Institution: University of Sheffield		
Unit of Assessment: C-13 Architecture, Built Environment and Planning		
Title of case study: Enhancing pedestrian road lighting provision: promoting evidence-based practice		
Period when the underpinning research was undertaken: 2008–2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Steve Fotios	**Role(s) (e.g. job title):** Professor of Lighting and Visual Perception	**Period(s) employed by submitting HEI:** 2005 onwards
Period when the claimed impact occurred: 2014–2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

This work concerns road lighting for pedestrians. Research led by Professor Fotios has shown that whiter lighting improves visual performance and that satisfactory visual conditions do not need the higher light levels of previous standards. This work has led to changes in the design criteria recommended in UK (BSI) and international (CIE, IESNA) guidance. The changes in guidance support lower light levels that in turn can reduce energy consumption, reduce sky glow, and reduce impact on the natural environment. For his work on pedestrian lighting Fotios received the quadrennial Distinguished Services Award from the International Commission on Illumination in 2015.

2. Underpinning research (indicative maximum 500 words)

Over the past 100 years, there has been an increase in the light levels recommended in design guidance for road lighting in the UK **[R1]** that can result in increased energy use, sky glow, and detrimental effects on natural habitats.

In the UK, there are 215,000 miles of minor roads. For these roads, pedestrians are the target user group for lighting design. Local authorities in the UK use British Standard BS5489-1 to determine road lighting design criteria such as light level (illuminance), uniformity of illuminance, and lighting colour (lamp spectrum). In this guidance, the highest light level recommended for minor roads increased by 50% from 10 lux in 1992 to 15 lux in 2003. However, there was no robust empirical basis for the set values of these criteria **[R1]**, so it was unknown whether the levels were optimal (maximising safety without unnecessary surplus energy use or sky glow) nor whether reducing light levels in order to reduce energy consumption and sky glow would have implications for pedestrians.

Research carried out by Fotios and his team provided a more robust empirical basis on which to base design recommendations. EPSRC funded Projects (2008-2018) investigated pedestrians' visual needs **[F1]** and subsequently how lighting can be optimised to support the ability to detect trip hazards **[F2]**, evaluate the intentions of other people **[F3]** and the feeling of safety **[F4]**. Ongoing EPRSC and Horizon2020 research is investigating pedestrian visibility to drivers. This work investigated the colour (spectrum) and level (illuminance) of light. The main findings were:

F1. To establish optimal lighting, the team first needed to know what pedestrians need to see for safe movement. This was done using **eye tracking**, developing a novel approach to interpretation (a dual cognitive task) to identify critical visual fixations **[R2]**. This confirmed the previously assumed (but not empirically validated) tenets of lighting design that detecting trip hazards and evaluating other people are critical visual tasks for pedestrians.

F2. A series of experiments was carried out to investigate **trip hazard detection**. While higher light levels improve detection, the results revealed a threshold above which further increase in light level brings negligible return. An optimal light level (1.0 lux) was interpolated by establishing first the characteristics of a critical trip hazard. Previously, it was assumed that the critical hazard was a 25 mm change in vertical height. Using eye tracking, foot clearance and injury record data, Fotios and colleagues showed that this should be a 10 mm height, smaller and thus more visually demanding than a 25 mm hazard **[R3]**. The results also revealed that pedestrian age and lamp spectrum are significant factors but only at light levels <1.0 lux.

F3. We determined facial emotion recognition (FER) to have better validity for characterising the visual cues used in **evaluating other people** than the conventional approach of facial identity recognition. The eye tracking data **[R2]** were interpolated to characterise the nature (distance and duration) of gaze behaviour towards other people, revealing a greater distance (15 m) than that previously assumed (4 m). The experiments demonstrated that light level has a significant effect on FER but that lamp spectrum does not (refuting previous evidence based on incorrect methodology) **[R4]**.

F4. Past studies have concluded that higher light levels are associated with an improved **perception of safety**. We demonstrated that this is an effect of stimulus range bias **[R5]**. While the conventional approach has been to compare different roads with different light levels, we instead compared perceived safety after dark with perceived safety in daytime at the same location. Good lighting is that which minimises the day-dark difference **[R6]**. Findings of this research suggested light levels of around 3.0 to 5.0 lux to be sufficient for pedestrian perception of safety, which suggests the higher light levels of the permitted range (2.0 to 15.0 lux) are not necessary.

3. References to the research (indicative maximum of six references)

Sheffield researchers in **bold:**

R1. **Fotios, S.**, & Gibbons, R. (2018). Road lighting research for drivers and pedestrians: The basis of luminance and illuminance recommendations. *Lighting Research & Technology*, *50*(1), 154–186. https://doi.org/10.1177/1477153517739055

R2. **Fotios, S.**, **Uttley, J.**, **Cheal, C.**, & Hara, N. (2014). Using eye-tracking to identify pedestrians' critical visual tasks, Part 1. Dual task approach. *Lighting Research & Technology*, *47*(2), 133–148. https://doi.org/10.1177/1477153514522472

R3. **Fotios, S.**, & **Uttley, J.** (2016). Illuminance required to detect a pavement obstacle of critical size. *Lighting Research & Technology*, *50*(3), 390–404. https://doi.org/10.1177/1477153516659783

R4. **Yang, B.**, & **Fotios, S.** (2014). Lighting and recognition of emotion conveyed by facial expressions. *Lighting Research & Technology*, *47*(8), 964–975. https://doi.org/10.1177/1477153514547753

R5. **Fotios, S.**, & **Castleton, H.** (2016). Specifying Enough Light to Feel Reassured on Pedestrian Footpaths. *LEUKOS*, *12*(4), 235–243. https://doi.org/10.1080/15502724.2016.1169931

R6. **Fotios, S.**, **Liachenko Monteiro, A. L.**, & **Uttley, J.** (2018). Evaluation of pedestrian reassurance gained by higher illuminances in residential streets using the day–dark approach. *Lighting Research & Technology*, *51*(4), 557–575. https://doi.org/10.1177/1477153518775464

4. Details of the impact (indicative maximum 750 words)

This research has had direct impact on the bodies that set lighting standards and the practitioners who use them. This includes the International Commission on Illumination (**CIE**), recognised by the International Standardisation Organization (ISO) as an international standardisation body; the Institution of Lighting Professionals (**ILP**), a large and influential professional lighting association in the UK and Ireland; the British Standards Institute (**BSI**); and the Illuminating Engineering Society of North America (**IESNA**), the USA national body for lighting.

[Text removed for publication].

BS5489-1 is the British Standard for the design of road lighting. [Text removed for publication]. It informs the practice of professionals including lighting engineers and lighting product manufacturers. To reach these users and to guide practice nationally, Fotios set out to engage with BSI to modify this key document based on the research findings.

Fotios has engaged with key bodies for the lighting profession (CIE, ILP). This engagement included, since 2003, founding, chairing, or being a member of specialist technical committees to promote empirical data to inform pedestrian lighting design criteria. As ILP representative on the British Standards Institution (BSI) panel, he motivated the inclusion of new evidence-based guidance into BS5489-1 based on technical reports (as lead author) produced by CIE and ILP.

Since January 2014, **the research has informed changes to four key national and international documents**. This can be separated into two strands relating to initially the colour of light, which led to changes in BS5489-1:2013, followed by the amount of light which led to changes in BS5489-1:2020.

The colour of light

Technical report CIE-206:2014 [S4] demonstrated that using lighting of higher S/P ratio (whiter light than the orange sodium lamps previously used across the UK) allows a lower light level to be used whilst maintaining the same degree of visual amenity. [Text removed for publication]. Table A.7 is an evidence-based system which allows lighting professionals to adjust light levels according to the S/P ratio of the light source. In recognition of Fotios' significant contribution to CIE-206:2014, he was awarded the quadrennial CIE's Waldram Gold Pin for exceptional contribution in research in Applied Illuminating Engineering in 2015 [S5].

BS5489-1:2013 was published at the end of the previous assessment period; subsequent use of BS5489-1:2013 during the current assessment period has led to widespread change in practice for UK lighting professionals. As an example, from 2017 Manchester City Council has invested

£13.7M to undertake a programme of street light renewal, to convert 56,000 streetlights to white LEDs [S6], with this work being done in accordance with BS5489-1:2013 [S7].

Similarly, Trafford Council Street Lighting Planned Maintenance Works Procedure states [S8] that:

*"… BS 5489-12013 … utilised nationally for implementing design criteria states that the use of a 'white light' source on residential roads, with an Ra of 60 or greater, allows the lighting class for that particular road to be lowered to the levels quoted in **Table A7** … due to the perception of improved lighting from white light. This would lead to a reduction in the number of new lighting columns hence a reduction in electrical energy consumption and thus a reduction in carbon emissions."*

The amount of light

CIE-206:2014 and subsequent changes to BS54891:2013 provided an empirical basis to show how lamp spectrum could be used to promote lower light levels. However, the light levels recommended in BS5489-1:2013 remained unqualified. Ongoing research by Fotios has since informed further technical guidance demonstrating that pedestrians' visual benefits of road lighting are optimised at lower light levels. These new data [F1-F4] informed a technical report from the CIE [S9], design guidance from the IESNA [S10] and the 2020 revision of BS5489-1 [S11].

The two key revisions to BS5489-1:2020 are:

(i) The range of light levels recommended for minor roads is reduced from 2.0 to 15 lux (EN 13201-2: 2015) to 2.0 to 7.5 lux. In other words, a 50% reduction in the maximum recommended light level. (See Table A.5. The reduction is shown as recommendation of lighting classes P3 to P6 rather than the range P1 to P6)

(ii) The trade-off between S/P ratio and light level is now used in reverse, showing the need for higher light levels when (e.g.) sodium lamps are used rather than white light sources.

[Text removed for publication]

Fotios' research and technical expertise has also influenced road lighting guidance in the USA [S10]. [Text removed for publication].

[Text removed for publication].

Where the light levels recommended in previous guidance documents were based on unknown data, they are now based on published scientific evidence. This means that lighting designers now have a solid evidence base upon which to make informed decisions, and provides new opportunities to reduce energy use, emissions and sky glow whilst maintaining pedestrian safety.

5. Sources to corroborate the impact (indicative maximum of 10 references)

S1. [Text removed for publication].

S2. [Text removed for publication].

S3. [Text removed for publication].

S4. CIE report 206:2014. The Effect of Spectral Power Distribution on Lighting For Urban And Pedestrian Areas. Commission Internationale De L'Éclairage, Vienna, 2014. ISBN 978-3-902842-33-6

S5. CIE distinguished services award, 2015, to Steve Fotios. This is reported in the conference proceedings: CIE 216:2015. Proceedings of the 28th Session of the CIE, Manchester, 28 June to 4 July 2015. Volume 2. Page 6.

S6. Combined: Manchester City Council. "We are replacing your streetlights". https://secure.manchester.gov.uk/info/500350/signs_lights_and_road_markings/7469/we_are_replacing_your_street_lights and MCC Capital Strategy and Budget 2018/19 to 2023/24, https://democracy.manchester.gov.uk/documents/s5053/Capital%20Strategy%202019-2020.pdf (Page 13)

S7. Manchester City Council. Report for Resolution: Street Lighting LED Retrofit Programme. 12 February 2014

S8. Trafford Council. Highways Service. Street Lighting Planned Maintenance Works Procedure. DRAFT dated 9th September 2014

S9. CIE 236:2019. Lighting for Pedestrians: A Summary of Empirical Data. Commission Internationale De L'Éclairage, Vienna. 2019.

S10. ANSI/IES LP-2-20. *Lighting Practice: Designing Quality Lighting for People in Outdoor Environments. An American Standard*. New York, USA: The Illuminating Engineering Society. 2020. ISBN 978-0-87995-066-8

S11. British Standards Institution BS 5489-1:2020. Code of Practice for the Design of Road Lighting Part 1: Lighting of Roads and Public Amenity Areas. London: BSI, 2020.