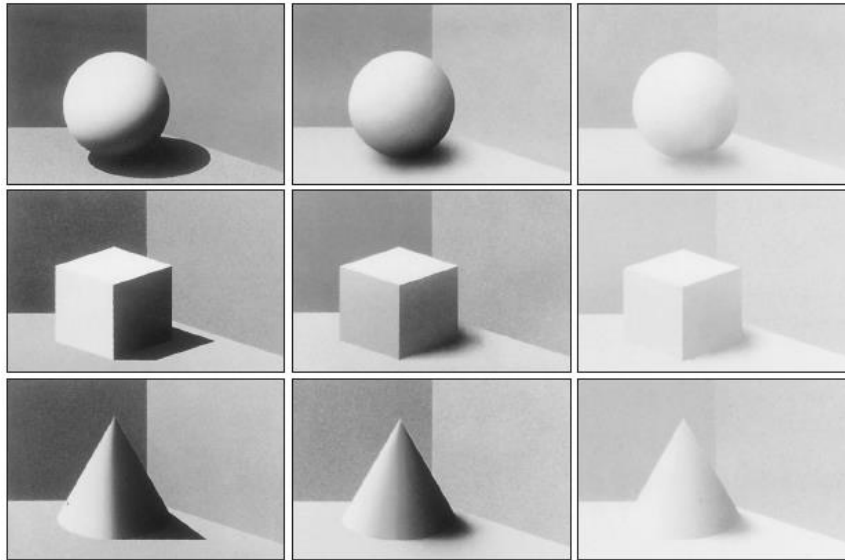


Figure 3. Some forms and surface structures at different lighting angles (Ganslandt and Hoffman, 1992).



Figure 4. Examples of purpose-built angled lighting.

Incorrect positioning of the fixture to the wall shape will cause the surface to be perceived incorrectly. Again, just like wall lighting, the correct and incorrectly positioned angular lighting in the painting lighting in a museum serves the purpose or causes a bad appearance to be perceived by deviating from its main purpose. Figure 5 shows the correct and incorrect positioning of the angular lighting (Ganslandt and Hoffman, 1992).

2.2. Surface Texture and Lighting Effect

The texture features of the surfaces are one of the most important elements that affect the perceived size of the space and determine its volumetric expression. It affects the spatial width estimation, such as the perception of surfaces as far or near the user in line with the user's perspective.

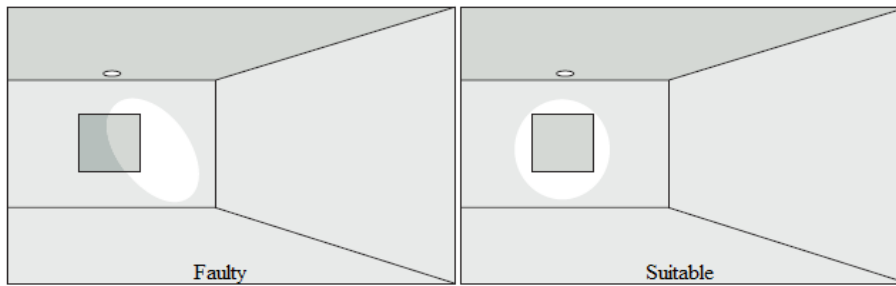


Figure 5. Correct and incorrect positioning of angular lighting.

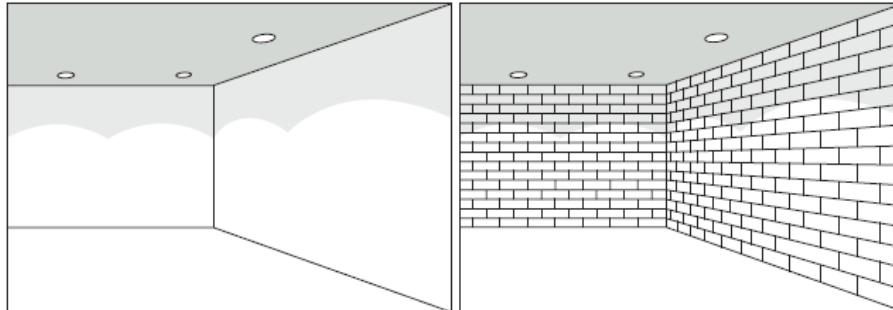


Figure 6. Light effect on the plastered and unplastered wall surface.

The most important reason why texture has such an effect on the perception of space is its interaction with light. It is possible to convey the effect desired to be created in the space with the texture used, to the user, with the help of artificial light, which makes the texture visible and increases its impressiveness with its features such as type, color, direction, and location. Light has properties such as making a soft texture look like a hard texture or creating shadow plays on the surface. Not applying the appropriate lighting solution only to the surface texture causes the visual effect of the space to decrease. If the relationship between texture and light is established incorrectly, unwanted images will occur and the perception of space will change. It is seen that two different types of luminaires are used as linear and spotlighting in Figure 4. With the linear luminaire, the light first touches the ceiling and then the textured surface. With spot luminaires, the light is transmitted on the surface in a directional manner and at an angle of 45 degrees. Two different effects are seen on the surface as a result of the change in the position, direction, and direction of the light. As a result, it should be decided what the desired effect is and accordingly, the type of luminaire, its location, etc. should be determined and selected.

Illuminating a textured surface with a directional light increases the visual effect of the surface. On a surface illuminated by a diffused light, the applied light reduces the visual effect of the texture and even obscures the three-dimensional feature. Diffused light prevents the texture effect from reaching the user, causing the space to be monotonous and unemotional. A surface texture illuminated by a point light source directionally may appear different from its real state because the textural details on it are enlarged, creating harsh and sharp

shadows. In this application, the small size of the light source and the hard shadows formed accordingly create exaggerated images on some parts of the surface. Again, in directional lighting, small differences in the texture as a result of shadows and penumbras are difficult to distinguish as the size of the light source increases, but on the other hand, this soft shaded illumination provides the perceptibility of the concave-convexity of the surface and the three-dimensional structure of the tissue. The angle of the directional light, on the other hand, affects the hardness of the tissue depending on the shadows it creates on the surface texture, causing its appearance to change. For example, if a directional light hits a textured surface at a right angle, shadow formation is very low, thus reducing the visual effect of the texture (Aytug, 1989; Kazanasmaz, 2003; Çagal, 2020). While the illumination distribution on an unplastered wall is the dominant feature, the same illumination distribution on a plastered-even wall is interpreted as the background. In Figure 6, a light effect can be seen on the plastered and unplastered wall surface (Ganslandt and Hoffman, 1992). Figure 7 shows the use of the light angle as a background or disturbing decor. A light distribution that is not compatible with the architectural structure of the space is perceived as disturbing patterns that have nothing to do with the space. The light angle determines whether the light is perceived as a background or as a disturbing shape.

2.3. Orientation of Light

The effective transmission of the light emanating from the light source to the desired location is the main issue of lighting. In addition, necessary precautions must be taken to prevent this light from creating glare. Materials with reflection, refraction, absorption, and diffusion properties are used to direct the light. Under normal

conditions, only a small amount of light falling on a surface is reflected. This reflectance rate depends on the type of surface, the angle of the light, and the spectral composition of the light. Depending on the surface type; It is classified as specular reflection (glossy surfaces such as aluminum and glass), diffuse reflection (matte and rough surfaces), and mixed reflection (glossy paper and

glazed ceramic surfaces) (Kazanasmaz, 2003; Sirel, 2007; Cengiz et al, 2015). In Figure 8, light reflection is seen according to the surface type. Figure 9 shows the refraction of light (absorption and reflection), that is, the passage of light between two surfaces of different intensities.

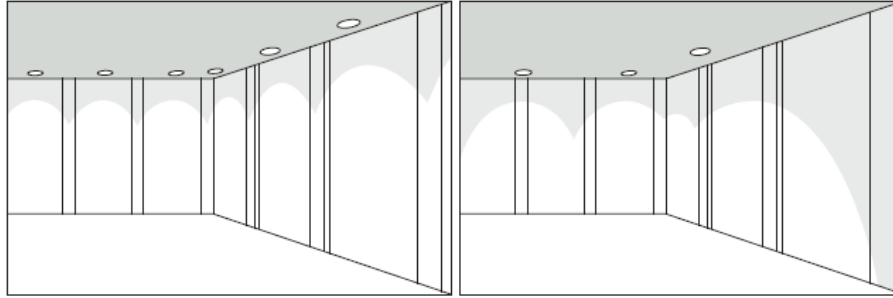


Figure 7. Use of light angle as background decor or disturbing décor.



Figure 8. Reflecting light by surface type.

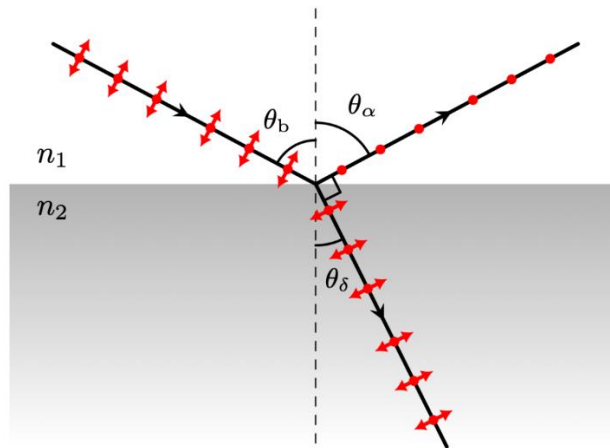


Figure 9. Refraction of light (absorption and reflection).

In lighting design, spaces, where highly reflective materials and colors are used, are illuminated more efficiently. These spaces are seen as wider and warmer than the spaces where low-reflective materials are used. For this reason, it is necessary to know the reflectivity of the material used before the lighting design is made in the space. Illumination of a surface with a bright texture on which fine works are worked on, with a directional light source will cause specular reflection on the surface, causing the image of the user and the light source to be reflected from the surface. As a result of this, it will cause the work to be invisible, make it difficult to perceive, glare, and therefore errors. Therefore, it is very important to pay attention to the way the surfaces reflect light in the space and to choose the light source on the surface characteristics and the function performed. If the surface of the material is not completely reflective or

permeable, some of the light is absorbed by the surface. The light disappears and turns into heat. The absorption of light makes an object dark relative to the wavelength of the incident radiation. Wood is opaque to visible light. Some materials are opaque to some frequencies of light but transparent to others. Glass is opaque to ultraviolet radiation below a certain wavelength, but transparent to visible light. The properties of the surfaces that make up the space increase or decrease the dispersion of the light coming from its source. Therefore, the relationship between surface materials and lighting elements is of great importance for a successful lighting design. The texture features of the surfaces can be emphasized or hidden by choosing and positioning the appropriate luminaires. With the use of a glossy surface, the form of glare can be controlled (Kazanasmaz, 2003; Şerefhanoglu, 2003; Sirel, 2007).

3. Space Design by Light Angle

Today, the increasing demand for original lighting design forces differentiated lighting designs to be produced. Differentiated lighting requires angular lighting designed to cope with specific lighting tasks. For example, to achieve angular lighting on a wall in a hall or exhibition space, or to highlight a single object, completely different angular lighting is needed. Today, the development of technical possibilities and lighting applications has led to a fruitful correlation. Advances in lamp technology and luminaire design continue to evolve to suit the specific applications required by lighting designers. New lighting developments have allowed spatial differentiation and more flexible lighting. From the place of open incandescent and fluorescent lamps to the illumination of large surfaces using wall ceilings or highlighting a defined area, the era of purposefully directing light to certain areas or objects has begun.

The expression that describes how a light source scatters light is called beam angle. The light angle is expressed in degrees, its symbol is ($^{\circ}$). Light sources can be classified as narrow-angle from 5 degrees to 45 degrees and wide-angle from 45 degrees to 120 degrees. In illumination, the light angle is calculated with the Full Width and Half Maximum management. Because at the point where the light is scattered, it is practically impossible to measure the light on both sides without limit. The angle specified as the light angle is the angle at which the light beam falls below 50 percent of its initial intensity. In another saying; the center of the light beam, that is, the point where the light intensity is highest (Şerefhanoglu, 2003; Kazanasmaz, 2003; Sirel, 2007; Turan et al., 2016). Then, it goes towards the beam up to half of this value in one direction. The angle of light is obtained by taking twice the angle found. In Figure 10, the view of the illumination area of the light angle is given.

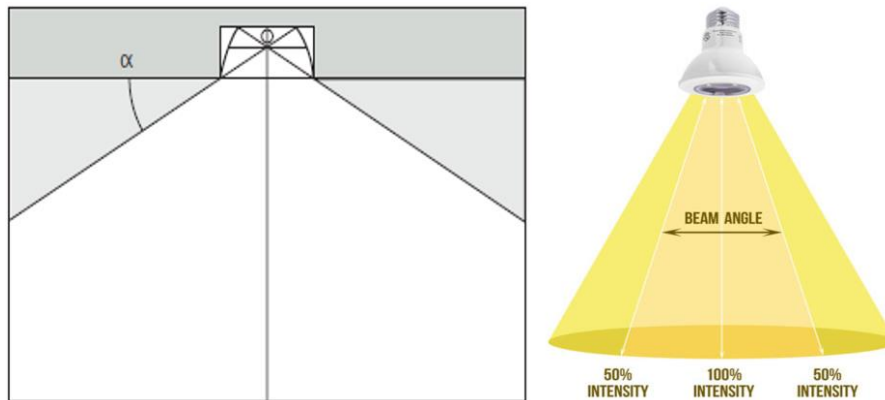


Figure 10. The view of the lighting area of the light angle.

The light angle is determined by the ceiling height indoors and by the height of the pole or mounting location outdoors. If the lighting element is to be placed at a high point, it should be narrow, and if it is to be positioned at a low point, it should be chosen with a wide angle. Lighting elements with a wide angle of light do not emit more light than light sources with a narrow angle. It just scatters the light more widely. When the light angle is narrowed, the luminous flux, that is, the lumen value, remains constant, but the luminous intensity that is, the candela value, increases. The light of wide-angle lighting elements cannot reach far points. For this reason, narrow-angle skylights are usually chosen when lighting from high points. For example, lighting elements in buildings with high ceiling heights generally emit light at a narrow angle. In interior lighting where the ceiling height is low, lighting elements with a wide light angle are used as much as possible. In this way, the formation of dark and very bright spots is prevented, and more homogeneous lighting is provided. As the ceiling height increases indoors, the illuminated surface becomes larger, that is, the light spreads over a wider area. However, in such a case, a decrease in the level of illumination is observed. LEDs, which are light sources, usually emit light at an angle of 120 degrees when no

optical material is used (Şerefhanoglu, 2003; Sirel, 2007; Kaynaklı et al., 2016; Efe and Varhan, 2020). However, in some LED types, such as Power LED, the optical material called primary optics may be located on the LED light source. In this way, the LED package itself can have a light angle of 30, 60, or 90 degrees. To use all these angled lighting sources, it is necessary to know the height of the space between the ceiling and the floor. In addition, the spot opening in the pan should be known. The ceiling spot opening directly affects the area of light falling on the surface. This variable should not be neglected in the calculation. According to this information, while the ceiling height is 5m and 10m, the light area illuminated on the floor surface is calculated in Table 1.

3. Results and Discussion

It is the light and material duo that responds to the many needs of the space, determines the character of the space, keeps the space alive, and surrounds the space. Light and material are two important and indispensable elements that have a great impact on the general appearance of the space, the feelings of the user, the perception of space, the experience of the space, and the interpretation of the space.

Table 1. Light angle and surface illumination areas by distance

Distance between light - surface (m)	Light angle (°)	Minimum spotlight diameter (m)	Light field on the surface (m ²)
5	15	1.32	1.37
	30	2.68	5.44
	45	4.14	13.45
	60	5.77	26.13
	75	7.67	46.18
	90	10.0	78.50
10	15	2.63	5.43
	30	5.36	22.55
	45	8.28	53.82
	60	11.55	104.72
	75	15.35	184.96
	90	20.0	314

Without the texture, color, and form in the material, every space would be the same. In other words, in the absence of light, spaces would be undefined and emotionless. In addition, if there was no light, the visual properties of the materials would not make any sense in the space. Therefore, the materials and the light that makes the materials visible strengthen the perception of space by emphasizing the texture, form, and color of the materials. Light and objects in space are not separate from each other, on the contrary, the light-space duo must take place in space as part of each other. In architectural design, it is important to choose the materials according to the function and concept of the space, as well as to illuminate each different building material by considering its characteristics. The appearance of each material in the face of light application varies. For this reason, material properties are effective in determining the color, direction, angle, and position of the light source to be located in the space. The fact that the light used changes the perception of space significantly as a result of its effect on the surface shape, color, direction, and quality of the shadows, reveals the necessity of constructing the relationship between material and light in the best way. In order not to cause unwanted images while creating this setup and to increase the efficiency to be obtained, lighting design by considering the visual comfort conditions ensures the most correct decision for the space and the most effective solution.

The use of various materials in the space and the combination of lighting design should nurture and strengthen the design of the space and make the design interesting. Material and light source properties should be compatible with each other to avoid random light effects. The principle that a material with a smooth structure and a material with a rough structure cannot be illuminated with the same lighting method should be followed. The color of the light should be chosen in harmony with the color of the surface for the material colors to look close to their color, suitable for the desired color and not to mislead the user. The color rendering of the selected artificial light should also be high.

5. Conclusion

The direction and angle of the light source create various shadow effects on the surface. Care should be taken to determine the effect desired to be created with a textured surface used in the space before the light application and to determine the direction and angle of the light source in this direction. Since light-colored surfaces reflect the light at a higher rate than dark-colored surfaces, in other words, they have more brightness, light-colored materials can be preferred more for energy saving in a place where a high level of illumination is desired. After the change in the form, texture, and color of the materials in the space designed with a certain lighting scheme, the level of illumination will also change. Because the light, which is a design element, will appear dimmer or brighter in terms of illuminance, depending on the color of the new materials. For this reason, the characteristics of the light source such as direction, color, and angle are also changing. Since different actions are carried out in the space, lighting the space with a single lighting scheme is a weakness in terms of light design. For this reason, lighting composition should be created with different lighting schemes such as general daylighting, (homogeneous) lighting, task lighting, accent lighting, or decorative lighting. Such need-oriented lighting will increase the functionality of the space and positively change the aesthetic appearance of the space.

Today, the increasing demand for original lighting design forces differentiated lighting designs to be produced. Differentiated lighting requires angular lighting designed to cope with specific lighting tasks. For example, completely different angular lighting is needed as it is used to achieve angular lighting on a wall in a hall or exhibition space or to highlight a single object. Today, the development of technical possibilities and lighting applications has led to a fruitful correlation. Advances in lamp technology and luminaire design continue to evolve to suit the specific applications required by lighting designers. New lighting developments have allowed spatial differentiation and more flexible lighting.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	M.S.C.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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