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Considering Luminance In-situ in Building Interiors Using Innovative Mobile Phone App:
Exploratory Study in USA and Australia

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Abstract

The people world over enjoys theatres, museums, food service and hair salons etc. A key design element in all architectural interiors is lighting. Architectural lighting is a complex field. Older adults need more light, but are sensitive to glare. Glare is caused by excessive luminance or contrast. Luminance on the other hand, is the intensity of emitted light, and cd/m^2 is its unit of measure.

Although many studies measuring Illuminance exist, research measuring interior building luminance however, has not been widely published. Hence, there is a critical need to: understand the vision challenges facing older adults as confounded by lighting; explore luminance in different building types; quantify levels; visually communicate plots in false colour. This study begins to fill a gap in the literature.

This exploratory study tackles luminance in in two countries. A convenience sample of six various building interiors were visited in the USA, and Australia. Objectives: Use smart phones and innovative free app to photo-document Interior scenes; capture images of luminance in false colour; record luminance quantities. A number of 87 digital photographs, and false colour image luminance plots were captured. The luminance ranged from 0.49 to 316.36 cp/m². The results were compared to 100 cd/m² lower boundary for adequate light prescribed for tasks, and 84 measurements (96.56%) did not comply. The measurements taken demonstrated high contrast. While taking measurements, bare bulbs and large windows contributed to glare. Such an app could potentially aid in assessing interior properties for the general population, but also for the ageing contingent within it.

Keywords: *Architecture, Building Interiors, Light, Luminance, Older Adults*

Introduction

Older Adults

Illuminating Engineering Society (2007: p. 2) tells us that *"[between] the years of 1995 and 2030, it is anticipated that the percentage of elderly will increase in all developed countries [...].* Projections indicate that by 2030, the number of people over the age of 75 in the U.S. will exceed those under the age of 17. In Australia too, the population is aging (abs.gov.au, 2016). The Illuminating Engineering Society – known as 'the' standard for lighting in North America – generally defines older adults as those over 65 years of age (DiLaura et al., 2011). In Australia, people over 65 are generally classified as 'older', as the Australian Bureau of Statistics (ABS) tells us (alrc.gov.au, 2017).

Older adults need more light to see at the same level as younger adults, and further, the former is also very sensitive to glare (DiLaura et al, 2011). It is also observed that too much luminance (glare) on the other hand, may obscure vision. According to sageglass.com (2021), *"[...] perception of glare is generally caused by excessive luminance or contrast of luminance in the field of vision, or a combination of the two [...]".* The term luminance is defined as the intensity of emitted light [with] cd/m^2 as the unit of measure. Also, some individual characteristics may influence the perception of glare and the discomfort it causes, such as age" (sageglass.com, 2021). Given this, lsu.edu (2023) states that *"Glare [and] brightness ratios affect visibility and the ability to see easily, accurately, and quickly. Poor lighting is uncomfortable and possibly hazardous".*

Despite the growing number of older adults, there remains a shortage of scholarly research addressing issues related to glare and luminance for this demographic. The older adults enjoy restaurants and other food services, according to Barbaccia et al., (2022), as well as other venues such as theatres, museums and hair salons. Too much glare or too little light may decrease older adults' potential enjoyment, or even decrease their patronage levels of some building properties.

Given this view, there is a compelling humanitarian and financial incentive to enhance the experience of older adults in various buildings and establishments, encouraging their enjoyment and patronage. However, it is noted that people of all ages may also have some form of visual impairment, and therefore, require more light than younger persons in comparison (DiLaura et al., 2011). As early as two decades ago, Steen et al., (1994) had examined viewers' age on perceived glare and luminance. Similarly, Kanaya et al., (1987) investigated the effects of glare and light levels on the perceptions of visual comfort or discomfort with a relatively small number of younger participants (between 20-41 years of age).

This research was conducted in a laboratory setting, which was meant to evoke an office interior. In non-laboratory settings, common sources of glare may include bare (unshielded) bright light bulbs or open (un-lensed) light fixtures, aimed such that their direct brightness is visible at normal viewing angles. Moreover, undraped windows are also potential glare sources, which can obscure older adults' visual tasks. Some common visual tasks found in facilities frequented by older adults (*i.e.* theatres, museums, hair salons and food service venues etc.) may include walking/negotiating stairs, distinguishing faces of other users/patrons, viewing art objects (and their descriptions) as well as reading (*i.e.* menus, programs, prices and signage etc.). In this context, the Illuminating Engineering Society (2007: p.2) states that *"[…] many age-related changes in the visual system can be compensated for by proper illumination […]"*. Its recommendations identify Illuminance deemed necessary for users to perform various functions and tasks (DiLaura et al., 2011). In terms of measuring, illumination levels (lux) may be quantified with a light meter.

Theoretical Background

Luminance

The factor of 'luminance' differs from 'Illuminance'. The recommendations on luminance provide guidance for another aspect of the lighting design process, which is to provide appropriate surface brightness in a given space. Surface brightness limits discomfort as well as disability glare, and establishes/controls brightness variations for aesthetic/architectural balance, or form-modelling purposes (IES, 2011). Given this, xrite.com (2023) tells us that luminance is the luminous intensity projected on a given area and direction. Luminance typically describes the intensity of emitted light. According to lsu.edu (2023), luminance may also be defined as *"[…] photometric Brightness – The amount of light emitted and reflected from an area of a surface measured in* *footlamberts. A surface emitting one lumen per square foot has a luminance of one footlambert […]".* Luminance can be measured in candela per meter squared (cd/m²) as the unit of measure (xrite.com, 2023).

Charness and Dijkstra (1999) studied younger and older participants in non-laboratory settings. They utilized luminance in their research, and recommended 100 cd/m² as a convenient lower boundary for judging that there is adequate lighting for reading tasks. Considering this, the Illuminating Engineering Society (2007: 17) states that *"[…] the elderly do have some special needs: most often they require […] freedom from glare, and enhanced luminance or chromatic contrast […]. Designers [should] limit abrupt chances in luminance between contiguous spaces […]. Communication among architects, lighting designers, optometrists, ophthalmologists and those who write standards or enforce building codes must be improved so that this rapidly growing segment of the population is appropriately and adequately served […]"*.

Luminance Camera App

The *Fusion Optix SmartBeam® Luminance Camera App* (FOSLCA) offers an opportunity to make quick and meaningful assessments of surface light levels. According to fusionoptix.com (2024), *"[…] this app increases the capacity of smart phones into 'professional luminance cameras' […]"*. The FOSLCA augments the human visual system, and increases its dynamic range. Further, it enhances the ability of the eye to perceive variations in luminance. This is achieved by representing images from the smart phone camera through a calibrated false colour filter, in real-time. This accentuates the differences in luminances in an easy-to-read manner. The app is intended *"[…] as a useful, quick and easy-to-use-tool […]"* (fusionoptix.com, 2024). Although not advertised specifically for property managers, the current research hypothesizes that the app may prove useful to that particular market. Previous research has been carried out by using the app to document and assess museums as well as other facilities frequented by older adults (Hébert, 2023; Hébert and Tanfield, 2024).

Need for the Current Study

Visual light is a complex field. While many tools exist to measure Illuminance (*i.e.* light meters, data loggers etc.) and colour rendering index (*i.e.* spectrophotometers etc.), research examining interior building luminance *in-situ* has not been widely published. Hence, there is a critical need to understand luminance and the potential vision challenges facing older adults, as confounded by lighting. The older adult populations are growing, and there is a dearth of scholarly literature regarding glare and luminance that relate to them. Consequently, there is a need to explore luminance (photometric brightness) in building interiors, quantify luminance levels, and also visually communicate luminance plots in false colour. This study fills a gap in literature, and explores luminance in the interiors of various building types in two countries.

Methodology

In the current research, a total of six properties (building interiors) were visited, and an *in-situ* study was conducted over an eight-month study period. A convenience sample of building interiors that had been generally known to attract older adult patrons were selected for this purpose. Touliatos and Compton (1988: p. 63) tell us that *"[…] convenience sampling [...] consists of simply taking the cases that are available and continuing the process until a designated sample size is reached [...]. There is no way of knowing how representative an accidental sample is of a larger population [...]*. The research tackled building interiors which were public and accessible. Three of the building interiors (Sites A, B and C) in the USA were visited in June, 2023. Later, the project was expanded in January 2024, and three properties (Sites D, E and F) were visited in Australia. The USA sites included a theatre, a museum, and a restaurant/lounge. The Australian sites on the other hand, included a coffee shop, a hair salon and a bakery. All of the building interiors in both countries appeared to serve older adults as one segment of their target markets. The older adults were casually observed at all of the sites during the research period. Any photographs of older adults/other participants, or any other data about them was not collected. This study focused only on the luminous quality of the built environment.

An Apple iPhone 12 Pro Max (Model Number MG923LL/A, iOS Version 17.2.1) was used to take traditional, colour photographs of the aforesaid six public building interiors. While in the USA, the researchers downloaded the SmartBeam® Luminance Camera App from www.fusionoptix.com website; prior to capturing luminance data in the USA and Australia. The researchers selected angles for the photography *in-situ* at their convenience, in an attempt to illustrate variations in the luminous environment. Subsequently, colour-coded luminance plots were taken from the same angles, with the same iPhone, of the same building interior scenes, using the FOSLCA. With the iPhone and the app, each selected scene was visually recorded twice: 1- in traditional digital colour photography, and 2- in false colour (as the app also instantly produced quantified luminance indications). The resulting luminance levels were compared to Charness and Dijkstra (1999) recommendation of 100 cd/m² (as a lower boundary for adequate lighting).

Results and Discussion

The smart phone and innovative app were found to be easy-to-use by the researchers. A total of 87 digital colour photographic images (each with a companion false image luminance plot) were captured at Sites A. B, C, D, E and F. Refer to Figures 1 - 12 for samples of these photographs and app images. Across the Sites, luminance plot metrics varied, and results ranged from 0.49 to 316.36 cd/m².

Fig. 1: Site A: Theatre, USA, Digital Photograph. **Source**: Author (2023)

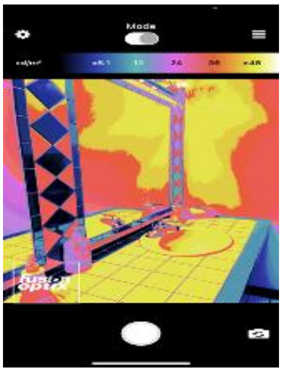

Fig. 2: Site A: Theatre, USA, Luminance Image Using App. **Source**: Author (2023)

Fig. 3: Site B: Museum, USA Digital Photograph. **Source**: Author (2023)

Fig. 4: Site B: Museum, USA, Luminance Image Using App. **Source**: Author (2023)

Fig. 5: Site C: Restaurant/Lounge, USA, Digital Photograph. **Source**: Author (2023)

Fig. 6: Site C: Restaurant/Lounge, USA, Luminance Image Using App. **Source**: Author (2023)

Fig. 7: Site D: Coffee Shop, Australia, Digital Photograph. **Source**: Author (2023)

Fig. 8: Site D: Coffee Shop, Australia, Luminance Image Using App. **Source**: Author (2023)

Fig. 9: Site E: Hair Salon, Australia, Digital Photograph. **Source**: Author (2023)

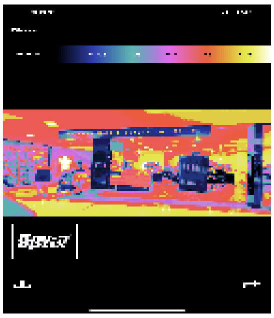

Fig. 10: Site E: Hair Salon, Australia, Luminance Image Using App. **Source**: Author (2023)

Fig. 11: Site F: Bakery, Australia, Digital Photograph. **Source**: Author (2023)

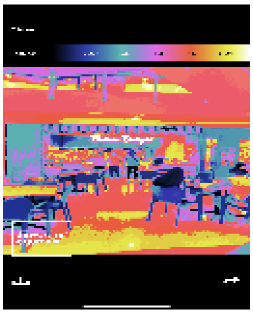

Fig. 12: Site F: Bakery, Australia, Luminance Image Using App. **Source**: Author (2023)

Point Reading	cd/m²
1	<8.0 - >63
2	<1.9 - >14
3	<1.3 - >10
4	**<43 - >348***
5	**<40 - >320***
6	<1.3 - >10
7	<2.1 - >16
8	<1.1 - >8.7
9	<1.6 - >12
10	<2.7 - >21
11	<3.5 - >27
12	<2.7 - >21
13	<2.0 - >15
14	<2.8 - >22
15	<5.0 - >39
16	<9.0 - >72
Maximum	348
Minimum	1.1
Overall Max/Min Ratio	316.36

Table 3. Luminance Site C: Restaurant/Lounge, USA.
Source: Author (2024).
NOTE: *Exceeds the 100 cd/m² recommendation.
Photographs taken facing windows during daytime.

Point Reading	cd/m²
1	<3.2 - >25
2	<3.9 - >20
3	<9.5 - >75
4	<6.1 - >48
5	<6.8 - >54
6	<2.7 - >21
7	<3.0 - >23
8	<2.3 - >18
9	<7.4 - >59
10	<2.3 - >18
Maximum	75
Minimum	2.3
Overall Max/Min Ratio	32.6

Table 4. Site D: Coffee Shop, Australia.
Source: Author (2024).

Point Reading	cd/m²
1	<2.3 - >18
2	<5.3 - >42
3	<5.1 - >40
4	**<15 - >125***
5	<6.0 - >47
6	<5.7 - >45
7	<1.7 - >13
8	<9.3 - >74
9	<9.2 - >73
10	<2.9 - >23
11	<3.0 - >24
12	<2.0 - >16
Maximum	125
Minimum	2
Overall Max/Min Ratio	62.5 to 1

Table 5. Site E: Hair Salon, Australia.
Source: Author (2024).
NOTE: *Exceeds the 100 cd/m^2 recommendation. Photographs taken facing windows during daytime.

Point Reading	cd/m²
1	<0.79 - >6.3
2	<0.86 - >6.8
3	<1.0 - > 8.3
4	<0.84 - >6.7
5	<1.3 - >10
6	<0.76 - >6.0
7	<0.6 - >4.8
8	<1.5 - >12
9	<1.0 - >8.0
10	<0.79 - >6.3
11	<1.7 - >13
12	<0.92 - >7.4
13	<1.2 - >9.3
14	<7.3 - >58
15	<9.8 - >78
16	<11 - >93
17	<6.1 - >48
18	<3.7 - >29
19	<4.2 - >33
20	<0.50 - >4.0
Maximum	93
Minimum	0.5
Overall Max/Min Ratio	186 to 1

Table 1. Luminance Site A: Theatre, USA.
Source: Author (2024).

Refer to Tables 1-6 for luminance measurements in candlepower/square meter for Sites A, B and C in USA; and Sites D, E and F in Australia.

Point Reading	cd/m²
1	<2.7 - >21
2	<2.3 - >18
3	<3.5 - >27
4	<3.5 - >27
5	<2.9 - >22
6	<9.2 - >73
7	<8.0 - >63
8	<8.7 - >69
9	<6.0 - >47
10	<8.0 - >63
Maximum	73
Minimum	2.3
Overall Max/Min Ratio	31.74 to 1

Table 6. Site F: Bakery, Australia.
Source: Author (2024).

Point Reading	cd/m²
1	<0.65 - >5.2
2	<0.62 - >4.9
3	<0.61 - >4.9
4	<1.3 - > 10
5	<1.8 - >14
6	<2.2 - >17
7	<1.2 - >9.7
8	<0.69 - >5.5
9	<0.65 - >5.2
10	<0.30 - >2.4
11	<0.92 - >7.4
12	<0.52 - >4.2
13	<7.1 - >56
14	<7.1 - >57
15	<1.3 - >10
16	<1.6 - >12
17	<0.58 - >4.6
18	<0.91 - >7.2
19	<2.0 - >16
20	<0.77 - >6.1
21	<0.83 - >6.6
22	<0.80 - >6.4
23	<0.66 - >5.2
24	<0.49 - >3.9
25	<5.0 - >4.0
26	<1.6 - >12
27	<0.72 - >5.7
28	<0.58 - >4.6
29	<1.1 - >8.4
30	<1.0 - >8.3
31	<0.80 - >6.4
Maximum	57
Minimum	0.49
Overall Max/Min Ratio	116.33 to 1

Table 2. Luminance Site B: Theatre, USA.
Source: Author (2024).

The luminance results varied, and were compared to Charness and Dijkstra (1999) recommendation of 100 cd/m^2 (as a lower boundary for adequate lighting). A number of 84 of the 87 measurements taken (96.56%) fell below (mostly very far below) the lower boundary for adequate lighting. The luminance measurements which met or exceeded the requirement* were only found in the hair salon (n=1) and the restaurant/lounge (n=2).

Most measurements demonstrated high luminous contrast ratios. In one of the buildings (Site A - theatre, USA), two rooms with bare bulbs were found. Also, in one of the buildings (Site C - restaurant/lounge, USA), large untreated windows were found.

Implications

It was confirmed that the resulting traditional photographs and innovative app images taken in tandem at various building interiors in this study, allow viewers to see that the app can supplement the human eye. It allows for a graphic, false colour, quantified, representation of cd/m^2, which supports a new understanding of luminance in field settings (*i.e.* building interiors). The app could effectively aid architecture and design professionals to see their building sites in a new way. The architectural, interior and lighting design professionals could potentially assess luminance, and also visually as well as empirically document luminance with this portable, innovative, yet low-cost tool. The Professionals could inform lighting improvements resulting in better visual support for all users and patrons; especially, for those who are older adults.

Conclusions

The innovative luminance app used in the study could aid in graphically mapping and quantifying lighting issues experienced by older adults in many facilities. Researching luminance in various building types in two different countries helps to increase knowledge about luminous environments. Comparing luminance levels measured in-situ to prescribed luminance recommendations reveal lighting problems. While closing the gap in literature related to luminance, this study helps to inform future luminance standards, and improve lighting design in the built environment. It further contributes to the ultimate aim of this line of research of enhancing the quality-of-life of older adults, by contributing to the body of knowledge regarding interiors of various building typologies.

This study consisted of only six building interiors-from only two countries (*i.e.* USA and Australia). Only a total of 87 digital colour photographs were taken, and paired with false colour luminance app images captured. The current study addresses only a limited number of buildings from a limited number of building application-sectors. Certainly, the general population and older adults, also visit healthcare sectors (*i.e.* hospitals, urgent care facilities, clinics, doctor's offices, etc.), entertainment venues (*i.e.* arcades, cinemas, live performance halls etc.) as well as educational, governmental and religious institutions, which all have different building types and associated visual tasks. These building interiors should also be explored. The issue of cultural norms regarding light levels across countries, religions and other institutions should also be investigated.

The current study utilized a small, convenience sample of building interiors. It is established that there is no way of knowing how representative an accidental sample is, of a larger population. Given this, the researchers suggest however, that if the findings of such investigations are repeated with new groups of subjects, confidence is gained in the generalization of the results as suggested by Touliatos and Compton, N. (1988, p. 63). A large, random, sampling method would allow the opportunity to conduct more advanced statistical analyses, potentially revealing more trends. A much larger sample size should include building interiors that are visited by a variety of ages for comparison purposes. Further, a diverse sample, reflecting variety in terms of users' and patrons' gender, race, religion, socio-economic groups, etc., should also be pursued. A demographic survey of users and patrons could be used to supplement the photographs and app images with luminance measurements. Documentation of users' and patrons' demographic variables would allow for a robust analysis of the data.

More luminance measurements, as determined with the FOSLCA, across various countries and sectors, should be compared to applicable lighting standards, lighting codes, and energy codes enforced in individual countries, worldwide. Acquiring perceptions of the older adult populations via supplemental surveys, targeted towards those who visit the aforementioned building types, should be included in future studies. Such surveys could include demographic and also perception questions.

A colleague in Australia reported that the FOSLCA could not be downloaded. The cause for this problem was not determined. However, the current researcher was able to fully utilize the FOSLCA at sites in Australia, after previously downloading the app, while in USA. Other tools could be utilized to supplement the smart phone and app used in the current study. Light meter data loggers (to measure light level in Lux), spectrometer data loggers (to measure Colour Rendering Index and Colour Temperature properties of the light) etc. could also record useful empirical information about light at building sites. The empirical data generated from these additional tools could also offer the opportunity for a comparison and analysis of all of the data in order to paint a fuller picture of the lighting conditions at various sites.

The use of the app could aid architects in assessing building interiors for the ageing population, communicating with stakeholders, and guiding lighting improvements. Since it was ascertained that the bare bulbs and large windows in some buildings in the current study contributed to glare, these light sources should be shielded to allow for more visual comfort and acuity. Clip-on shades or lenses could be used to mitigate bare bulb effects. Window coverings (draperies, blinds, shades, etc.) could be utilized to soften the offending fenestration as needed based on outcomes compared with standards. Where luminance was measured to be too low at in some interiors properties to meet the minimum recommended level, Illuminance should be increased. Supplemental lighting could be installed, if practical, in some buildings that were not in compliance with the minimum recommendations. Otherwise, light bulbs' (lamps) lumens could be increased with higher wattage bulbs with care taken to not create glare. Retrofitted into existing luminaires, if allowed by code and also as advised by the respective luminaire manufacturers. It is anticipated that improved lighting may increase the quality of life for older adults by helping them to better see visual tasks in the interior environment. It may also increase their patronage and enjoyment of building interiors.

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