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1.4.4 Luminance

Contrary to the definitions of luminous intensity and illuminance, which are strictly valid for the point light source, the definition of luminance assumes the source of real dimensions.

Luminance (L) in a given direction containing a point M on a luminous or reflecting surface is defined as the ratio of the luminous intensity (dI) in that direction and the projected area (dS_n) of a unit area dS of the surface containing point M (dS_n is the projection of dS on a plane perpendicular to the given direction) – see **Fig. 1.10**. Thus,

$$L = \frac{dI}{dS_n} = \frac{d^2\Phi}{d\omega dS_n}. \tag{1.19}$$

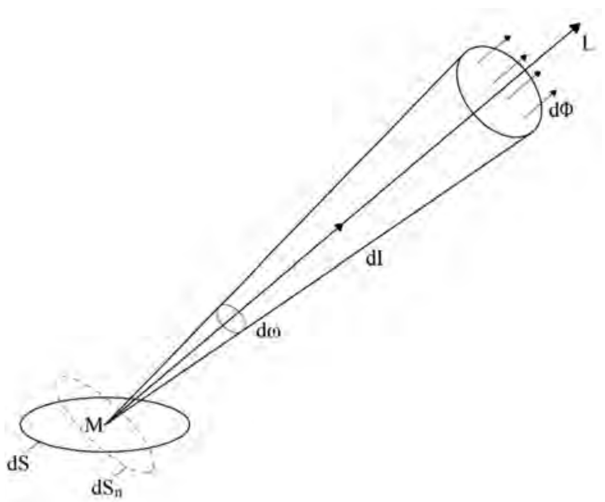

Figure 1.10 Sketch for the definition of luminance

According to **Fig. 1.11**, another formula can also be derived:

$$dE_A = \frac{dI}{r^2} = \frac{L \cdot dS_n}{r^2} = L \cdot d\omega', \tag{1.20}$$

i.e.

$$L = \frac{dE_A}{d\omega'} \tag{1.21}$$

(dE_A is the component of illuminance at point A lying on the observed direction that corresponds to that direction, and ω' the solid angle originating at point A and subtended by dS).

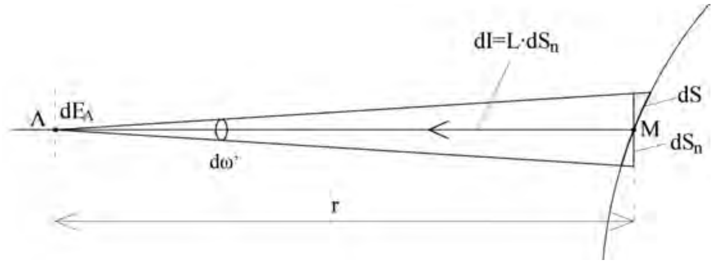

Figure 1.11 Sketch for another definition of luminance

The SI luminance unit is candela per square metre (cd/m^2).

Figure 1.12 shows how the luminance in a given direction, containing the optical centre of a real light source (luminaire), can approximately be calculated under an assumption that the observer is sufficiently distant from the light source, i.e. that the source dimensions are small compared to its distance from the observer. The following formula can be used:

$$L_\gamma = \frac{I_\gamma}{S \cdot \cos\gamma}. \tag{1.22}$$

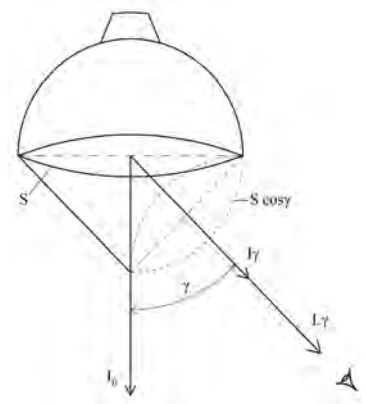

Figure 1.12 Sketch for an approximate calculation of luminance of a real light source (luminaire)

Formula 1.19 and **Fig. 1.10** show that luminance is equal at all points belonging to the considered direction, which was also valid for luminous intensity.

According to **formula 1.22**, small light sources can be characterised by high luminances.

Let us repeat that the definition **formula 1.19** may be applied to calculate the luminance of either luminous or reflecting surfaces.

Sometimes the luminance coefficient is used, defined as the ratio between the surface luminance and its illuminance. It is obvious that it depends on the surface reflection properties and the geometry between the light source, surface and observer (Boyce 2009).

After defining all photometric quantities of light, it can be proved that the intensity of the visual sensation of an object is proportional to its luminance, which is one of the most important facts of the theory of light.

As in Jovanovic (1949), let us consider a very small flat object with a surface S placed normal to the eye axis and viewed by the eye at a solid angle ω (**Fig. 1.13**). If the object luminance at the eye axis is L and the image of the object covers a certain number of the light sensitive retina's receptors (cones) having an overall surface S_i, the luminous flux reaching the retina can be calculated as:

$$\Phi = S_i \cdot E_i = (1-a) \cdot S_p \cdot E_p, \tag{1.23}$$

where:
E_i – illuminance of the part of the retina covered with the image,
E_p, S_p – illuminance of the pupil and its surface, respectively, and
a – overall absorptance of the eye substances, placed between the pupil and the retina.

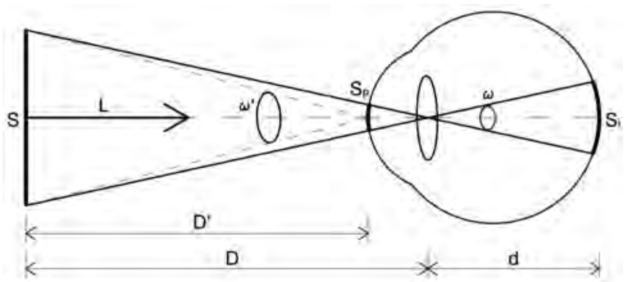

Figure 1.13 A tiny object and its image on the retina

Since the following equation (approximate, but sufficiently accurate) can be derived from **formula 1.20**:

$$E_p = L\omega' = L\frac{S}{D'^2} \approx L\frac{S}{D^2}, \tag{1.24}$$

the following can be obtained from **formula 1.23**:

$$\Phi = \frac{(1-a)S_p LS}{D^2} = \frac{(1-a)S_p LS_i}{d^2}, \tag{1.25}$$

i.e.

$$E_i = \frac{\Phi}{S_i} = \frac{(1-a)S_p L}{d^2} = K \cdot L. \tag{1.26}$$

As the factor K has a constant value (it only depends on the eye parameters), it can be concluded that the illuminance of the image is proportional to the luminance of the observed object. On the other hand, the luminous flux density on the cones covered by the image, representing the image illuminance E_i, is a measure of the intensity of the visual impression. Therefore, the intensity of the visual sensation is proportional to the luminance of the observed object.

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6.2 Recommendations for the illumination of buildings

Unlike daylight, artificial lighting offers various possibilities to control the light beam and direct light in order to emphasise the significant building elements or details, which may not be sufficiently distinguished in daylight. Lighting can accentuate elements of style, decorative details, reliefs and ornaments, which may possess historical, architectural or artistic values. (Djokic et al. 2008)

Without limiting creativity in any way, the aim of the recommendations offered below is to:

- indicate numerous relevant factors which need to be evaluated through the process of architectural lighting design,
- offer guidelines for achieving attractive lighting solutions, and
- point out possible errors.

It should be emphasised that architectural lighting design does not belong to a single field of expertise, which is why representatives of different professions should be involved in the design process.

R 1 When defining the lighting concept, it is important to analyse all relevant views

In a dense street front, the facades are usually viewed from distances close to the street width. In these cases, their intense illumination is not required. However, it is necessary to emphasise the facade's attractive parts, elements and details which are clearly visible.

Two examples of adequate lighting of buildings which can only be seen from close by are shown in **Figs. 6.1** and **6.2**. In both cases mild contrasts stress the significance of the important details. Not being as attractive as the front facades, the sides of both buildings are moderately illuminated. Both solutions include local lighting of the architecturally valuable building elements and details, as well as general lighting from a distance which softens the contrasts on the front facades.

Figure 6.1 Rectorate of the University of Belgrade, Serbia

Figure 6.2 House of Princess Ljubica, Belgrade, Serbia

Figure 6.3 shows the University Library in Leuven, illuminated in full. It is visible from distances up to 100 m and the lighting is clearly emphasising all of the important building features. The hierarchy of the building elements is stressed, becoming more comprehensible than in daylight. Besides a mildly dramatic effect, exceptional harmony is achieved by lighting. The slanted roof is realistic, due to the lighting concept which strengthened the impression of

perspective. The method for showing the depth of space, frequently used in painting, was applied: luminance of the building elements decreases as their distance from the observer increases. It is interesting to notice that the depth of space was additionally emphasised by the reduction of the size of roof windows which are further away from the observer.

Figure 6.3 University Library, Leuven, Belgium

Another example is the Metropol Palace hotel in Belgrade (**Fig. 6.4a**), which is dominant in the street view and from a park located directly behind the building (**Fig. 6.4b**). It can be seen from distances up to 50 m. Except for the entrance, only the window frames are discreetly emphasised. Even though this concept is appropriate for a modern building without reliefs or ornaments, it is important to notice that shields might be necessary to protect the hotel guests from the stray light (produced by the window luminaires) wandering inside. The warm colour of light with subtle intensity contributes to an inviting effect. Smaller in size and less remarkable, the sides of the building are moderately illuminated, but enough to communicate the building function and importance. The side view clearly demonstrates the necessity for prompt and appropriate lighting maintenance.

(a) (b)

Figure 6.4 Hotel Metropol Palace, Belgrade, Serbia – street view (a) and park view (b)

On the same street and only 100 m away from the Metropol Palace is the University Library, which can only be viewed from nearby (**Fig. 6.5**). Its uniform illumination is inappropriate for a facade containing ornaments.

Figure 6.5 University Library, Belgrade, Serbia

The facade is lit exclusively by wide beam floodlights set at a distance of a few meters from the building. The resulting effect lacks emphasis of ornaments, due to the absence of contrasts and shadows, which would contribute to the expression of the facade. As a consequence, the protruding central part with the entrance seems to be in the same plane as the indrawn side parts. Due to the lighting concept, the academic style facade with its strong symmetry, expressive pediment, columns and decorative cornices is presented as flat.

In order to emphasise an urban landmark, it is necessary to analyse its relationship with both its immediate and further surroundings. The Cathedral Church in Belgrade (**Figs. 6.6a,b**) represents one of the most important city landmarks. Due to its setting on a narrow street and tall, dense trees surrounding it, the street view of the Church, shown in **Fig. 6.6a**, is much less important than its panoramic view. Even so, the pediment and mosaic niches on the lower part of the building are illuminated locally in order to be adequately presented to the visitors and observers in the immediate surroundings. Due to its clear functional and historical significance (it served as a church for anointment and crowning of Serbian rulers through the XIX century), its location in the old part of the downtown area and role in the panoramic view, the Cathedral Church was the first building in Belgrade to obtain decorative illumination. The illumination underwent revision several times, the last one done in 2012. The principal aim of illuminating the Church was to emphasise its Baroque tower, as well as strengthen its role of an important city landmark, dominant in the panoramic view. The uniform illumination of the tower, done by narrow beam reflectors mounted on nearby poles and surrounding buildings, has accomplished the set aim, providing it to be easily recognised from distant views, especially those from the opposite side of the River Sava (**Fig. 6.6b**). In addition, the warm colour of light, achieved combining metal-halide and just a few high-pressure sodium lamps, contributes to the attractiveness of the building at night.

The panoramic view is an advantage not all cities possess. It enables the city landmarks to easily come into view and be recognised. Especially if the urban landscape is hilly, a larger urban area can be experienced in the panoramic view. The city landmarks, when easily seen and recognised, provide orientation in space and, therefore, a stable feeling of security during the day, and, if illuminated, during the night. Also, in twilight they contribute to the city silhouette. (Djokic et al. 2011)

Figure 6.6a
The Cathedral Church of St. Michael the Archangel, Belgrade, Serbia – street view

Figure 6.6b
The illuminated Rectorate of the University of Arts in front of the Cathedral Church of St. Michael the Archangel – panoramic view

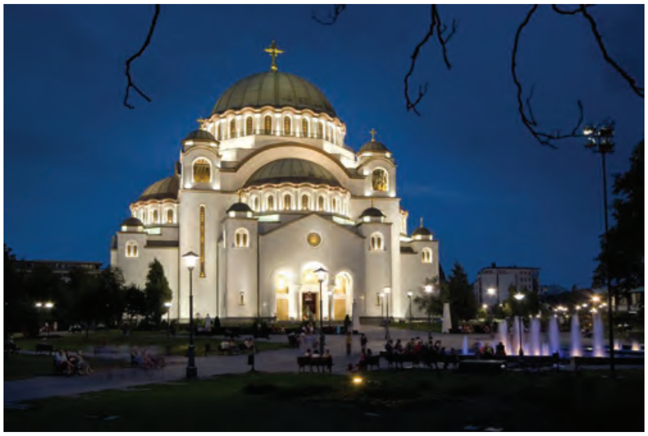

Figure 6.7
The Church of Saint Sava in Belgrade, Serbia

Major city landmarks experienced from both close and distant views deserve special attention. In such cases it is necessary to satisfy the requirements of close up views, emphasising the significant building elements. On the other hand, distant views generally require uniform illumination, so that the building form can be understood and the landmark recognised. The Church of Saint Sava in Belgrade (**Fig. 6.7**), the largest Serbian Christian Orthodox church, is surrounded by a large plateau and dominates Belgrade's cityscape. Since the plateau enables close up views, the building details have been emphasised. The illumination is respectful toward the form and function of the architectural elements, but it also stresses the specific details. Luminaires with metal-halide lamps, as well as LEDs, are set on the building, emphasising the entrance, mosaics, windows, rosettes and cornices. Additional narrow beam luminaires situated on the surrounding poles accentuate the Church domes. At the same time they reduce the upper facade contrasts, which are not appropriate for distant views (it is important to keep in mind that the impression of contrasts become stronger as the observer's distance increases). Each pole carries several luminaires with metal-halide lamps and one luminaire with a high-pressure sodium lamp, the latter installed to produce a ”warmer” look for the cold white stone facade.

Cities with waterfronts, even if not on a hilly terrain, have areas which are exposed to views coming from the water (ocean, sea, lake, river,...). Therefore, they offer possibilities to create memorable images during the night.

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