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Visual Impairment and Lighting: Comparing Guidelines and Illumination in Homes

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Abstract. Universal Design aims to ensure that as many people as possible can participate equally in society, with equal access to housing, education, workplaces, institutions, and public spaces. In the construction field, many of our existing guidelines still need to catch up regarding the diversity of user needs and preferences. Recent developments in low vision rehabilitation have underscored the pivotal role of domestic lighting in fostering independent living and enhancing the quality of life for people with visual impairments. Moreover, several stakeholder organizations and associations in the field of low-vision rehabilitation have published lighting guidelines for this target group. A direct comparison of the different guidelines is difficult, as their focus, vocabulary, and level of abstraction differ: the rehabilitation process focuses on optimizing lighting to support and aid the individual's abilities in the existing environment. It is not directly related to the design- or construction process. Yet, how do the guidelines for lighting fit the actual settings and conditions in Danish homes of people with incipient vision loss or visual impairment today?

In this paper, a selection of these guidelines is assessed and analyzed in relation to three lighting categories: illuminance, luminance, and the visual system. The guidelines are also compared to the initial findings of an ongoing field study. This field study, a crucial component of the research, investigates the role of lighting for individuals experiencing incipient vision loss. This comprehensive approach, which includes both theoretical guidelines and real-world observations, ensures the reliability and relevance of the research, providing a solid foundation for the findings. The practical implications of this research are significant, as it provides valuable insights for architects, researchers, and individuals with visual impairment. Through observations and walk-along interviews in their home environment, we get their personal narratives and observe their lived everyday environments. 37 walk-along interviews were conducted from October 2023 - March 2024 during dark hours. The preliminary findings of the field observations, including observations and measurements, are compared to the guidelines of both the context of building design and -construction and the context of low-vision rehabilitation and stakeholder organizations.

Keywords. Universal design, visual impairment, regulation and guideline, lighting design, domestic lighting, illuminance, luminance

1. Introduction

Vision informs us of the world we live in. The eye is the essential human sensory organ that, through stimuli from light, extracts information about our surroundings [1]. The eye depends on light to function; when there is light, we can see; when there is no light, we

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cannot see. Light supports our everyday life and well-being. However, if the lighting scenario is inappropriate, the light is no longer the solution but the reason for failure to thrive. This points towards optimal lighting scenarios to increase the quality of life for people in general, especially for fragile people with visual impairments [2, 3]. Recent findings in low vision rehabilitation have also recognized domestic lighting as a key to independent living and quality of life for people with visual impairments [4]. This highlights that being able to see is also being able to understand and take an active part in society. Therefore, it is interesting to look into the Convention on the Rights of People with Disabilities, which defines Universal Design as a tool that ensures that as many people as possible can participate equally in society [5]. This regards equal access to housing, education, workplaces, institutions, and public spaces.

Guidelines are essential when discussing and designing the visual environment. They provide inspiration and concrete recommendations suggesting which aspects of light to be aware of and how to create lightscapes that promote good illumination and, thereby, well-being. The Danish Building Regulation specifies guidelines concerning daylight and electrical light [6]. Historically, the concern for light has been overshadowed by other themes such as fire, energy consumption, and sustainability [7]. Thus, the qualities of light have been overruled by other concerns. In a Danish context, the built environment is governed by legislation for specific building typologies and specific functions for shared environments like office space, common access areas, and public buildings. Privat homes are likewise governed by legislation, though they have less regulation.

The legislation provides general recommendations for people but none for those challenged by low vision. To have good advice and suggestions for people with low vision, one has to approach user- and stakeholder organizations' guidelines. Therefore, one of the intentions of the research project "The role of light when the vision changes—Enabling and disabling aspects of lighting in and around the home" is to expand this knowledge based on users' experiences of light and well-functioning lightscapes, applicable in design. Older adults with low vision were interviewed in their homes. The interviews concerned their experiences of challenges with low vision and preferences regarding artificial light in their homes combined with the layout and design of the lighting. This paper draws on the preliminary findings from the interviews and compares them with seven guidelines. It addresses the following research questions: *what are the recommendations for lighting in the guidelines provided by legislation, user – and stakeholder organizations? And how do the project's preliminary findings match these recommendations?*

2. Theoretical framework: illuminance, luminance, and the visual system

The relation between illuminance, luminance, and the processing of the electrical impulses of light in the brain creates a visual impression [8]. Light is described through the laws of physics by its luminous intensity, where the unit of measurement is candela [9]. Only when electrical light became widespread did a definition of daylight and electrical light become necessary. Using well-defined light units in lighting research allows for the traceability of measurements [10].

Illuminance is the luminous intensity or flux falling on a unit area of a surface, measured in lux, used to quantify light distribution from a light source [8]. Lux is the most well-known and widespread unit for communicating light intensity and is used in

lighting design. Traditionally, it is measured on a horizontal plane 0,80-0,85 above the ground.

Luminance is the luminous intensity emitted per unit projected area of a source in a given direction measured in cd/m2. When the luminous flux interacts with a surface, the surface becomes essential, where "the luminance of a surface is a correlate to its brightness*"* [8 p.7]. This means that illuminance is what you measure, and luminance is what the human eye perceives. This distinction is crucial as it can also entail misunderstandings of lighting designs communicated through light units.

The *visual system* is an image-processing system developed through a complex interaction between reflected light (luminance), the eye, and the brain [11, 12]. This means that the luminous flux falling on or emitted from a surface does not alone create the visual impression humans perceive.

With increasing age, the eye becomes less efficient. From around 60 onwards, the eye is a fixed-focal optical system [8], and glasses are needed to help the visual system function. The ability to adjust the pupil size becomes less operational, which causes older people to be less able to compensate for too much or too little light than younger people. Boyce points out that other elements of the eye also change. The photoreceptors decrease, likewise with both neurons in the visual cortex and ganglion cells in the retina [8]. This is all part of the normal process of aging.

Damage to one or more elements that make the visual system function can impair or lower the visual function. The malfunction will be perceived differently depending on where and how the eye is damaged, and psychological processes will impact how people cope with and handle the impairment. For people experiencing visual impairment, the quality or character of light can be crucial for the functioning of the residual vision, where elements like increased light levels, variation in light level to enhance specific areas or a characteristic shadow pattern can be pivotal for creating a supportive visual environment. This is not least because suggestions on supportive light focus on the central vision, which is extremely sensitive to light intensity, and do not consider the peripheral vision, which is less sensitive to light intensity [13].

Altogether, the complex relation between light and the eye's capability results in the human visual system informing us about our surroundings. Together, the well-defined units of light and the knowledge of the human visual system form the theoretical base of this paper.

3. Methodology: a thematic comparison

Seven guidelines have been reviewed and compared. Three of the seven guidelines provide general legislation recommendations, and four specifically target people with visual impairments. All the guidelines that have been studied are generally used and referred to in a Danish context.

Based on the theoretical definitions of light [8], themes on lightning properties from the seven guidelines have been extracted and organized into four main themes and more subthemes: *illuminance* (suggestions for lux levels, uniformity of illuminances), *luminance* (adaptation, glare, contrast) *visual system* (modelling and form-enhancing shadow pattern, uniform/non-uniform light distribution, directionality of light, ambient/focused light) and *light source* (correlated color temperature/K, color rendering Ra/CRI, flicker). Of the four themes, the first three are discussed. Aspects of electrical light sources are left out, as the guidelines mostly inform about their properties rather

than suggest recommendations about the spatial perception of light. The seven guidelines studied are:

On general recommendations

- *Accessible homes. SBi-anvisning 222*, BUILD, Aalborg University, DK [14]
- DS/EN 12464, *Light and lighting - Lighting of workplaces - Part 1: Indoor workplaces*, Danish Standards Association, EU/DK [15]
- JIS Z 9119, *General rules of recommended lighting levels*, JIS Japan Industrial Standard, JP [16]

On specific recommendation for visually impaired people

- TIBS, *Accessibility for blind people and people with low vision*, Danish Association of blind people, DK [17]
- IBOS, *Lighting in everyday life*, Institute for Blind and Low Vision, DK [18]
- DTHS, *Guideline – light, and lighting*, Danish speak, hear- and vision institutions, DK [19]
- TPT *Lighting in and around the home*, Thomas Pocklington Trust, GB [20]

The guidelines' recommendations extracted from the survey are compared with the preliminary findings observed in the homes of visually impaired people. As part of the research project "The role of light when the vision changes - Enabling and disabling aspects of lighting in and around the home," 37 walk-along interviews in peoples' private homes were conducted during the winter season (October 2023 - March 2024). The participants are 55+ years old; 27 live with visual impairments, and 10 without and act as a reference group. The interviews were conducted at their homes during dark hours to avoid additional light from daylight and to study only the effect of the electrical light. The interview guide included questions on how the participant uses the electrical light, how it supports various daily activities, where it is perceived as optimal in the home, and where it is less supportive. Furthermore, based on the informants' narratives, light measurements were conducted as spot measurements on a horizontal plane 0.85m above the floor or at the work surface.

The themes of the guidelines are compared to observations of the lighting scenarios of the visually impaired people's homes to see if the exact instructions of the guidelines are relevant to them and the needs they highlight.

4. Findings: illuminance, luminance, and the visual system capability of modelling

The findings are organized into three themes: illuminance, luminance, and visual system, as introduced above. They all include elements essential to humans perceiving the visual environment. Likewise, each theme relates to basic knowledge of light and vision, as introduced in the methodology chapter.

4.1. Illuminance

The guidelines' illumination recommendations can be a valuable tool for indicating light levels in lighting design projects, as the lux level can be an abstract number. The general guideline DS/EN 12464 recommends illuminance (lux) for many activities, but recommendations for private homes are not included. In a Danish context, though,

DS/EN 12464 is important as it is the guideline that legislation refers to. Also, some of the guidelines for visually impaired people (TIBS, DTHS) refer to this standard for suggestions of light levels.

The general guidelines do not have particular specifications for visually impaired people but emphasize older people as a specific group to pay attention to. JIS Z 9110 recommends higher illuminances when designing for older people. DS/EN 12464 suggests increasing the light levels on the worksurface in offices from 500 lux to 750 lux, and the guideline for Accessible homes suggests the lux level be times three of what DS/EN 12464 suggests.

Of the guidelines that specifically target visually impaired people, TIBS questions the many different suggestions for illuminance levels by saying: "In Sweden, they recommend 350 lux on task area and in Denmark 200 lux, while in the USA they require 1000 lux for the same, without therefore assuming that American eyes are constructed differently than Swedish and Danish ones" [17 p.227]. A research paper by Mills and Borg compares recommendations for office lighting in different countries. It concludes that the recommendations vary not only from country to country but also throughout time [21]. Going through the guidelines illustrates no unanimous agreement on an appropriate illuminance, as the recommendations differ significantly.

Looking physiologically at the eye, increasing illuminances on target areas makes sense to the older eye. As part of natural aging, the visual system becomes less effective. The central vision needs more light to see details and color than the peripheral vision. Therefore, an increase in illuminance compensates for the older eye not being capable of letting in as much light as the young eye. An increase in light level can help many elderly people, but as Boyce states: "There is no reason to suppose that aging is limited to only the optical elements of the visual system." He continues: "The fact that the neural elements of the visual system also show changes with age is important because it implies that the compensation for visual system aging that can be provided by lighting is inevitably limited" [8 p.432]. Therefore, eye malfunctions of people with visual impairment can be caused by many circumstances that are not necessarily related to the amount of light. This supports the preliminary findings from the interviews of visually impaired people where extra light on task areas can be helpful to some, but to others, it creates discomfort. Therefore, it also makes sense that all four guidelines for visually impaired people underline that it is highly individual how much light they need to feel comfortable, and thus has vague recommendations or ultimately leaves out any recommendations for concrete lux level.

4.2. Luminance

Luminance is defined as the emitted light from a surface. The human eye does not see the light itself but the reflection of light from a surface, e.g., the surface of an object [22]. This complicates the work with luminance, as it always relates to the surrounding surfaces and objects to reflect light. DS/EN 12464 highlights the importance of a well-balanced luminance distribution, and to create that, one must ensure that all surfaces' luminance is considered and explains: "They [the luminance] are determined by the reflectance of and the illuminance on the surfaces" [15 p.9], which highlights the relationship between more components of a room than just the light emitted from a light source. The guideline continues: "Although luminance requirements would be a representative way of describing the visual environment, this document lists illuminance requirements as luminance requirements are more complex due to their dependence on

exact material characteristics and viewing position" [15 p.9]. Thereby stating that it does not include recommendations for luminance but only illuminances.

The nature of luminance is complex and correlated with adaptation and contrast, as well as glare. These topics relate to the interplay between illuminance, luminance, surface reflectance, and the human eye perceiving the luminance pattern. The guidelines for visually impaired people all pay attention to the occasion of glare and state that it is essential to avoid it. Likewise, challenges with adaptation are underlined, and the guidelines recommend a balanced luminance pattern. DTHS and TPT emphasize that having a manageable amount of variation between the light levels in one room next to another is essential, as it can cause problems with adaptation and potentially cause glare. Only TIBS indicates concrete guidelines for luminance patterns by proposing a ratio between the task area, the intermediate surrounding area, and the background area.

Extracting precise luminance patterns throughout a space is difficult when visiting visually impaired people. While visiting the respondents, it is interesting to observe that enhanced contrast to help or as a reason for discomfort is not always consistently recognized. The preliminary findings illustrate that many respondents often preferred a luminance pattern with a large ratio from the highest to the lowest luminance. These luminance patterns resembled patterns that people with normal vision prefer, where the private home has isles of light with high luminance to enhance a specific functionality like the dining table, reading area, etc.

4.3. Visual system

High illuminance and a large ratio of the luminance pattern do not support the visual system alone. Creating visual surroundings that support vision is also a matter of making space and objects stand out, revealing their form clearly. To enhance form, it is essential to be aware of the combination of direct and diffuse light and the shadow pattern it produces [23, 24, 25]. DS/EN 12464 also reflects this point of view: "The general appearance of an interior is enhanced when its structural features, the people and objects within it are lit so that form and texture are revealed clearly and pleasingly" [15 p.19]. All these considerations are made concerning people with normal vision. However, what is important to people with normal vision can be essential to people with low vision. That is reflected in the guidelines for people with visual impairments, as they all comment on the importance of combining general ambient light with focused, task-specific light. Furthermore, they highlight how a balanced shadow pattern can enhance and make objects stand out. However, TPT is more concerned with not enhancing contrast or different levels of light to challenge adaptation and glare. Unlike the others, the uniform light is pinpointed as very useful. TPT states: "There should ideally be a high and even level of ambient light throughout the home to allow people to move around safely, and sufficient light for specific tasks" [20 p.10]. This point of view TPT repeats when summing up good advice and stating that supportive lighting should "offer an even level of light" [20 p.12].

Looking at the respondents' lighting scenarios, task lights with clear directionality prove that a clear shadow pattern on target areas is frequently applied and supports their ability to see details, read, knit, or sew. However, the diffuse light between the task areas is often shallow. This illustrates that the respondents have needs or preferences other than those TPT recommends. None of the guidelines provides a precise ratio apart from describing the shadow pattern as balanced. This also comes down to the fact that knowledge of the shadow pattern is complex and not widely known. Many of the

preferred lighting scenarios of the respondents' private homes would probably be characterized as non-uniform because of the significant difference in luminance combined with a strong directionality of light, creating a precise shadow pattern.

5. Discussion and concluding remarks: the ratio of human vision

The guidelines are welcome tools to help people design suitable visual environments. Also, introducing light units and explaining terms are valuable. The study presented in this paper focused first on comparing the guidelines and second on observing how people with visual impairment organize their visual environment and whether they resemble the guidelines' recommendations. The comparison of the guidelines is challenged by having different focuses. The general guidelines target design- and construction processes unfolding units and terms often related to describing minimum light levels concerning people with normal vision and work-related situations. The guidelines targeting visually impaired people focus on giving prescriptions relating to creating a stimulating visual environment that supports vision as best as possible. The guidelines targeted visually impaired people have many valuable recommendations to inspire and exemplify more concretely how to organize a visual environment ideal for people with low vision and thereby include more people in everyday activities.

Several guidelines recommend that extra high illuminance will benefit both elderly and visually impaired people. However, as Boyce states, extra light only targets a few specific eye problems, which can be an argument for looking broader at solutions supporting visually impaired people. Different preferences and needs were seen within the individual homes and across the participants, both in the group of visually impaired participants and control groups.

The four guidelines for visually impaired people are, in general, less specific when it comes to numbers and ratios. This reflects that they know their target group, as visually impaired people often have very individual needs when it comes to light. To some, it can be of decisive importance to have extra light, especially in target areas. But to others, it can create discomfort and even more problems. Our preliminary results from the summation of the interviews also illustrate this. Some have incredibly high illuminance in target areas, while others live in dimly lit homes.

TPT stresses uniform light distribution as one of the recommendations. However, we observed the opposite. Often, the ratio of light level spans very high illuminance at the target area and shallow light level in between. A lighting scheme character that is useful for people, in general, but can be essential for people with visual impairment. Furthermore, we observed that non-uniform lighting is often supplemented by directionality in light, producing clear shadow patterns that enhance space attributes and object form. In a sense, resembling a UD approach to lighting, ensuring a greater palette of possibilities, both due to the different activities and the different needs and preferences of the users. As the study was conducted in Denmark, one can argue that this non-uniform lighting pattern reflects a lighting culture that the visually impaired might adopt as preferable without considering whether it suits them. To answer this question, the preferences of non-uniform light distribution need to be studied more closely to investigate whether there is a relation between light preferences and eye disease.

The initial findings indicate that the mindset of Universal Design could be beneficial to implement in the guidelines. TPT guidelines are the only guidelines to refer to the seven goals of Universal Design [21 p.18]. As a tool, Universal Design implies

that one solution does not fit all, and the survey of the visually impaired people illustrates this. By broadening the range of solutions and viewing the lighting scenarios targeted to visually impaired people as manifold, new approaches to lighting design could emerge, creating safe, functional, and aesthetic light for more people.

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