Road Lighting and Future Factors

A thesis submitted to Middlesex University in partial fulfilment
of the requirements for the degree of Master of Science by Research

Ajay Parmar
M00397944

School of Science and Technology
Middlesex University London

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Declaration

I hereby declare that all of the work in this thesis was written by myself unless stated otherwise. I have been supported by both my Director of Studies and Supervisor.

This thesis satisfies the requirements for a Masters by Research degree from Middlesex University.

Abstract

Street lighting is currently a growing market that is adapting to and benefiting from numerous technological developments. This dissertation maps the technological factors that will contribute to the future of road lighting in order to aid professionals working in the field, such as lighting designers and engineers. Therefore, this dissertation makes a contribution to knowledge in this area by developing a framework tool (Figure 41. SLSNF - developed on draw.io) to assist stakeholders seeking to implement a new street lighting system. This is based on insights gathered through mixed methods of research from a varied group of professionals associated with street lighting. Furthermore, it also establishes a summarising model (Figure 49. Road lighting and associated factors overview, developed by Ajay Parmar, using www.mindmeister.com) to illustrate all of the considerations surrounding road lighting as a domain. One of the primary focuses of this research targets how lighting professionals interact with lighting standards. Data is collected by mixed methods research of both interviews and a questionnaire. This research confirms that good collaboration amongst a range of different professionals is required for new street lighting projects to develop efficiently. Due to the interdisciplinary nature of these projects, the proposed tool (Figure 41. SLSNF - developed on draw.io), which has been developed as a result of the data collected, will assist those involved to identify and mitigate any possible oversights in a street lighting installation at an early stage.

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Glossary

Definitions

Big Brother
A concept where people's privacy is being invaded by means of CCTV and infiltration of their social platforms.

Binning
How manufacturers classify their LEDs. They are sorted by lumens, colour temperature and voltage.

Circadian rhythm
More commonly known as the 'body clock', the circadian rhythm is a cycle that tells our bodies when to sleep, rise and eat. The circadian rhythm regulates many bodily processes.

Colour temperature
This determines the tone of white light. It is based on how the light would radiate from a pure black body.
[Tc] Temperature of a Planckian radiator whose radiation has the same chromaticity as that of a given stimulus
Unit: K
Note: The reciprocal colour temperature is also used with unit K-1 or MK-1 (where 1 MK-1 = 10-6 K-1) whose previous name "mired" is now obsolete. See Figure 1 for a full scale.

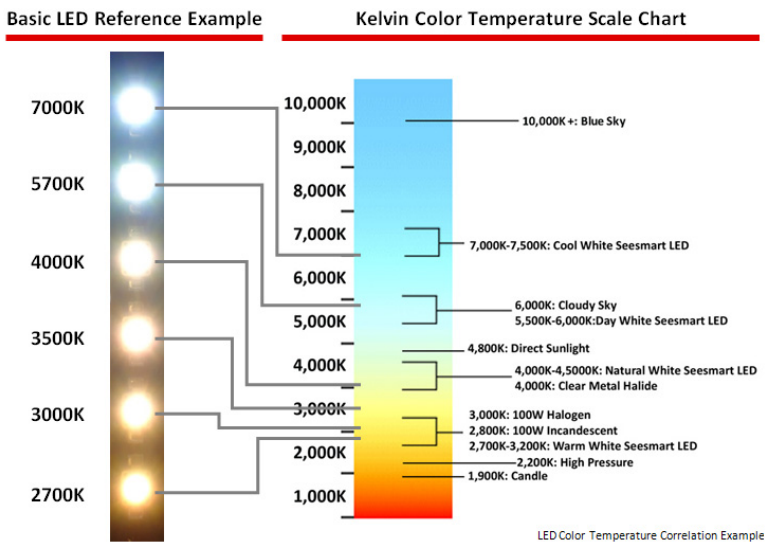


Figure 1. Colour temperature scale for White LEDs

(Shenzen Everest Lighting CO.LTD, 2015)

Colour discrimination
The ability to distinguish the difference between colours. This will be harder under light sources of a lower value CRI.

Gonioreflectometer
Instrument for measuring quantities pertaining to reflection.

Glare
The result of excessively bright light. It can cause discomfort and obscure vision.

Grid
The National Grid distributes electricity from power stations to consumers. It supplies the country's electricity by means of various energy resources, whatever the demand. If a system is off-grid, it is powered by an independent electricity supply.

Illuminance
The amount of light emitted from a light source.
Quotient of the luminous flux dΦv incident on an element of the surface containing the point, by the area dA of that element.

Incandescent
A lamp in which light is produced by means of an element heated to incandescence by the passage of an electric current.

Luminance

$$L_{\mathrm{v}} = \frac{\mathrm{d}\,\Phi_{\mathrm{v}}}{\mathrm{d}\,A\cos\theta\,\mathrm{d}\,\Omega}$$

Where:
dΦv is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle, dΩ, containing the given direction;
dA is the area of a section of that beam containing the given point.
Θ is the angle between the normal to that section and the direction of the beam
Unit: cd·m-2 = lm·m-2·sr-1

Luminance coefficient
A measure of how light is diffused after being reflected from a surface.
Quotient of the luminance of the surface element in the given direction by the illuminance on the medium

$$q = \frac{L}{E}$$

Where
L is the luminance in cd·m-2;
E is the illuminance in lx
Unit: sr-1

Luminous efficacy
A measure of how efficiently a light source produces visible light.
Quotient of the luminous flux emitted by the power consumed by the source
Unit: lm·W-1

Lux
The SI unit of illuminance, equivalent to one lumen per square metre.
Illuminance produced on a surface of area 1 m2 by a luminous flux of 1 lm uniformly distributed over that surface.
Symbol: lx = lm·m-2

L70
The lifetime of an LED is recognised as the time it takes until its light output reaches 70% of its original output.

Phosphor
A substance that has luminescence. When phosphor absorbs blue light energy from an LED chip, the phosphor emits light of longer wavelength.

Photoreceptor
A part of the eye that responds to light.

Specular factor
The intensity of a reflection at low incident angles compared to those of high incident angles.

Wavelength
The distance between two peaks of a wave.
Distance in the direction of propagation, of a periodic wave between 2 successive positions at which the phase is the same.
Unit: m

Acronyms

AONB Area of Natural Beauty
An area of outstanding natural beauty (AONB) is land protected by the Countryside and Rights of Way Act 2000 (CROW Act). It protects the land to conserve and enhance its natural beauty.

ANSI American National Standards Institute
A non-profit organisation that monitors the standards practised in the United States.

Cd Candela
SI base unit for photometry: luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×1012 Hz and that has a radiant intensity in that direction of 1/683 W·sr-1
Symbol: cd = lm·sr-1

CIE International Commission on Illumination
Acronym of the International Commission on Illumination, derived from the French name: Commission Internationale de l'Eclairage

COB Chip on Board
A newer form of LED, which involves numerous LEDs in a condensed format, creating a high lumen per space solution.

CCFL Cold Cathode Fluorescent Lamp
Similar to CFLs, however, they are more suitable for dimming and flashing. They have a longer life span and turn on instantly.

CCT Correlated Colour Temperature
This is the same as colour temperature, but also takes into account the position of the light source.
Temperature of the Planckian radiator having the chromaticity nearest the chromaticity associated with the given spectral distribution on a diagram where the (CIE 1931 standard observer-based)
Coordinates of the Planckian locus and the test stimulus are depicted. Unit: K
$u', \frac{2}{3}v'$

CFL Compact Fluorescent Lamp
Light bulbs that are often used as energy-efficient replacements for filament bulbs.

CMS Content Management System
A tool to manage and control a series of devices such as smart street lights.

CRI Colour Rendering Index
A scale from 0 to 100, indicating how accurately a light source produces colour compared to its actual values. Measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation.

DFT Department for Transport
The government body responsible for the English transport network.

EIR Edge Illuminance Ratio
Average illuminance on strips, which are adjacent to the edges of both sides of the carriageway, to the average illuminance on the adjacent strips in the carriageway (EIR replaced SR).

EV Electric Vehicle
New cars that use electric motors instead of combustion engines.

GPRS General Packet Radio Service
The same as a GSM network, but also supports data. GPRS based networks are being replaced by newer 3G and 4G installations.

GSM Global System for Mobile Communications
A digital mobile network that is widely used by mobile phone users in Europe and other parts of the world. It operates at either the 900 megahertz (MHz) or 1,800 MHz frequency band.

IDA International Dark Sky Association
A well-established non-profit organization that actively works on the fight against light pollution.

IES Illuminating Engineering Society of North America
A society who wish to expand and share their vast knowledge of lighting.

ILP Institution of Lighting Professionals
The UK and Ireland's largest and most influential professional lighting association.

IoT Internet of Things
A seamless integration between everyday items, enabling sending and receiving of data wirelessly.

LAN Light at Night
Artificial light emitted during hours of darkness.

LED Light Emitting Diode
A highly energy-efficient lighting technology which has developed significantly.
Solid-state device embodying a p-n junction, emitting incoherent optical radiation when excited by an electric current.

LDD Luminaire Dirt Depreciation
The build-up of dirt on a luminaire, affecting its output.

LDP Light Diffusing Power
A measurement of how much light has been diffused, measured on a scale from 0-1.

LPS Low-Pressure Sodium
A gas discharge lamp emitting yellow light (1800K), commonly used in street lighting.

LTP Light Technical Parameters
A term used by Australian and New Zealand lighting standards.

HID High-Intensity Discharge
Electric discharge lamp in which the light-producing arc is stabilized by wall temperature and the arc has a bulb wall loading in excess of 3 W·cm-2.

HPS High-Pressure Sodium
A gas discharge lamp (2200K), commonly used in street lighting.

MH Metal Halide
A lighting technology that emits light by means of an electric arc through a mixture of mercury vapour and metal halides (4000K). High-intensity discharge lamp in which the major portion of the light is produced from a mixture of a metallic vapour and the products of the dissociation of metal halides.

MLT Melatonin
A hormone produced by the pineal gland. It is involved in many processes, mainly regulating sleeping and waking cycles.

Nm Nanometre
A division of a metre (1×10-9).

PCB Printed Circuit Board
A board which electronically and physically connects a series of components.

POS Point of Sale
The time and place where a transaction is completed.

PWM Pulse Width Modulation
Rapidly turning a device on and off, to simulate a voltage somewhere in between the maximum voltage and 0.

SMD Surface Mounted Diode
A type of LED that has its own PCB.

SR Surround Ratio
Average illuminance on strips, which are adjacent to the edges of both sides of the carriageway, to the average illuminance on the adjacent strips in the carriageway (EIR has replaced SR).

SI International System of Units
A system of units based on the metre, kelvin, candela, and more.

WHO World Health Organisation
A specialist agency of the United Nations that is concerned with international public health.

WSN Wireless Sensor Network
A collection of dispersed sensors for collecting data on things such as the environment.

YAG Yttrium Aluminium Garnet
A hard synthetic material used in laser technology.

The term ‘road lighting’ has been used when referring to all illumination present on a road which can be a combination of light pollution from houses, cars, advertising and more. The term ‘street lighting’ has been used when referring to a luminaire mounted on a column. All significant changes post-viva have been highlighted in yellow.

1. Introduction

1.1 Problem definition

Artificial light has been in use for several hundred years with the primary purpose of extending the number of hours available within the working day. With the invention of artificial light, people no longer had a fixed number of dark hours within each twenty-four-hour cycle. It provided the public with both greater security and freedom. This brought many benefits, such as allowing working productivity to be increased and more leisure time. This includes illuminated sports grounds, twenty-four-hour service stations, super markets as well as late-night television. Modern society would not exist as we know it without light (Ekirch, 2006; Gaston et al., 2015).

Advancements in technology present a range of new opportunities for their application in street lighting. For example, at a time when many concerns exist about our environmental impact on the Earth, LEDs present a great opportunity to significantly reduce our carbon footprint and our energy usage. While LEDs still have drawbacks, such as blue light emission (Huaizhou et al., 2015) and heat build-up (Sim et al., 2012), the challenge is to find ways to utilise their benefits, such as their longevity and low-energy consumption, to create solutions that work most effectively in the range of different scenarios in which they can be employed. This will undoubtedly require the creation and revision of legislation and regulation surrounding the use of street lighting, as well as ensuring that designers and engineers have the ability to access, interpret and implement these regulations effectively. Street lighting is a constantly growing field, with Figure 2 illustrating just how large the domain of street lighting has now become.

Studies have shown multiple issues for designers and engineers in integrating performance requirements and mitigating negative impacts in new street lighting installations. The American Association of State Highway and Transportation Officials state that before a direct reading reflectometer was introduced, the equivalent lighting test required took three hours to set up and another hour to collect reflection data. In total 864 hours would be required to complete a data collection for just one light due to the required five degree increments of the measurements taken (Roadway lighting design guide, 2005). Time consuming processes such as this often create a negative impact on its surroundings due to narrowing of traffic lanes, alternative routes, general congestion and interference. Cook, Shackelford and Pang (2008) reported in 'LED Street Lighting Host Site: City of San Francisco' that:

'Technologies that engender significant negative qualitative response will continue to face market resistance no matter how much energy they save'

Cook, Shackelford and Pang have made it clear that LEDs fall within this category due to the negative impacts they create such as light pollution and blue light emission. However Kenber et al (2019) show a contrasting perspective in 'Lighting the clean revolution'. In four cities where public surveys were conducted, residents, drivers, pedestrians and shopkeepers all expressed a strong preference for LED lighting compared to HPS. Participants said they felt safer and very few had anything negative to comment.

The well-being branch of Figure 2 illustrates some of the problems associated with street lighting that need to be taken into consideration when planning a new project (Griffiths, 2017). These issues make it difficult for designers and engineers to satisfy all users when they implement a new street lighting installation, as new light installations must meet light performance requirements at the same time as avoiding contributing to a large number of potential negative impacts (Transactions of the Illuminating Engineering Society, 1936; Tien, 1979; Artificial Light in the Environment, 2009). Current street lighting regulations add to the difficulty of satisfying these requirements because they are often difficult to navigate and are not particularly user-friendly (Schreuder, 1998).

In Street Lighting Projects: Phase 1 Report, Tien (1979) states the existing street lighting standards are lacking in several respects. They focus much on cars and not enough on pedestrians. This has a consequent effect that designers of street lighting projects focus on roadway lighting and not enough on illuminating walk ways. Tien mentions, project designers often assume that if roadway lighting requirements are met then walkway lighting requirements will automatically be satisfied. This assumption is not always the case. The lighting standards are based on the opinion of experts and unfortunately not backed up by scientific research.

Question 12 from the data collection in chapter 7.2 states that 25% (18/72) of the questionnaire participants do not know about all the standards relevant to their role associated with street lighting.

This issue is further complicated by the fact that many countries' have their own set of guidelines regarding street lighting, roads and other elements that may present safety concerns. While some countries' guidelines share the same information such as 'AS/NZS 1158.2:2005 Lighting for roads and public spaces' and 'BS 5489-1:2013 Code of practice for the design of road lighting Part 1: Lighting of roads and public amenity areas', most have variations due to their own unique circumstances, such as road width and weather impacts (AS/NZS 1158.1.1:2005, 2005; BS 5489-1:2013, 2012; Kim et al., 2017). However, for the effective implementation of street lighting

projects, it is essential that all relevant bodies have a clear understanding of the regulations and legislation involved in their own country (Griffiths, 2017).

Therefore, while improvements in technology can be said to have provided potential new solutions to previous issues with street light installations, a number of complex and interconnected problems are always present when planning, designing and implementing street lighting projects. As societies seek to address these problems by improving the regulations and legislation surrounding the implementation of street lighting, it is becoming increasingly difficult for designers and engineers to navigate these and to ensure that their projects meet all of the necessary requirements. Appendix 13.18 illustrates that the majority of questionnaire participants from chapter 7 see problems with the current lighting standards. The majority of these participants are post graduate professionals with more than 21 years in the lighting industry hence their insights are of high value for this research. The majority states that the British Standards does not cover all content needed in terms of road lighting and future factors (appendix 13.23). 94.5% (69/73) participants stated that an interactive tool guiding users based on their profession to the location of standard; further information and additional guidance would be useful (appendix 13.28).

This dissertation aims to seek ways to address this issue by attempting to create a tool that aids this process.

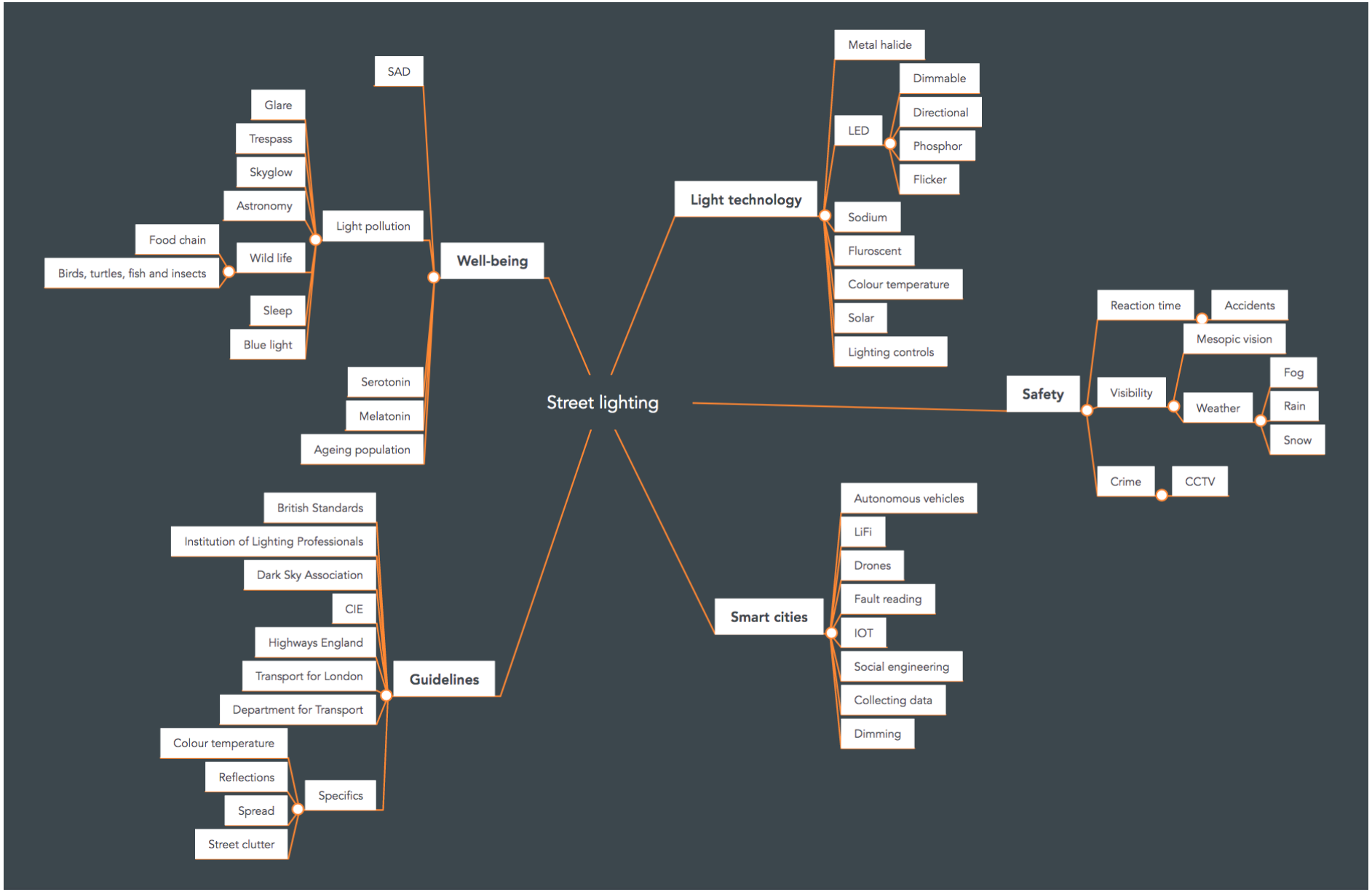


Figure 2. Street lighting and future factors, developed by Ajay Parmar, using www.mindmeister.com

1.2 Aims and objectives

This thesis analyses the negative consequences of artificial light created by street lighting at night. It explores the drawbacks, as well as who they impact and why these issues occur. However, the primary objective of this thesis is to explore how lighting designers and engineers navigate the current street lighting guidelines and regulations, as this is directly linked to the negative consequences created by street lighting.

The findings from the research will be analysed and summarised. The data collected from the questionnaire and interviews will determine what is the best solution to assist lighting designers and engineers, and whether or not any action should be taken or tool should be developed in regards to the current street lighting regulations. With this objective in mind, the developed tool is purposely condensed and minimalist in order to best highlight the key points that may otherwise be overlooked.

There is already a considerable amount of research that has been conducted in this area, such as blue light emission, circadian rhythms, light pollution, tarmac reflectivity, colour temperature and reaction times, fog penetration and much more (discussed further in chapter 3). This dissertation draws and builds on the existing work carried out in these papers and projects. It also makes use of primary mixed methods research to develop a useful framework tool (SLSNF-chapter 8) that will help assist lighting designers and engineers.

1.3 Research question and limitations

The research question controls all parts of this research project. It determines what data is to be collected and how this is analysed. This ensures that the research is 'both feasible and worthy of academic attention' (Jensen and Laurie, n.d.). A good research question will pinpoint the areas to be explored and provide a focus and purpose to the work undertaken.

This thesis will answer the following question:
What can be done to assist lighting designers and engineers to effectively and efficiently implement lighting standards and regulations?

This has recently become a sensitive topic with the introduction of numerous LED street lights across the UK. There are many mixed views on this. With this being such a key topic, it is important that street lighting designers and engineers can easily navigate through standards and regulations to find the key information they require.

The purpose of this research is to explore the current lighting standards and any problems that users may experience with them. This thesis is important to the field of street lighting as one of the outcomes will be a framework that will offer guidance on navigating street lighting standards. This will help practitioners make more efficient use of their time. It will also allow non-experts to become involved in a street lighting project due to its easy-to-understand user interface.

This research will analyse the regulations concerning street lighting and associated areas, such as:

- Safety
- Well-being
- Smart cities
- The environment
- Light pollution

The current method of how lighting practitioners currently navigate lighting standards will be explored in order to evaluate if this is working or if this process can be made more efficient. As the area of street lighting is vast, and it can involve a large number of different stakeholders and agencies, this dissertation will focus on guidelines and standards and how they are implemented in order to limit the scope of the research.

1.4 Outline

After the abstract, introduction and methodology, the remainder of this thesis is split into two main sections. These are:

- Secondary research conducted through the literature review (chapter 3)
- Primary research conducted through the development of the street lighting tool (chapter 6), questionnaire (chapter 7) and Street Lighting Standard Navigation Framework (SLSNF-chapter 8).

The literature review covers a vast span of guidelines and regulations associated with street lighting. Weaknesses within these documents are pin-pointed throughout, such as a lack of consideration for new technologies such as LED lighting and dimming (chapter 3).

A look into current and future technologies provide insight into the potential of the future of street lighting, as well as other concerns such as health, sleep, cost and pollution (chapters 4 and 5).

It transpired that the lighting standards and guidelines were difficult to navigate. After analysing other navigation and project management tools (chapter 6.1), a street lighting tool was developed (chapter 6.2). Professionals associated with street lighting were then interviewed regarding this street lighting tool and the direction of this thesis (chapter 6.3).

The street lighting tool's main flaw was that it did not point users to the exact standard required. This provided the foundation for a new data collection to be carried out by means of a questionnaire. Evidence was found that professionals find it difficult to navigate through the lighting standards and guidelines, and would benefit from an interactive website to make more efficient use of their time (chapter 7).

The Street Lighting Standard Navigation Framework (SLSNF) is developed by means of a paper prototype (chapter 8). Tests were carried out to compare the speed of navigating by means of SLSNF against using traditional PDFs. The participants were also asked a number of questions regarding the SLSNF and how useful they found it. The results show a vast time improvement for participants completing a few navigating tasks using the SLSNF as opposed to the standard system of navigating PDFs.

2. Methodology

2.1 Literature search

The literature review has been triangulated from a number of different sources. Some key search topics include: blue light emission, light pollution, lighting regulations and dark sky. After sourcing over 100 publications, guidelines and standards from IEEE, Google Scholar, British Standards and other research repositories these individual publications were categorised into groups. These groups include: current technologies, future technologies, guidelines and regulations, light pollution, studies and tests, and sunlight and health. It was clear to see a trend of lighting experts being sceptical about the government introducing LED street lights, often without input from lighting designers, mainly just for financial benefits (Griffiths, 2017). It was also apparent that LED street lighting has not been taken into consideration within the majority of the lighting standards and guidelines. It transpired that there was a gap of knowledge for lighting designers and engineers to refer to within the guidelines and regulations they base their street lighting plans on.

2.2 Interviews

Personas are reliable, realistic representations of a target audience. These characterisations are only as good as the research behind them. All good personas are based on solid data (UX Planet, 2018) (Affairs, 2018). The key reason for adopting user personas is to help design for the wants and needs of the actual users and not the wrong audience (Trydesignlab.com, 2018). The Street Lighting Standard Navigation Framework (SLSNF, Figure 65) and summarising model developed throughout this thesis are aimed to aid two target audiences; lighting designers and lighting engineers).

Rather than develop personas, professionals related to the street lighting industry were asked for their comments on this research project and Figure 37 (street lighting tool). Professionals with varying backgrounds were selected to gain as many varied insights as possible (Merriam and Tisdell, 2016), ranging from a supply technician, an architect and a lighting designer. The questions asked were varied depending on the participant's association with street lighting.

2.3 Questionnaire

Questionnaires are a well-established method for obtaining demographic data and opinions. Questionnaires can easily be issued to a greater number of participants when compared with interviews. It also enables participants in remote locations or those with busy schedules to participate (Sharp, Rogers and Preece, n.d.). The purpose of this questionnaire is to gather insights and develop a clear understanding of how professionals utilise and interact with the current lighting standards, and to explore issues they may experience. After reading about how best to extract the information required from the participants, a questionnaire was drafted (Krosnick, 2019). This was written as an online Google doc allowing others to comment and make suggestions. A pilot questionnaire was issued to explore how participants may react. The questionnaire went through a few iterations with input from both the Society of Light and Lighting and UCL University. The interview data collection was revisited several times and analysed. Emerging themes or gaps of information such as 'which standards are used?' and 'should content such as blue light be implemented within the standards?' became a firm starting point for the questions to be asked throughout this questionnaire.

By collecting quantitative data from this questionnaire and combining it with the qualitative data from the interviews, the data collection became mixed methods research, which combined both positivist and post-positivist perspectives on the topic of street lighting and navigating through the street lighting regulations (Merriam and Tisdell, 2016). Mixed methods research can answer questions that other methodologies cannot, as it provides tougher interventions. It presents a wider diversity of perspectives (Cameron, 2015). There are many things to take into consideration besides the data collection when carrying out a questionnaire. These include ethics, data protection and consent. All participants were asked for their consent for the data collected to be published in this thesis. There is no publication of any personal information (Moreform.mdx.ac.uk, 2019). Ethics approval can be found in appendices 13.33 and 13.34.

Within the field of street lighting, there is a wide variety of professions and skill-sets. To ensure the data collection was as valuable as possible, the questionnaire was issued to professionals with varying backgrounds. These included: architects, designers, engineers and researchers. The target was to reach 50 participants who had expertise in road lighting. This is because more opinions on a topic will give a better overlook and uncover anything that may have been missed (Creswell, 2013). This stage simply built upon the data gathered from the interviews and helped to clarify the conclusions. This data collection specifically targeted people with street lighting involvement and those who engage with lighting standards. This data collection involved the same questions being used from person to person to ensure repeatable results.

It was possible that if participants were reused from the previous data collection, they might have provided biased answers that influence the research findings. To eliminate this possibility, participants that had previously been involved were not used in the second data collection. The questionnaire was developed by reviewing the interviews. Although useful, the last data collection of interviews would have been better if the questions were consistent. This would have allowed for direct comparisons amongst individuals; however, trends might not be identified as they are all from an array of backgrounds. This data collection aligns with the rest of the thesis as the research question queries the user-friendliness of the current lighting standards. By interviewing professionals in the lighting field, feedback will be obtained from those that use the current lighting standards. The data collected was of value as it was sourced directly from those who will benefit from it.

Online questionnaires were the best method for this data collection as they are time efficient and provided the opportunity to reach a large target audience of 50 people in the lighting industry. 74 participants were achieved by networking at lighting events and by discussing this thesis with relevant people, such as architects and street lighting managers, who connected the research with like-minded people. Many agreed to share the questionnaire throughout LinkedIn, newsletters and emails. More details are shown in appendices 13.2 – 13.7 (Merriam and Tisdell, 2016).

Once the data was collected, it was analysed and the data was displayed using graphs. Any common trends were discussed and explored. Where necessary participants were asked further questions.

The majority of the papers that have been referenced throughout this thesis have built their data collection from observations and by means of technology, for example, measuring reaction times using buttons. (Dong et al., 2017). However, using technical data for the data collection in this dissertation was not appropriate as it involves the way in which humans interact.

It would, however, be possible to carry out data collection on eye-tracking while a lighting practitioner navigated the standards and perhaps a revised graphically enhanced lighting standard system for comparison. However, as the main limitations were time and money, it was decided to use online questionnaires as a cheaper and less invasive alternative.

2.4 SLSNF

The Street Lighting Standard Navigation Framework builds upon the prior data collection. The literature review provided a vast analysis of current lighting standards and emerging technologies. The interviews provided some primary opinions on Figure 37 and highlighted weaknesses such as gaps of information. One theme that emerged from the Figure 37 comments was that it did not have enough information to satisfy all needs. The SLSNF on the other hand is an open source framework, allowing others to contribute. This way, the more professionals that use, add and interactive with it; the more valuable the SLSNF will become.

The questionnaire further built upon this by extracting information from professionals and highlighting what it is that would benefit them whilst navigating lighting standards. Using insights taken from the questionnaire carried out in chapter 7, the SLSNF provides a user friendly, time efficient method of navigating the street lighting standards. The data collection in chapter 7 was carried out amongst 73 professionals, the majority of whom have a post graduate degree and over 21 years of experience in the lighting industry, hence this provided a solid foundation for the SLSNF to be built upon.

Three participants were asked to carry out a number of tasks using the SLSNF, to test its usability. Having a large number of participants is not important for qualitative research (Creswell, 2013; Merriam and Tisdell, 2016; Patton, 2015). These participants are not from the street lighting sector. All participants have a post graduate degree and good experience working with electronics and LEDs. Participant 1 has many years in the construction industry working as an electrician and has worked on several lighting projects. Participant 2 has experience working alongside architects and surveyors hence she is used to following regulations and guidelines similar to those surrounding street lighting. Participant 3 has a keen interest in design and works as a user experience designer which is beneficial to the development of the SLSNF, this particular person is used to displaying buttons and graphics on screens and exploring people's behaviours when it comes to interacting with a digital tool or website.

As the participants were not street lighting designers or engineers, they cannot comment if the SLSNF is useful to the street lighting sector. However, their comments on the overall usability will be of value. This data collection was a pilot test. Due to the limits of time and money this was not issued to street lighting designers or engineers. This would be a future research area.

2.5 Ethics

Appropriate ethics for the primary research carried out were taken into consideration and approved by Dr Carlisle George on behalf of Middlesex University (see appendices 13.33 and 13.34). Informed consent was obtained throughout. The purpose of the data collection and this thesis was explained to all participants. All participants gave consent to use the results for the purpose of this thesis (see appendix 13.9).

Anonymity and confidentiality were protected throughout. The data was collected via Google Forms and was stored securely on Google Drive, which was password protected. With the data collection now complete and summarised any personal information has been deleted. Participants were given the opportunity to withdraw at any point. No deceptive practises were carried out. The data collection was not used for any purposes other than this thesis.

All participants were happy to take part in all three stages of data collection and any data collected did not have any personal information attached other than a contact email address to eliminate any possibility of a GDPR breach. The email address was only used if the participant agreed to be contacted following the data analysis in case there was something that needed further clarification.

2.6 Synthesis

The interview data collection was all qualitative, the questionnaire data was mainly quantitative. Where possible, data was visualised by means of pie charts and spreadsheets. The majority of participants interviewed stated that Figure 37 was a useful tool, however, it did have its flaws and would have benefitted from additions such as SBD, SSSI, AoSP, Country Parks and telling users where to look for guidance from the lighting standards, this is discussed in chapter 6.3.7. As the data was analysed; themes began to emerge from the data collection. It became apparent the method of how lighting designers and engineers currently interact with the lighting standards and regulations should be explored (Creswell, 2013). This created the foundation for the questionnaire.

After a few iterations and a pilot run, it was issued through a network of lighting contacts, LinkedIn, social media and word of mouth. The large questionnaire data collection was significant and mainly displayed using pie charts. The remainder was visualised using Excel spreadsheets. Question 13 (Which lighting standards do you utilise?) had to be filtered down more than once because of the vast array of responses. This was visualised in Appendices 13.20-13.22. Appendix 13.20 showed the complete data collection, Appendix 13.21 refined this collection by only

showing standards or guidelines that were selected by five or more participants. This reduced the spreadsheet size, eliminated anomalous results and focused on the useful data. Appendix 13.22 went one step further and eliminated any results from participants that were not lighting designers or engineers. This last step was completed because lighting designers and engineers are the target audience for the SLSNF (Street Lighting Standard Navigation Framework).

3. Literature review

3.1 Previous research

The following section summarises some of the existing research on road lighting that has already been conducted. Each research piece has a unique way of tying into the domain of road lighting.

Amber lenses to block blue light and improve sleep - 23/12/09 (Date accepted)

This trial involved testing the sleep quality of participants with amber lenses to remove blue light. Although the sample size was small, the outcome was clearly positive and indicated that a reduction in blue light prior to sleeping resulted in better sleep quality (Burkhart and Phelps 2009). This reiterates that street lighting should be of a lower colour temperature below 3000K (reducing blue light emission) to minimise the impact on the sleep quality of those subjected to street lights in the evenings.

Bright light exposure does not prevent the deterioration of alertness induced by sustained high cognitive load demands - 14/3/17

This test involved patients being subjected to controlled light exposure, where they were examined before and after. Results showed no correlation to the lighting and their sleepiness or alertness. The participants became progressively more tired with the engaging task regardless of the lighting condition (Borragán et al., 2017). Colour temperature is not specified within this paper. This shows that light intensity is less of an important factor when considering a street lighting installation. This is not to be confused with visibility.

Limiting the impact of light pollution on human health, environment and stellar visibility - 3/6/11

This study involved an in-depth analysis of how melatonin production is suppressed when exposed to an array of light sources. An unexpected finding was that for the same luminous flux the amount of blue spectra emitted by a light source can vary greatly. This paper proposes a set of rules for the control of light pollution, one of which is: “strongly limit the short-wavelength ‘blue’ light” (Falchi et al., 2011). The installation of street lighting with a colour temperature below 2000K complies with the rules specified in this paper.

Driver’s visual attention as a function of driving experience and visibility - Using a driving simulator to explore drivers’ eye movements in day, night and rain driving - 27/9/09

This test involves a comparison of eye movements during participants driving a simulator in various conditions.

The two groups of participants are experienced drivers and less experienced drivers. The results predictably show far more eye movement with the participants who are more experienced. It was observed that there was decreased eye movement for both groups in night and rain conditions due to visibility, this explains the increased risk of accidents during these times. This paper clearly shows that a decreased visibility for motorists results in a higher accident rate, thorough planning must go into street lighting installations to ensure visibility is sufficient (Konstantopoulos, Chapman and Crundall, 2009).

Effect of light colour temperature and intensity on the behaviour of male mice - 29/8/16

Mice were given several tasks to perform such as marble burying. During this time, they were subject to various lighting conditions. Results showed that mice exposed to cool light of 4000K displayed anxiousness. Those exposed to warm light of 2500K were less anxious. Higher intensity lighting showed similar results to the higher colour temperature where the mice displayed more stress and anxiousness (Kapogiannatou et al., 2016). Once again this reiterates that light of a lower colour temperature below 3000K has far less negative effects on the well-being of most species, due to its reduced blue light emission.

Investigation of human eye pupil sizes as a measure of visual sensation in the workplace environment with a high lighting colour temperature - 18/12/15

In this study, pupil diameters were measured under various conditions. A trend of larger pupil diameter was observed when exposed to higher colour temperature and increased brightness. This indicates a higher level of visual sensation when exposed to these lighting conditions (Choi, 2015). Previous papers have stated that light of a lower colour temperature causes less harm to our health. However, roads with vehicles are dangerous, hence it is important that the eyes of motorists are stimulated with light of a high enough colour temperature so they can easily identify hazards.

The impact of LED correlated colour temperature on visual performance under mesopic conditions - December 2017

Participants were subject to 24 different lighting conditions. This included a variety of CCT, CRI and background luminances. Reaction times were collected by the participants pressing a button when they observed a light spot. The data collected showed:

- Reaction time decreased with increased CCT
- Reaction time decreased with lower CRI

Although light of a lower colour temperature implements less harm on our circadian clock, wildlife and many other factors, for the safety of our roads we must ensure that the right balance

of colour temperature is utilised to ensure motorists have sufficient reaction times to react to hazards (Dong et al., 2017).

Is lighting the pavement important? - 24/10/17

This study explored people tripping on UK pavements and the reasoning behind it. When people were asked why they tripped at night time, they explained it was due to the weather, lack of concentration or bumps in the pavement. For those that tripped during day time, the reasons were being startled by a motorbike, blistered paving or dragging their feet due to an illness. Very few people blamed it on lack of adequate lighting of the pavement (Unwin et al., 2017). This research provides the opportunity to decrease the intensity of lighting in some locations. Not only will this decrease light pollution and its effects but it will also reduce energy consumption.

An epidemiological study of the risk of cycling in the dark: The role of visual perception, conspicuity and alcohol use – 15/08/13

Many cities now encourage cycling as a better alternative to car trips. However, the risk of injury to cyclists is higher than that of car occupants. A study was carried out in the Netherlands, and the analysis showed that in urban areas the risk of cycling in the dark was about twice that of cycling in daylight. For rural areas, this was about a factor of 5 higher. The higher crash rate in both darkness conditions supports the expectations that reduced visibility plays a role. Increasing rates of cyclists injuries are partially due to the poor visibility of the environment. The injury rates in early morning darkness are higher than that of late-night darkness, which suggests that 'darkness', is not the only contributing factor.

Below is a quote discussing existing research that reinforces the discussion on cyclist visibility:

Thornley et al. (2008) studied the relation between conspicuity and bicycle crashes in New Zealand. They concluded that low cyclist conspicuity may increase the risk of crash-related injuries, and suggested the promotion of high-visibility clothing as a simple intervention to increase cycling safety. However, it will take extra efforts to convince cyclists of the necessity of it, as studies on the accuracy of the cyclist's estimates of their own night-time conspicuity showed cyclists to overestimate their visibility for approaching drivers (Wood et al.), and to underestimate the effect of the value of conspicuity devices, such as reflectors and bicycle lights.
(Twisk and Reurings, 2013)

Measurement of the reflection properties of road surfaces to improve the safety and sustainability of road lighting - 2009

In this study, the measured parameters were: specular factor and average luminance coefficient. Roads vary in reflectiveness greatly. Reflectiveness is increased by traffic polishing and oil spills. The binder in asphaltic concrete surfaces often forms part of the reflective surface.

Data was collected by means of a mobile road reflectance gonioreflectometer known as Memphis, as shown in Figure 3. This tool was developed from a 4-year research project at the University of Liege in Belgium. Results showed a huge range of reflective properties.

It was suggested that before carrying out repairs on a road, the government does testing or has a database stating what aggregates, chip seal and asphalt combinations were used and do their best to match it. This would eliminate unexpected reflection properties of the road and pavement resulting in both under lighting and over lighting which can consequently cause glare and sky glow. The surface reflecting the glow of a street light is almost as important as the luminaire itself.

In New Zealand wherever new lighting was installed, a reduction in night-time crashes of about 30% was observed. A similar study in the UK showed the same correlation (Jackett and Frith, 2009).

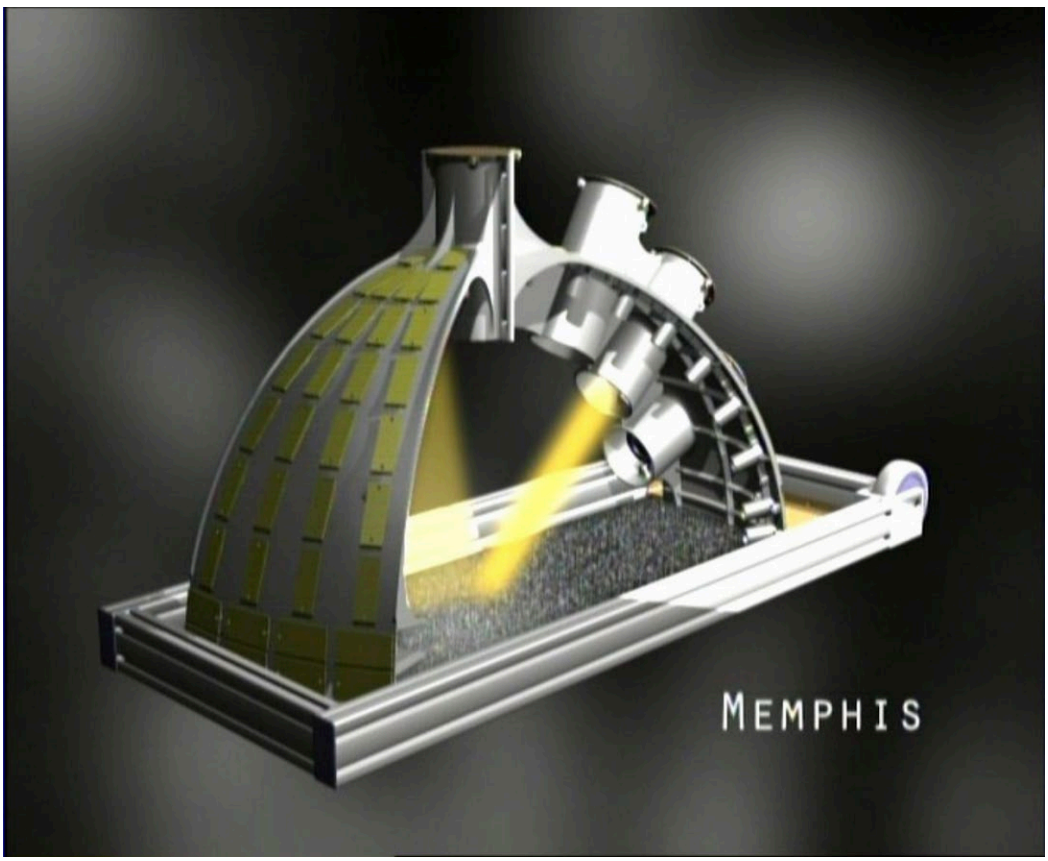


Figure 3. Memphis - a tool for measuring reflectivity of a road surface (Memphis, 2008)

Methods to control obtrusive light in consideration of urban structure and outdoor lighting in Asia - 25/10/17

This was a study of the lighting and consequent light pollution on the streets of busy cities in Asia such as Seoul. Asian cities have a different layout of roads, homes and lighting in comparison to European cities. The cities are far more condensed and light pollution can potentially come from both the front and the rear of a luminaire. There is no uniform distance between the luminaires resulting in an inconsistent spread of light. The current regulations on street lighting and light pollution have been devised with European cities in mind. They are not appropriate for Asian cities as previously discussed.

This paper proposes a new system for categorizing luminaires by the light pollution they emit. This would help both governments and lighting designers plan accordingly. It would help to foresee any potential problems with light trespass, glare and sky glow before any new street lighting installations receive approval for construction (Kim et al., 2017).

Research on the lighting performance of LED street lights with different colour temperatures - December 2015

For this study, a series of tests were conducted. The following conclusions were gathered from the data sets. Increased CCT resulted in:

- Increased dark adaptation time
- The human eye having an improved ability to distinguish colours
- Less penetration through fog and haze

An interesting observation was: as road illuminance increases so does dark adaptation time (Huaizhou et al., 2015).

Public street lights increase house infestation by the Chagas disease vector Triatoma Dimidiata - April 2012

Chagas disease in Mexico is mainly spread by Triatoma Dimidiata. This research shows that houses closer to public street lights were 1.64 times more likely to be infested than houses further away (Pacheco-Tucuch et al., 2012). This provides an insight into how the same rules will not apply globally for street lighting regulations. Although street lighting aids motorists with vision and provides pedestrians with a sense of security; in this instance, it results in an increased risk of local houses being infested with the Chagas disease.

Street lighting disturbs commuting bats - 14/7/09

This test involved the implementation of sodium street lights along the typical path of several bats. Results showed that the bats will take any detour possible to avoid light exposure, in some circumstances even returning to their roost and not feeding for the night. In some cases, where they are uncomfortable with nearby light exposure they may even abandon their roost (Stone, Jones and Harris, 2009). Despite this test being carried out with Sodium lighting (approx 2000K), the light was still substantial enough for the bats to change their behaviour. Although colour temperature is important when designing light installations, light pollution is a more significant factor.

The effects of coloured light on nature - February 2009

This paper increases awareness of gaps in information. There are currently no data sets on how certain species respond to certain spectra. The aim of finding these gaps is to identify lights that do not interfere with wildlife, but still allow humans to carry out tasks at night. These lights will, of course, be different depending on the species we are trying to work alongside (Musters, Snelder and Vos, 2009). It appears from current research that light of 2000K has the least impact on humans, whilst providing enough clarity to still carry out tasks (Falchi et al., 2011), however as mentioned before, light of the same colour temperature was enough to disturb the behaviour of bats (Stone, Jones and Harris, 2009).

3.2 Current street lighting model

3.2.1 Introduction

All street lights in Great Britain should conform to the British Standard regulations. There are other governing bodies, such as IESNA and ILP. The British Standards for street lighting relates to over 15 PDF documents and are roughly 50 pages long. They are highly technical and laborious to navigate. Despite this, there are some key points to take into consideration. Some of which are essential for the safety of motorists and pedestrians, others not so much.

3.2.2 Current guidelines

3.2.2.1 British Standards

BS EN 40-1:1992

Lighting columns Part 1: Definitions and terms

This is not so much a standard, more a glossary for terms such as ‘planting depth’ and ‘bracket projection’ (BS EN 40-1:1992, 1992). It is important to understand these terms in order to fully understand the rest of the regulations.

BS EN 40-2:2004

Lighting columns Part 2: General requirements and dimensions

This document specifies requirements of lighting columns, such as withstanding wind and vehicle impact. It specifies the dimensions for lighting columns, brackets, earthing terminals and more with annotated technical drawings. The following quotes are taken from this lighting standard.

'In the interest of safety the door opening should be positioned parallel to the bracket on the side away from the direction of traffic.'

'The door shall be secured by a locking mechanism to resist unauthorized entry.'

(BS EN 40-2:2004, 2004)

This provides safety in the event of a normal accident. In the event that a car may crash onto the other side of the road, this could result in the door being opened and a short circuit occurring. Therefore, it would be wise to have this positioned at 45 degrees away from the direction of traffic as shown in Figures 4 and 5.

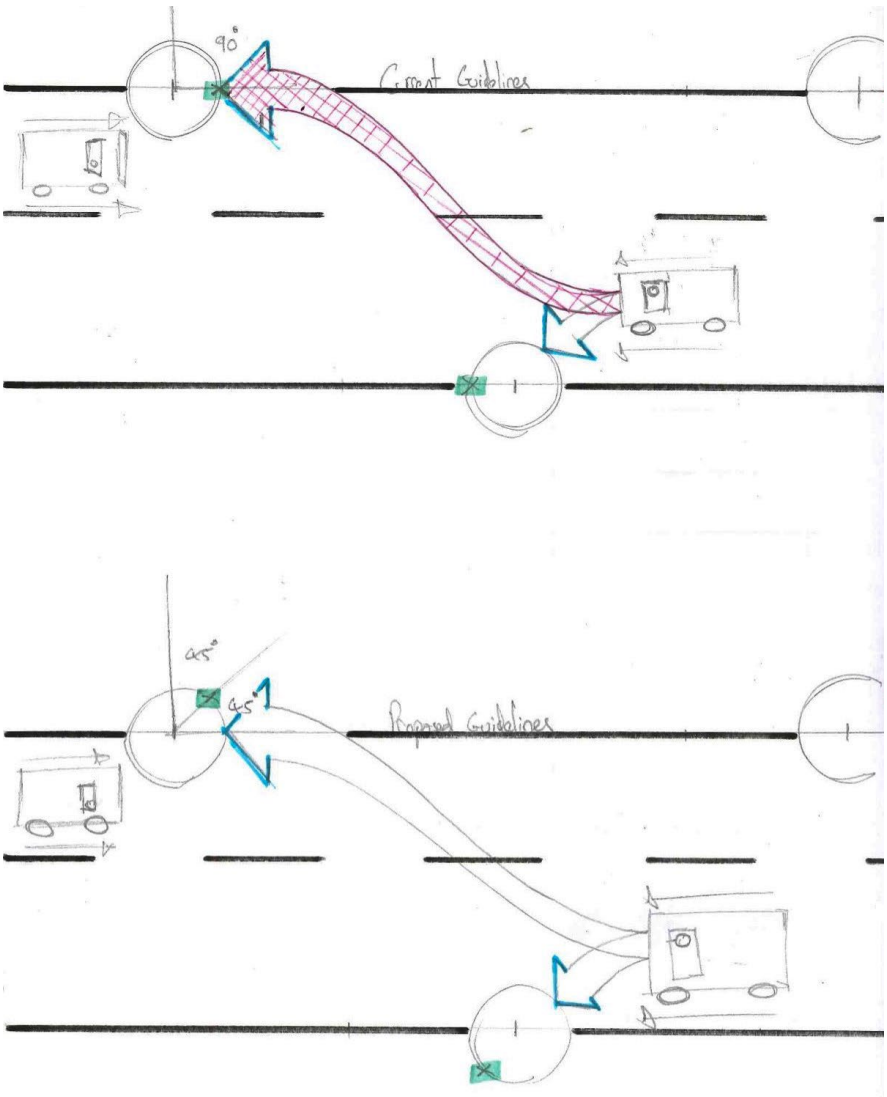


Figure 4. Proposed new street light door opening position sketch

The blue arrow in Figure 5 shows the same accident with less potential of the street light door opening. This new door position would allow access for an engineer, whilst still remaining shut during a collision.

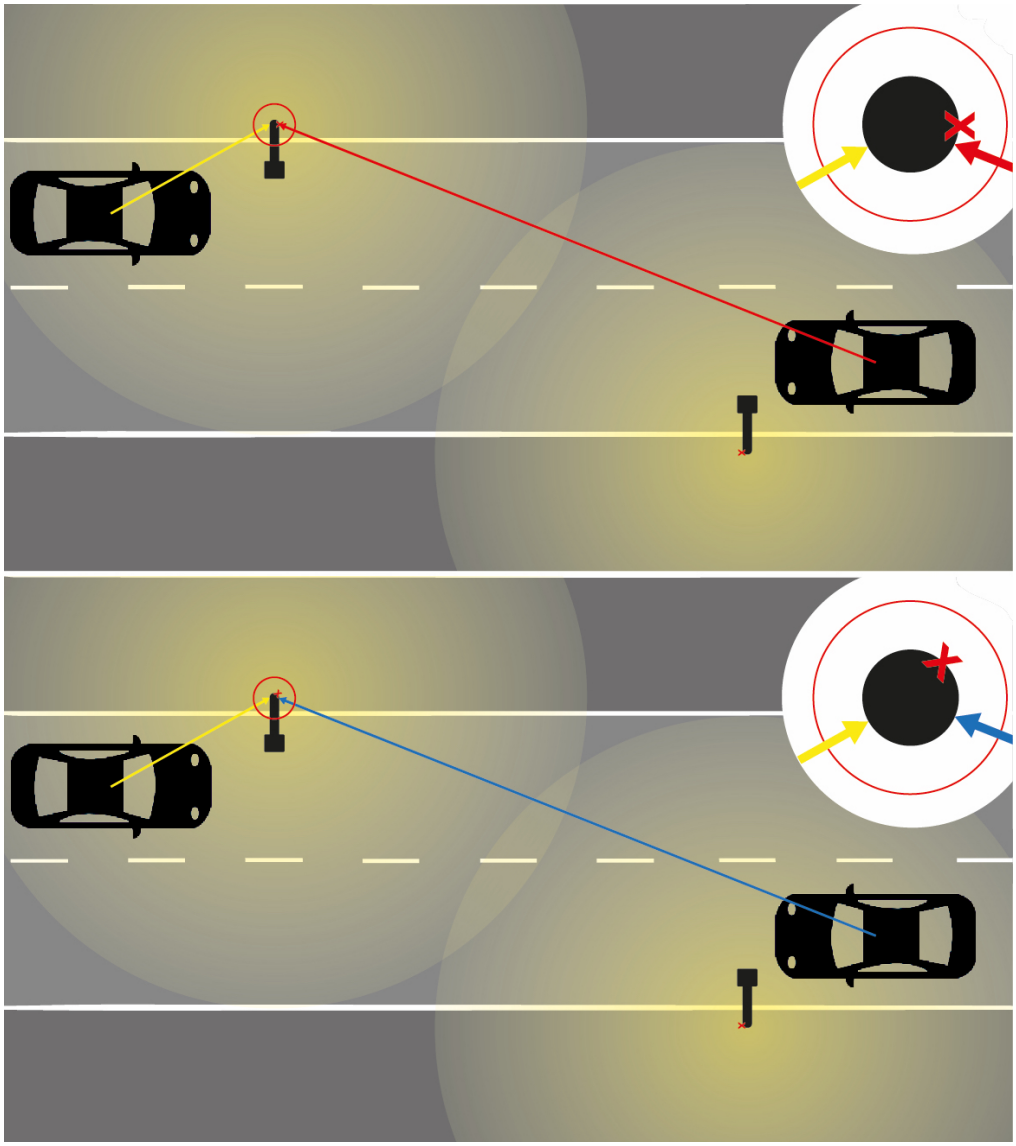


Figure 5. Proposed new street light door opening position illustration

These are precautions which are not laborious or costly to implement although they can save the public from a great deal of harm in the event of an accident. In the situation where a pavement is not present or it is very narrow, then the current system would be best to provide the engineer with sufficient working space.

BS EN 40-3-1:2013

Lighting columns. Design and verification. Specification for characteristic loads

This covers the lighting requirements for columns made from concrete, steel, aluminium and fibre-reinforced polymer composite. It does not cover those made from wood, plastic and cast

iron. This standard specifies the performance requirements for horizontal loads due to windage. The behaviour of loads under vehicle impact is addressed in EN 12767 (BS EN 40-3-1:2013, 2013).

BS EN 40-3-2:2013

Lighting columns. Design and verification. Verification by testing

This standard specifies a variety of tests to ensure that light columns meet specifications. This includes performance requirements for horizontal loads due to wind. Several formulas are used to calculate values such as 'torsional moment of resistance' and 'acceptance of design for strength'. Light columns included are those made from steel and aluminium. Testing for concrete and fibre reinforced polymer poles is specified in separate standards (BS EN 40-3-2:2013, 2013).

BS EN 40-3-3:2013

Lighting columns Part 3-3: Design and verification — Verification by calculation

Calculations must be carried out to analyse torsional moments and bending moments. The less material used the better, as it will be cheaper and lighter, however, the structure must be sufficient to withstand both windage and dead loads (BS EN 40-3-3:2013, 2013).

BS EN 40-4:2005

Lighting columns — Part 4: Requirements for reinforced and pre-stressed concrete lighting columns

This standard specifies performance requirements of concrete columns under horizontal wind loads and under-vehicle impact (passive safety). Specifics are given for values such as compressive strength of concrete and tensile yield strength of reinforcing steel. There are numerous categories of concrete columns. These must all pass either an impact pendulum hammer or free-fall hammer test. After 5 hits, they must not show any visible sign of cracking (BS EN 40-4:2005, 2006). These tests are to replicate the conditions that the columns might be exposed to in real life.

BS EN 40-7:2002

Lighting columns. Requirements for fibre reinforced polymer composite lighting columns

This standard specifies performance requirements of fibre-reinforced polymer composite lighting columns such as how their cut edges should be treated. Tensile, flexural and inter-plane shear properties are all specified (BS EN 40-7:2002, 2002). Sharp edges are one of many important considerations; some elderly or less-abled people may rely on a street lighting column for support whilst walking down the street.

BS 5489-1:2013

Code of practice for the design of road lighting

Part 1: Lighting of roads and public amenity areas

This guideline has a requirement to take into consideration the environmental aspects of lighting. It also states: 'There is no statutory requirement to provide road lighting.' Neither are there any statutory requirements to install a particular class of lighting if a decision is made to light a particular road. However, there are statutes that empower highway authorities to light roads.

'The provision of road lighting on a previously unlit road might involve statutory requirements and might cause the imposition of speed limits'. This should not be the case. In some circumstances, street lighting may not be necessary, which is absolutely fine. However, the circumstance in which no street lighting is necessary should fit under a specified annexe category, for example, a rural area with negligible night usage. The guideline then states that the lighting can be of any class. The lighting class should be specified by lumen output, CCT and light technology. Further specifics, such as voltage, amperage, LDP and cable gauge, can be decided depending on the specific circumstances.

'Adequate lighting on the surrounds helps the motorist to perceive more of the environment and make speed adjustments in time. The function of the surround ratio (SR) or edge illuminance ratio (EIR) is to ensure that light directed on the surrounds is sufficient for objects to be revealed'. 'Adequate lighting on the surrounds is beneficial to reveal vehicles emerging from side roads and people who might be about to step into the carriageway.' The two points above are useful when considering the area that a street light should illuminate. Any potential hazard which is not on the road should also be illuminated sufficiently.

'Maintenance programmes should include light source replacement, luminaire cleaning, renewal of failed parts, checking of gaskets, optical components, screens or baffles, checking of alignment and monitoring of operation. It is desirable to minimize the frequency of maintenance visits'. The checklist varies depending on the light source. It is something that must be enforced no matter what light source. With the implementation of new LED lights however, the service intervals will be far longer. However, the luminaires must still be cleaned regularly to ensure that light output is not affected. Unless designs start to incorporate low maintenance glass which is self-cleaning.

'The colour rendering index of the light source (Ra) should be suitable for the application or task and should be ≥ 20. In civic centres, shopping streets, boulevards, promenades and other places that are the hub of social activity and have a high night-time pedestrian use, light sources with an

Ra ≥ 60 should be used'. This is to ensure faces can easily be distinguished from a distance. This can help people to feel safer (Painter, 1996).

It is good that CRI has been taken into consideration. However, a constant CRI should be maintained in all circumstances when possible. CCT should be the only aspect which changes the CRI. This is because in all circumstances we want to see colours as we would under the light of the sun. The only drawback being the negatives of light pollution, which is where a lower colour temperature would help to minimise the negative impacts.

'Where street crime is a major problem and the police use CCTV for prosecution, they should be consulted regarding the lighting requirements, including colour rendering and level'. With the advance in CCTV technology, this is less necessary. Cameras now have night vision. Any light that falls onto suspects, however, can help with facial recognition. Research has shown improved street lighting has reduced burglary and theft crimes. It did not have an effect on violent crimes, however. Overall, the implementation of improved street lighting in an urban area showed a reduction in crime of 21%.

Surprisingly the decrease in crime was present during daylight hours as well; it is possible that new street lights reverse the 'broken window effect' and develop a sense of community pride. Some may say that a reduced crime rate in one area will move criminals to another nearby area.

Results showed that this was not the case and in fact the sense of community pride was because of the nearby new street lights having a spillover, benefitting local areas without new street lighting with a reduced crime rate as well (Library.college.police.uk, 2018).

'The colour appearance of light sources should be suitable for the application or task and is quantified by the correlated colour temperature (T_{CP}). Values of T_{CP} are usually categorized into one of three groups (warm, intermediate or cool colour appearance)'.

The text later states that there are 3 categories of colour temperature:

- Warm < 3300
- Intermediate 3300 - 5300
- Cool > 5300

Colour temperature has been briefly mentioned. However, where specific colour temperatures should be implemented has not. In a residential area where light pollution into residential windows is possible, it is crucial that any light that may spill should be of a warm CCT (2000K) and

no higher. In an area of high crime rate, it is key to have light of a high CRI. The same applies to roads of a speed limit higher than 30mph; this gives the motorist the best chance of reacting in time to a hazard. To achieve this light of 3000K should be installed (Falchi et al., 2011).

'In tree-lined roads, lower mounting heights than usual may be used to bring luminaires below the tree canopy'. Poor planning of the implementation of street lights near trees can result in short service intervals for both the tree and the luminaire. It is crucial to maintain a green landscape where possible, whilst not interfering with the designated illumination area.

'On roads where traffic speeds are high and there are few pedestrians or cyclists, the installation of passively safe (also known as breakaway or energy-absorbing) lighting columns is an alternative to rigid lighting columns to reduce the severity of injury'. These have been designed and tested to absorb the impact of a crash, reducing the impact on the motorists. However, all modern cars are fitted with crumple zones and some even have accident avoidance systems. Hence these columns are becoming less necessary in the world of today. Each time one of these columns is hit, a lot of labour and money is involved in replacing it.

In the event of an accident, it is only fair that the motorist pays for the damage of their car, rather than the government paying to repair a street light damaged as a result of the accident. An accident with a non-passive column will still damage the column however far less so. An accident with a passively safe column may result in the entire luminaire making contact with the ground. This can result in glass and other components being scattered across the road surface potentially endangering other motorists (Williams et al., 2007).

'The typical height to the eaves of a two-storey house is approximately 6 m.'

'Typical mounting heights are 5 m and 6 m for residential and subsidiary roads, 8 m, 10 m and 12 m for traffic routes, and 12 m and 15 m for high-speed dual carriageways and motorways; but in special situations where particular aesthetic or environmental factors apply, the use of other mounting heights might be more appropriate.' (Manual for Streets, 2007)

A higher mounting height can result in the need for lights of less frequent intervals. The drawback of this is an increase in light pollution. This can be minimised with a suitable lens and shade. The advantages of a lower frequency interval lighting system are less street clutter, less installation cost and less servicing. Light of a greater height would, of course, need stronger columns and deeper foundations. If lights were to be increased in height, then windage must be taken into

account for that specific area and luminaire, to ensure the pole can withstand the maximum forces that may be acted upon it.

‘A traffic calming scheme in Latton in Wiltshire reduced the height of lighting columns by around 40% to make the appearance less urban. In a survey of residents, 58% thought it was a good idea, and only 3% opposed it. This arrangement resulted in less intrusion of light into bedroom windows’ (Manual for Streets, 2007).

‘The control of discomfort and disability glare is not as critical for pedestrians as for motorists, because speed of movement is much lower, giving a greater reaction time. Methods for quantifying and controlling glare in pedestrian, cycling and low-speed traffic areas are given in BS EN 13201-2.’

Glare can be reduced by the implementation of targeted lenses, baffles, shields and light diffusion. Special care must be taken on crests of hills to ensure motorists are not dazzled.

‘It is common practice to reduce the spacing between lighting columns by 10% on a slight bend compared to a straight road.’

It is necessary to have higher visibility when driving around a corner to avoid last-minute hazards. This need will, of course, vary depending on the degree of turn and possibly other factors such as blind spots and a change in height. Light columns should not be installed where accidents frequently occur on bends.

‘In areas where there is a high crime risk, care should be taken to ensure that any potentially dark areas, which could provide cover for a criminal, are included within the relevant area to which the selected lighting class will be applied.’

‘It is recommended in such areas that the lighting levels are not reduced at any time of the night.’

‘Colour rendering can help in crime detection by permitting better identification of objects and people, and this should be taken into account in choosing a light source.’ (BS 5489-1:2013, 2012)

As previously mentioned street lighting should not only illuminate the road for the purpose of both pedestrians and motorists. Dimming street lights could still be implemented in these circumstances as they would return to full brightness once any movement is detected.

Durham county council follows BS 5489 stringently. In *Street lighting installations for lighting on new residential roads and industrial estates* it is stated that:

- Any deviation from the standards will require written approval from the street lighting engineer before work commences.
- Where an agreement has not been made the county council reserves the right not to adopt the equipment.

  (Street lighting installations, 2014)

BS 5489-2:2016

Code of practice for the design of road lighting Part 2: Lighting of tunnels

This standard focuses on the lighting specifically for tunnels, taking into consideration the different methods of transport that flow through these tunnels. The main difference between lighting roads and tunnels is the need for lighting during daylight hours. Insufficient lighting can result in a driver experiencing the 'black hole effect'. Technical terms used to ensure the lighting is sufficient are explained, such as SSD (Stopping Sight Distance) are declared depending on the speed limit (BS 5489-2:2016, 2016).

BS 8442:2015

Miscellaneous road traffic signs and devices – Requirements and test methods

This standard specifies tests and requirements for portable signs, internally illuminated posts, stop/go signs and much more. These signs must comply with regulations such as a specified resistance to bending, a radio interference strength no greater than a set amount. Any beacons must flash at specific intervals with specified 'on' periods.

This standard mentions non-retro reflective road studs, their dimensions and the height at which they should be installed. It does not mention in what environment or road they should be implemented. These studs are ideal for roads that have less motorist usage as well as those areas that are particularly sensitive to light pollution such as AONB (Area of Natural Beauty), rural areas and countrysides. Careful measures must be taken into account prior to installation such as road width. Many countryside lanes tend to have blind corners where two cars cannot always fit comfortably side by side. These studs present a great opportunity to minimise clutter, maintaining the maximum width of the road, reducing light pollution and eliminating the service cost of expensive street lights in remote areas (BS 8442:2015, 2015).

BS EN 12665:2011

Light and lighting — Basic terms and criteria for specifying lighting requirements

This standard defines essential lighting terms such as glare and visual comfort as well as a framework for lighting requirements and what should be considered. Numerous formulas for technical terms are included, for example: 'practical emergency lamp flux' (BS EN 12665:2011, 2011).

BS EN 12767:2007

Passive safety of support structures for road equipment

Requirements, classification and test methods

This standard defines the performance requirements to reduce the level of injury when a vehicle collides with permanent support structures. The severity of an accident can be varied by the type of support structure they crash into.

There are 3 categories of safety support structures:

- HE High Energy absorbing
- LE Low Energy absorbing
- NE Non-Energy absorbing

(BS EN 12767:2007, 2008)

Durham county council follows BS EN 12767 stringently. In *Street lighting installations for lighting on new residential roads and industrial estates* is it stated that: All new roads above 50mph should use 50mph passively safe columns in accordance with BS EN 12767 (Street lighting installations, 2014).

BS EN 12899-6

Fixed, vertical road traffic signs: Performance of retro-reflective sign face materials

This standard describes the performance requirements for retro-reflective sign face materials. There are numerous variables involved such as light distribution of headlights and condition of the driver's windscreen. Figure 6 illustrates dimensions used to describe vehicles (BS EN 12899-6, 2012).

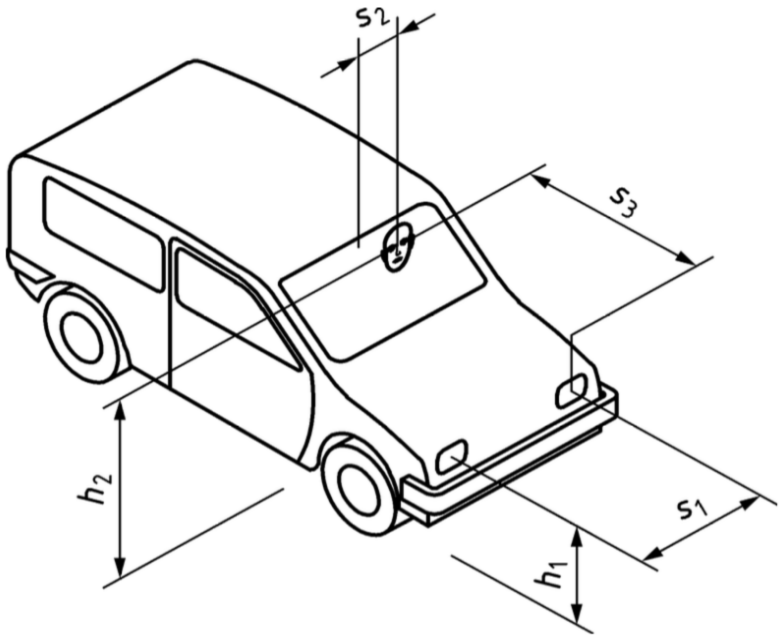


Figure 6. (Dimensions used to describe vehicles, 2012)

BS EN 13201-2:2015

Road lighting — Part 2: Performance requirements

Different circumstances are specified under different classes. These classes attempt to solve the issue of the need for different lighting on different roads, however, many of them overlap and this system is more complicated than it needs to be.

'The M classes are intended for drivers of motorized vehicles for use on traffic routes, and in some countries also residential roads, allowing medium to high driving speeds.'

'The C classes are also intended for drivers of motorized vehicles, but for use on conflict areas such as shopping streets, road intersections of some complexity, roundabouts and queuing areas, where the conventions for road surface luminance calculations do not apply or are impracticable. The lighting criteria are based on the horizontal illuminance and are expressed by the average and the overall uniformity. These classes have applications also for pedestrians and pedal cyclists.'

'The P classes or the HS classes are intended for pedestrians and pedal cyclists on footways, cycleways, emergency lanes and other road areas lying separately or along the carriageway of a traffic route, and for residential roads, pedestrian streets, parking places, schoolyards, etc.'

The SC classes are intended as an additional class in situations where public lighting is necessary for the identification of people and objects in road areas with a higher than normal crime risk.

‘The EV classes are intended as an additional class in situations where vertical surfaces need to be seen in such road areas as toll stations, interchange areas, etc.’ (BS EN 13201-2:2015, 2016)

Road surface luminance is an important factor to take into consideration. In an ideal world, it would be consistent; unfortunately, this is not the case. The reflective properties change depending on the aggregates used and binding agents. In some circumstances, the bind agents have a higher reflectivity than the aggregate. The reflectivity also changes with weathering and traffic wear (Jackett and Frith, 2009; Völker, Steblau and Buschmann, 2017).

BS EN 13201-3:2015

Road lighting Part 3: Calculation of performance

This standard specifies mathematical procedures to be used when calculating photometric performance of street lights. These procedures ensure different people performing the same tests would achieve the same result by following the same mathematical principles. These principles include many values such as: number of lanes of carriageway, photometric centre of the luminaire and average diffuse reflection factor of a surface.

Figure 7 illustrates the relationships between the observer, point of observation and the luminaire during light measurement (BS EN 13201-3:2015, 2016).

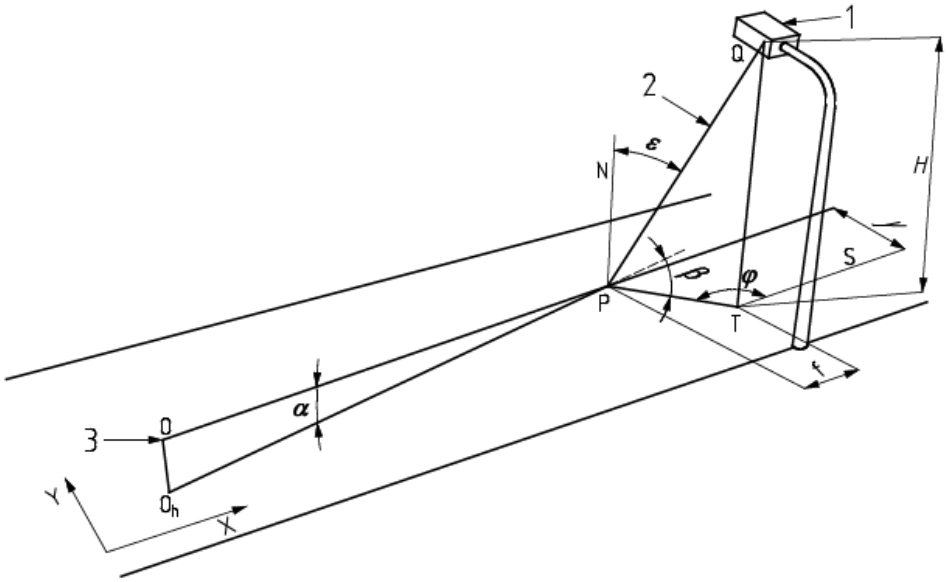


Figure 7. (Angular relationships for luminaire at tilt during measurement, observer, and point of observation, 2016)

BS EN 13201-4:2015

Road lighting — Part 4: Methods of measuring lighting performance

High wind speeds may make the luminaires oscillate. Components must be able to withstand this. The luminaires must also be able to endure harsh climates and temperatures. The IP rating will determine how resistant it is to weathering and the ingress of moisture (BS EN 13201-4:2015, 2016).

BS EN 50522:2010

Earthing of power installations exceeding 1 kV a.c.

This standard states the earthing required for high voltage installations such as substations and large factory components.

Although all UK street lights run from a 230V supply, this standard, in particular, is interesting as it shows the British Standards have rules and regulations for almost any public danger or concern. A case study is mentioned, which involves a street light near a substation which presents a public risk as illustrated in Figure 8. The risk consists of 3 probabilities:

- Probability of an earth fault event
- Probability of heart fibrillation
- Probability of exposure

(BS EN 50522:2010, 2012)

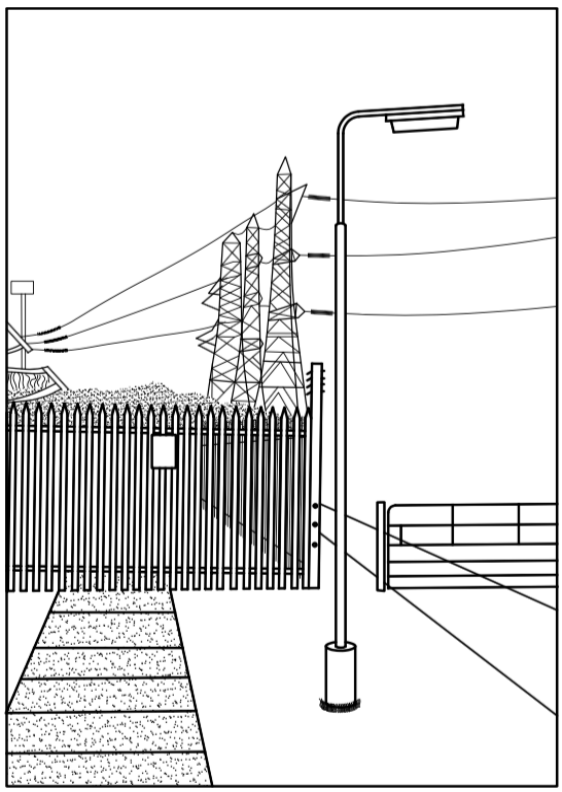


Figure 8. Potential risks of a street light near a substation

(Street light close to substation, 2012)

3.2.2.2 Non-British Standard guidelines

ANSI / IES RP-8-14-Roadway Lighting

This guideline covers a broad spectrum of roadway lighting. It takes into account many design considerations such as: background luminance, curb parking and number of pedestrians. Light pollution problems are also discussed such as: light trespass, glare and sky glow.

Other guidelines have failed to mention that off-road light sources can both assist and also distract drivers. Motorists need to view things other than just the road, such as signs. This guideline goes further in-depth on these topics. At higher speeds, the safe sight stopping distance can exceed the visual detection distance provided by low beam headlights. Low beam headlights only provide perfectly safe driving conditions by themselves for speeds of up to 30mph with little or no pedestrian activity (ANSI/IES RP-8-14, 2014).

This is the worst-case scenario with people that have delayed reactions, poor visibility, and a car with a long stopping distance.

'A universal feature of low beams is that the 'hot spot' is aimed relatively low and is laterally biased toward the near (passenger-side) shoulder of the road rather than straight ahead. While this reduces glare problems for oncoming motorists, this advantage comes at the expense of reduced visibility for objects or persons in the lane of travel or near the centre of the roadway'. 'Drivers' reluctance to use high beams is problematic and suggests that they fail to appreciate the visibility problems that accompany reliance on low beams'. Adaptive headlights change their beam pattern depending on conditions. It is estimated that these headlights have the potential to prevent 140,000 crashes a year in the USA. Motorists often 'overdrive' the useful range of their headlight beams and under-use their high beam headlight setting. Further, pedestrians overestimate their own visibility at night, and fail to appreciate the extent to which their own conspicuity depends on their clothing (Tyrrell et al., 2016).

Trees provide social, economic and environmental benefits. During summer, however, pavements may be less illuminated than in winter, due to the interference of lighting by leaves. Figure 9 shows that it is possible to have both adequate street lighting and trees together in harmony, provided they are trimmed appropriately. Roadway lighting and street way lighting differ from each other as roadways do not have any significant pedestrian or cyclist activity (ANSI/IES RP-8-14, 2014).

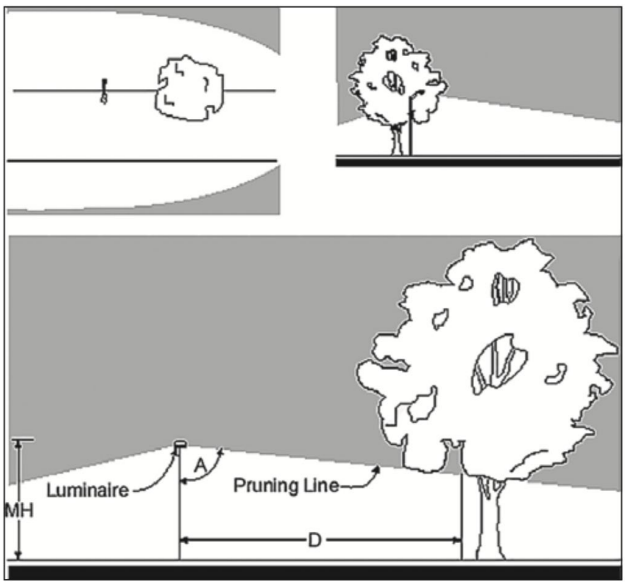


Figure 9. (Tree Pruned to Proper Height, 2014)

AS/NZS 1158.1.1:2005

Lighting for roads and public spaces

Vehicular traffic (category v) lighting - performance and design requirements

This guideline states the performance and design requirements including energy efficiency of the lamps and ballasts, luminaire data and other design data. Prior to the installation of street lighting, the category of vehicle and times of usage must be observed, to ensure appropriate luminaires are installed. Lighting applications have been divided into 5 subcategories: V1, V2, V3 , V4 and V5. They vary depending on type of traffic, traffic intensity and speed of traffic.

Luminance and illuminance are calculated by collecting data and inputting values into computer software. This is the same practice as in CIE 115: 2003. The appendix consists of 5 CIE publications, which enforces how much they are respected within the field of lighting.

A lighting plan may be carried out by luminance-based computer calculations. When evaluating a street lighting installation, an energy audit might be carried out. This takes into consideration three things:

- Electricity used in the lamp and control gear
- Energy used in the maintenance of the installation
- Hardware used (as well as the energy used for manufacture)

The preface, scope, contents page and general document structure have an almost identical layout to the layout of a British Standards guideline. The Australian standards still use some old terminology such as UWLR, but some terms remain the same such as LER: Luminaire Efficacy

Rating. Acronym usage is not the same as the British Standards, the Australian standards tend to spell out all terms (AS/NZS 1158.1.1:2005, 2005).

AS/NZS 1158.2:2005 Lighting for roads and public spaces

Computer procedures for the calculation of light technical parameters for category V and category P lighting

This standard outlines the required measurements for the calculation of LTPs and how they should be obtained. It provides basic formulas and the exact locations of where the observer should be positioned when collecting data on a luminaire. Some measurement specifics vary between New Zealand and Australia. This could be due to far lower population (one fifth) and the resulting reduced traffic usage when compared with Australia. Figure 16 clearly illustrates the vast difference in light pollution between Australasia and Europe (AS/NZS 1158.2:2005, 2005).

CIE 115: 2010

Lighting of roads for motor and pedestrian traffic

Conforming to this guideline reduces possible light trespass, sky glow and unwanted glare. It is, however, not very user-friendly to abide by. To conform to the regulations a series of specific measurements must be taken which are then entered into a computer program which hosts several mathematical formulas. There are many variables to take into account. For example, maximum values for intensity on luminaires in designated directions. (CIE 115: 2010, 2010)

IES DG-4-14

Design guide for roadway lighting maintenance

This standard provides detailed explanations on how all luminaires should be maintained and any problems that may occur with each type. Sodium lamps will flicker on and off, as they come to the end of their lives. If these are not replaced promptly; the ballast could fail and also require replacement. Different junction temperatures vary the lifetime of a luminaire, and an increased junction temperature tends to be due to a higher current. LEDs will last longer than the components associated with them, LEDs will not last as long if they are used at 100% of their brightness. Therefore, installations should be over-specified allowing the LEDs to run at 80% for longevity (Southall, 2017). Luminaires may need to be cleaned, to restore their original light output. Luminaires must be resistant to cleaning solvents that might be used to remove dirt such as tree sap. It would be better if luminaires were designed in a way that dirt accumulation did not affect light output. Sodium lights must have a specific input voltage, however, LED lights can have a wide range of input voltages and still function correctly (IES DG-4-14, 2014).

Model Lighting Ordinance

The purpose of this guideline is to regulate the use of outdoor lighting, minimise adverse off-site effects, help the natural environment and conserve energy and resources. This set of guidelines was brought to legislation with the combined efforts of the IDA and IESNA. The MLO is supported by the RP-33, the outdoor lighting standard enforced in the United States. The MLO explains a refined system to rate light trespass and glare. It has been named the BUG system for Backlight, Uplight and Glare as shown in Figure 10.

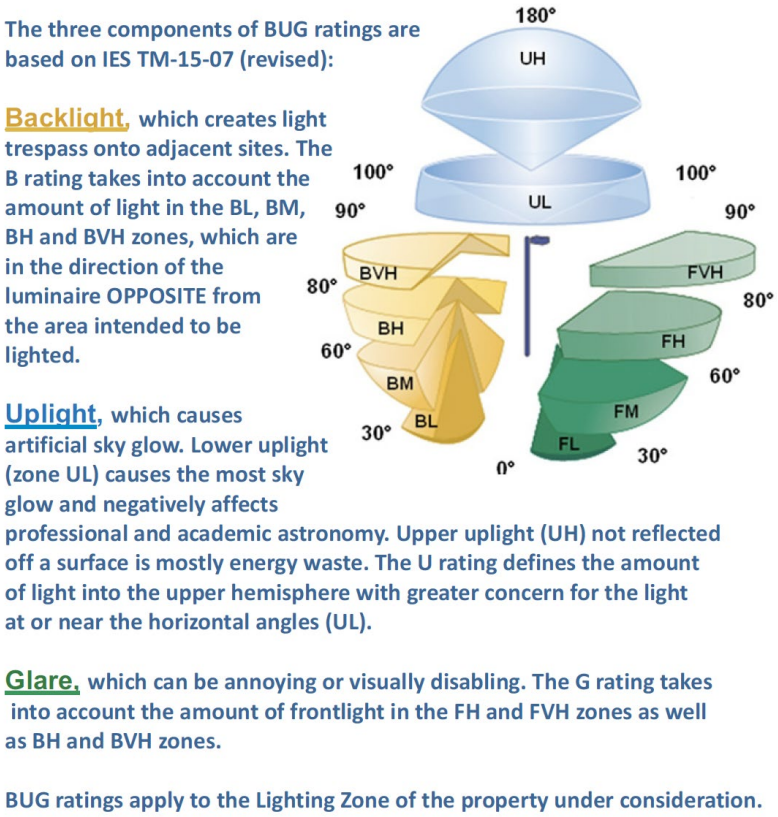


Figure 10. Backlight, Uplight and Glare divisions (BUG ratings, 2018)

All locations are categorised into 5 zones, LZ0, LZ1, LZ2, LZ3 and LZ4. LZ0 permits no ambient light due to the surrounding natural environment. LZ4 allows high ambient lighting levels for special circumstances such as highly active entertainment areas. Exceptions to these rules include; the illumination of staircases, building entrances and 24-hour shops. Uplighting should be restricted to historic buildings that have jurisdiction. The adopting jurisdiction should regulate and minimise adverse effects such as glare. Special use permits should be obtained for the use of aerial lasers, searchlights and any single luminaire exceeding 20,000 lumens (Walter et al., 2011).

Department for Transport - Manual for streets

This guideline refers to British Standards and reiterates previous points made. It also mentions that the implementation of street lights should be carefully planned so the streets do not become

too narrow which may cause problems for wheelchair users, pushchairs and blind people (Manual for Streets, 2007).

3.2.2.3 Guideline Summary

As shown, there are numerous standards and guidelines outlining almost every single detail of what a street light should be and do. However, these standards were created many years ago, when sodium street lighting was recently implemented and LED technology was used as nothing more than a power light on an electrical appliance. The above standards have been revised numerous times and even restructured. Even after such revisions, it remains an unorganised method of outlining the rules and regulations. It is difficult to navigate as the title and chapter headings are so specific for example:

'BS EN 12767:2007
Passive safety of support structures for road equipment
Requirements, classification and test methods'

From this review of the literature, it is clear that it would be beneficial to make these guidelines more user-friendly and easier to navigate. It would also seem that this is a timely opportunity to address this problem as the process of implementing new LED street lights is currently taking place. Therefore, this would be a good opportunity to create new guidelines that replace the old ones, so making a more logical system for finding technical specifics.

It has also become apparent that with the implementation of a new smart LED street lighting system the supporting columns can be much more. They can become the ideal chassis of numerous nodes which monitor and help to run our cities and towns. They can have multiple sensors that monitor air pressure, humidity, sound and weather. They can have car charging ports at their bases and can dim when there is an absence of traffic past midnight. Therefore, it is necessary that new standards take into consideration these factors and guidelines stated, ensuring they conform to safe and uniform regulations.

3.3 History of street lighting

Fire as lighting

Candlelight and fires were the first source of artificial light and they also provided warmth (Forbes, 1987), but these were not provided widely for the public good. They were the concern of individual households or institutions to maintain. The first organised public lighting system was not installed until 1417 in London, UK (Page, 2019). Each city would have a designated link-boy

who would light the candles in preparation for the hours of darkness (Illumination items: In its infancy, 2019).

The following three incidents are taken from the book *At Day's Close* (Ekirch, 2006) and occurred in the 1700s. These two accidents both occurred due to a lack of street lighting. This helps to clarify how long it took for street lighting to be implemented across the United Kingdom. In August 1738, a burglary was being carried out. The criminals carried 'dark lanterns' which emitted light from just one side. The first course of action was to extinguish their victim's lights and take necessary action to ensure link-boys did not re illuminate them. 'Put out the light, or we will blow your brains out' was a frequently used command. A Yorkshire man named Arthur Jessop was walking home one December evening and fell into a stone pit after losing his bearings. In his diary it was stated, the night was 'so extremely dark' that others too 'were lost and could not hit their way'. Arthur had a bruised leg and back. A similar incident occurred with a fifteen year-old girl in 1739, who stumbled into a newly dug grave and unfortunately died.

Candlelight involves the burning of hydrocarbons. The products of the process are thermal and light energy, carbon dioxide and water vapour. A candle's flame has its shape due to gravity; once the air is heated it is less dense and so it is forced to rise. NASA performed an experiment and lit a candle in a microgravity environment, where the result was a spherical flame as shown in Figure 11 (National Candle Association, 2018).

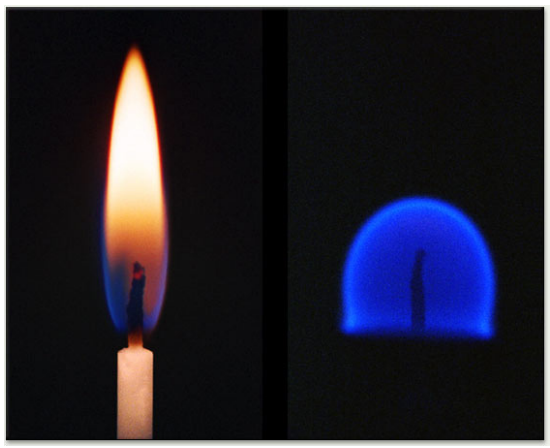


Figure 11. Comparison of candle flames with and without gravity (Dunbar, 2019)

Gas

As time went on, the next advancements made in the lighting industry were high-powered incandescent lamps and the electric arc lamp "Yablochkov candles" in the 1800s. In the 1900s, High-Intensity Discharge (HID) lamps were installed, such as Low-Pressure Sodium (LPS). These are still commonly used today (Page, 2019). In Italy, gaslight technology was in use between the 1850s and 1950s. A slow move to electricity occurred around the period of 1910 (Curto and Landi, 2019).

Figure 12 illustrates the high luminous efficacy that High-Pressure Sodium (HPS) and LPS lighting (the technology most commonly used in traditional street lights) have obtained over years of development. However, they are expensive, large in size and difficult to dispose of as HPS lights contain mercury. They do not respond well to fast cycling due to the time required for them to heat up. It can take one of these lights up to 10 minutes to reach its normal operating temperature. They also have very poor Colour Rendering Indexes (CRIs) (Effects of Technological Progressions on the Efficacy of Light Sources, 2018; LED Grow Lights Judge, 2018; Staff, 2018).

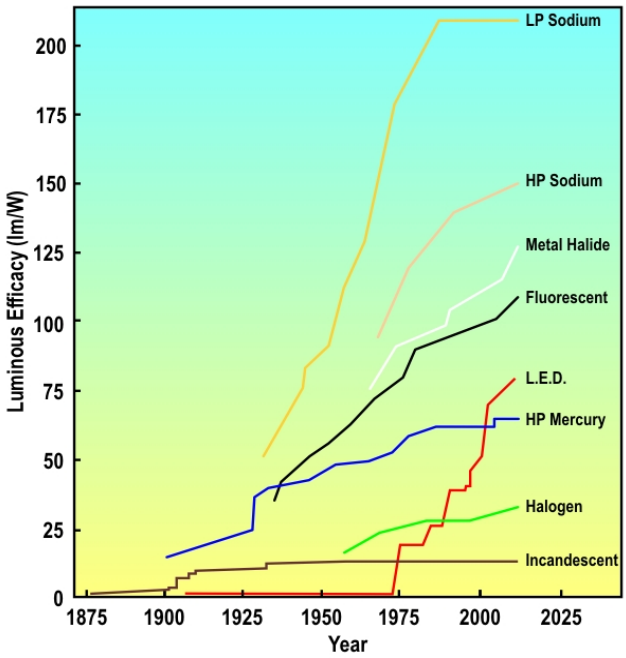


Figure 12. (Effects of Technological Progressions on the Efficacy of Light Sources, 2018)

The first gas street light to be implemented was in Pall Mall, London on 28/1/1807 by Frederick Albert Winsor (Long et al., 2019). The gas used was obtained from distilling coal. It was not until around 1850 that gas street lighting was more commonly used. The lights were well spaced out and did not have a high lumen output. This resulted in darkness between them as opposed to a continuous pool of light. Many gas lanterns are still in use today, although they have been retrofitted to run using modern bulbs (Page, 2019).

Tungsten

After gas light, the next development in lighting technology was with a tungsten filament; this light source is sometimes referred to as filament or incandescent. These bulbs are still widely in use today, however, they are slowly becoming phased out and being replaced with LED bulbs that utilise the same fittings.

In 1875, Joseph Swan experimented with incandescent lamps but lacked an adequate vacuum pump. After implementing the Spengel pump, he received a patent for the light bulb in 1878. In 1877, Thomas Edison was also working on electric lighting. Edison attempted to patent his bulb but lost in court for infringement against Swan. As part of the settlement, Edison was to take Swan in as a partner in his British electric works, later known as Edison and Swan United Electric Light Co. Figure 13 illustrates the front cover of the pricelist for this company. During the 1900s, the company became increasingly known as Edison Swan Electric Co.

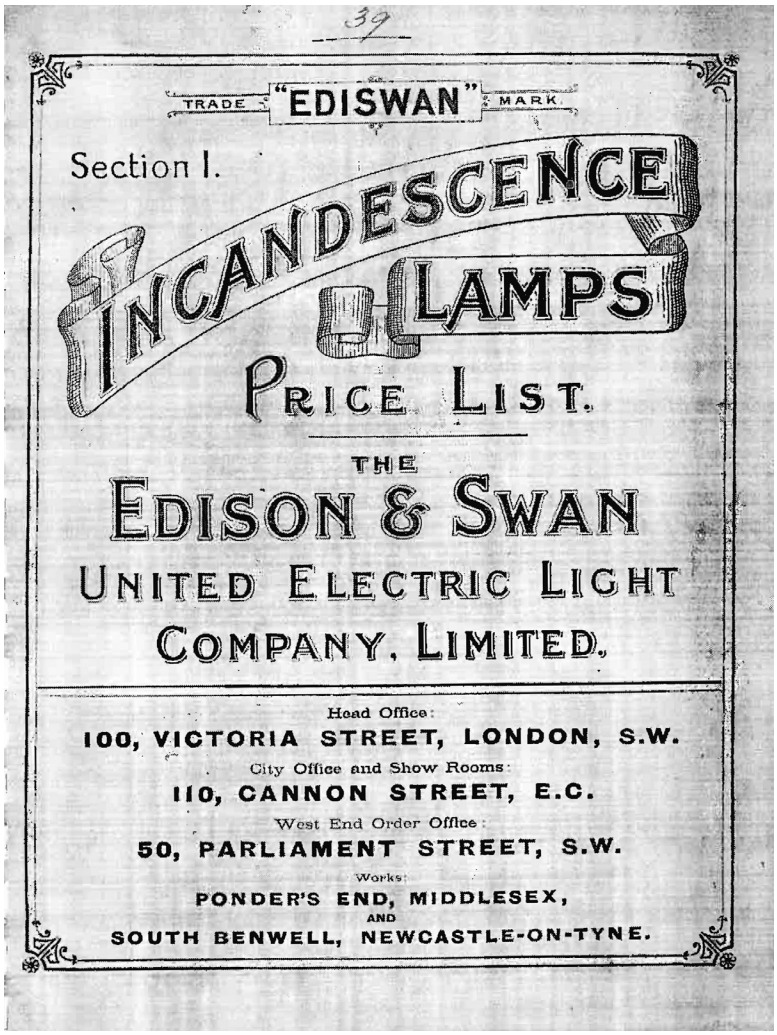


Figure 13. Edison & Swan United Electric Light Company Limited, catalogue and price list 1893, front cover (Ediswan, n.d.)

There were a few key stepping stones in the development of the light bulbs, such as tungsten filaments replacing carbon ones to increase their lifespan. The company grew with much success with a wide range of products and became known as Ediswan. It purchased numerous companies and even worked alongside Siemens in 1956 (Gracesguide.co.uk, 2018; Lamptech.co.uk, 2018).

The following two lighting technologies are not implemented for street lighting, however they have similar properties to traditional street lights.

Metal halide

This type of light comes under the category of HID. Most of the light comes from an electric arc within the bulb. It is a very efficient bulb in comparison with sodium lights and emits pure white light, unlike sodium lights. The bulbs have a high lumen output; they are frequently used in car parks, stadiums and external floodlighting. Unfortunately, due to the components involved, they are costly. These lights are often culprits of light pollution as they are frequently used in places where a bulb of lower lumen output could be used. However, these lights are often installed not conforming to guidelines which state that no light is to be emitted above the horizontal plane (Center, 2018).

Halogen

These bulbs are commonly used in vehicle headlights, as they can run on a low voltage such as a 12-volt car battery. They also have high luminous efficacy. They are cheap to produce and very easy to replace. They are available in a wide range of colour temperatures (Samardzija, 2018).

LED

LEDs are the next milestone in lighting technology, although they have been around for decades. Despite this, LED street lights were only installed in Somerset in 2011. LED street lights have immense potential for our streets, besides their financial benefits. However, it is not all positives, hence there is much controversy on this topic, as discussed on the following page (Clark et al, 2018; Smolensky, Sackett-Lundeen and Portaluppi, 2015).

LEDs come in many shapes, sizes, colours and wattages. LEDs are the future of lighting, for the following reasons:

- Highly efficient: Resulting in potential energy savings of over 50% when compared with HPS
- Long-lasting: Some LED luminaires are rated at over 50,000 hours till they reach their L70
- Instant-on: LEDs do not have a warm-up time, they operate at full brightness from the moment they are turned on. HPS lights can take up to 4 minutes to reach operating temperature. LEDs can be rapidly turned on and off without damage to components, which allows for dimming via PWM (Bltdirect.com, 2018; Analog.com, 2019)
- Directional: The light emitted from an LED is directional and can be very easily focussed with correct optics. Most other light sources emit light in all directions, often resulting in unwanted sky glow

- CRI: As LEDs come in all possible colours, it is possible to manufacture an LED that emits any visible colour temperature desirable. This has enabled the development of very high-value CRI LEDs. A higher CRI value means that objects can be seen with more clarity. In the case of street lighting this is highly beneficial as it aids drivers being able to spot hazards and read signs. Sodium lights have a much lower CRI value due to the lower colour temperature light that they emit (Lightingassociates.org, 2018; Staff, S. 2018)

LEDs, however, do have their drawbacks:

- Blue light: a 5000K white LED will, of course, emit more blue light than a HPS light of 2200K. The benefit, however, is the resulting CRI value. A solution to this is to simply choose a lower colour temperature white LED
- Heat: Some high power LEDs can reach very high temperatures. Incorrect designing of heat sinks and cable gauge can result in premature failure. This not only applies to LEDs, as most light sources can suffer from the same issue
- Binning: Some manufacturers may poorly categorise their LEDs. Brightness is a relatively easy thing to measure. Colour temperature is not. Depending on the manufacturer, what the LED says on the box might not always be the case. It is also possible for LEDs to change colour over time due to delamination or other manufacturing defects (Edaphic.com.au, 2018) (Ledbenchmark.com, 2018) (Street Lighting Retrofit Projects, 2018)

3.4 LEDs in depth

White light is a very broad term and is often specified by colour temperature. White lights will vary in colour temperature and create different effects, they are all suited for different applications. Figure 1 shows the way varying colour temperatures create different hues of white light. It also shows the colour temperatures emitted from different light sources. Figure 1 also shows direct sunlight has a colour temperature of 4,800K. Sunlight does not have a fixed colour temperature. Any colour temperature higher than that value results in white light with a blue tint. Below that value results in white light with a yellow tint. Figure 14 shows more accurate values of sunlight.

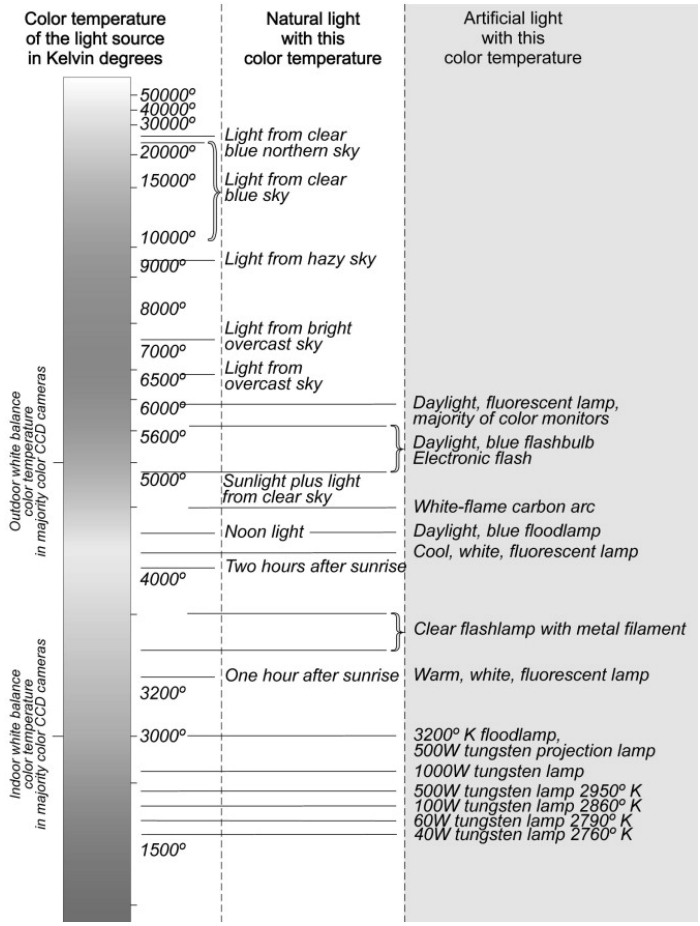


Figure 14. (Colour temperature of various light sources, 2019)

LEDs are manufactured with a phosphor coating to produce white light. It is difficult to create a uniform coating unless this is thin. The thinner it is, the higher the colour temperature. It is for these reasons that LEDs of a higher colour temperature are more commonly installed. LEDs of lower colour temperatures can result in uneven colour distribution. In a line of LEDs, this can create what is known as a pool of light, which can result in undesirable glare effects. Glare can be dangerous by obscuring the vision of a driver, potentially resulting in an accident (Liu et al., 2018; Southall, 2017). It has also been found that improved street lighting reduces crime (Library.college.police.uk, 2018). The majority of crime occurs in public areas between 18:00 and midnight. Darkness creates insecurity as it reduces visibility and recognition at a distance. Often street lighting is inadequate; in some circumstances, it is obscured by trees or shrubbery. Increased street lighting has been proven to reduce crime, fear of physical attack, make people feel safer and increase usage of the streets during the evening. Increased street lighting has helped to make elderly people feel safer, meaning they are more confident when walking in the evening (Painter, 1996).

With increased street lighting there are more people out when it is dark, and people tend to feel safer when there are others around them. If something were to occur, there is a higher chance of

someone being there to help. Some argue that increased CCTV makes them feel like they live in a 'Big Brother' society. Increased street lighting is a good method of increasing public safety without inducing the 'Big Brother' thought (Library.college.police.uk, 2018). However, the implementation of additional street lighting, especially that of a higher colour temperature, involves the emission of more blue wavelengths. Blue light has been proven to trigger the circadian photoreceptor in eyes, which in turn stimulates the brain. This is beneficial in the morning and can replicate a coffee-like stimulating effect, however, at night it is harmful and can reduce our sleep quality and delay our sleep cycle (Farrimond, 2018).

White light has been proven to be the most beneficial in terms of obstacle perception, security and driver reaction time as opposed to yellow sodium lamps. Using a blue LED with a YAG phosphor is one of the most efficient methods of creating white light. Other methods include RGB LEDs or the combination of blue and yellow LEDs (Nuttall, Shuttleworth and Routledge, n.d.). It is key that the light produced from street lights gives drivers the shortest reaction time possible to decrease the risk of an accident.

3.5 Colour temperature

Most LEDs are manufactured in Asia (see Figure 15), where LED lights of a much higher colour temperature are used. Colour temperature can be defined as the surface temperature of an ideal black body emitting such a light (Kapogiannatou et al., 2016). A 3,000K LED used in Beijing would make the scenery appear dirty due to a large contrast in colours, however, the same light used in London would create quite a fitting hue due to the complimentary sky colour and surroundings of stone buildings and greenery. A 6,000K LED light would look aesthetically appropriate in a city like Beijing, yet in London would not look natural as it would create undesirable aesthetics against the traditional listed buildings of the city (Southall, 2017).

Numerous lighting standards have suggested that high colour temperatures should not be used at low illuminances. Using a high colour temperature at low intensity can appear cold and dim. Using a low colour temperature at high intensity can appear overly colourful & unnatural. Finding the equilibrium between colour temperature & illuminance results in a pleasant lighting effect (Boyce and Cuttle, 1990).

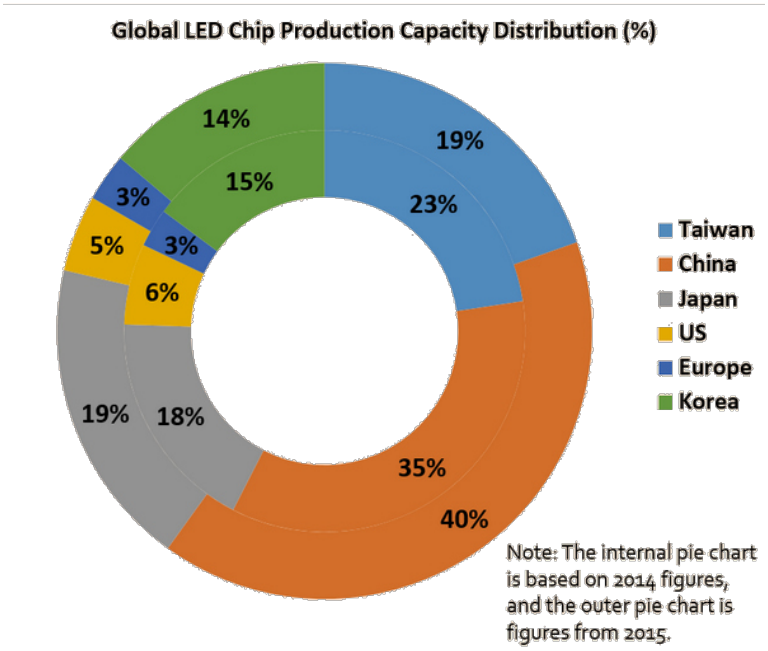


Figure 15. Global LED Chip Production Capacity Distribution (LED Inside, 2016)

Improved street lighting can decrease crime by deterring criminals due to the fact it is easier to identify them. Darkness creates insecurity, as it reduces visibility and recognition at a distance. On the other hand, over lighting creates shadows and can obscure vision, which may help criminals. The correct colour temperature can significantly change the sense of safety and security in areas such as a park. The right colour temperature can make it easier to identify faces and can eliminate indistinguishable dark areas (Painter, 1996).

The study 'Research on the lighting performance of LED street lights with different color temperatures' by Huaizhou et al. (2015) has shown that when white light is of colour temperature 3007K, colour discrimination accuracy is near 100% (Huaizhou et al., 2015).

A problem with current LPS lights is that, due to the significantly low colour temperatures, our eyes can find it difficult to pick up contrast, thereby, delaying our reaction to danger and creating a slight sense of insecurity.

Light of 3000K is the perfect equilibrium and has good dark adaptation time, colour discrimination capabilities and high luminous efficacy, making it ideal for road lighting. There are many factors

other than colour temperature to be considered when installing street lights. Such as height, pedestrian and motorist usage, wildlife, residents nearby and even astronomy (Huaizhou et al., 2018).

3.6 Reaction times and weather

Road crashes are the main cause of death for young people in the world (Aodha, 2018). The risk of a fatal crash is increased up to four times when driving at night (BACtrack, 2018). There is evidence to show a high number of these night time crashes are primarily due to visual problems associated with low luminance conditions leading to delayed reactions times. This suggests that, had the appropriate lighting been implemented in these locations, some of these crashes may not have occurred (Konstantopoulos, Chapman and Crundall, 2009).

It has been proven that reaction times are shorter with white light of a higher colour temperature than that of a yellow sodium lamp. This reinforces the previous point made on how crucial it is to have a street light emitting the correct colour temperature as a delayed reaction time could result in an increased accident rate (Dong et al., 2017).

Visibility is hugely affected by the weather. Crash rates in rain are increased up to 71%. This is due to a combination of decreased visibility and traction, which in turn increases braking distance. When driving a car in rainy conditions, once the wipers have cleaned the windscreen, new raindrops may affect the visual search pattern of some drivers, briefly altering their hazard perception (Konstantopoulos, Chapman and Crundall, 2009).

In the UK, there is a wide variety of weather conditions. Fog is defined as visibility less than 1000m on a horizontal plane (Ding and Liu, 2013). In general yellow light has better fog penetration than white light. Lower colour temperature LED lights (1870K) close to HPS lights (1954K) have the best fog penetration capability, which is essential for the large range of weather conditions in the UK. As colour temperature increases, fog penetration decreases. Hence, LED street lights with a blue tint have considerably less fog penetration than that of current yellow Sodium street lights (Huaizhou et al., 2018).

Age is also a key factor. Elderly drivers have longer reaction times than others; this results in a longer braking distance and delayed reaction to a hazard. 'At 450 nm the transmittance of the lens of 60 – 69-year-old adults is half that of 20 - 29-year-old adults. At 425 nm it is one third. At 555 nm it is only a few percent less while it is equal at 600 nm and above (Falchi et al., 2011). The percentage of elderly drivers is increasing with time due to people living longer (Cracknell, 2018).

New LED street lights are a problem for elderly drivers. Eye lenses decrease blue light transparency with age. Of course, visibility of an elderly person will not be of the same clarity as that of a young adult, however, the visibility of blue light, in particular, will be poor. This means that in an area of new LED street lights with a colour temperature above 4000K, elderly people will have an even longer reaction time than normal. People aged 60-69 see half as much 450nm wavelength light (blue light) than people aged 20-29, however, the amount of light elderly people and young people see, is equal at 600nm and above (orange and red light). Therefore, it would be beneficial for elderly drivers if new street lighting installations had a lower colour temperature between 2000K and 3000K, similar to that of traditional sodium lights (Falchi et al., 2011).

3.7 Well-being and pollution

A major concern of the new LED street lights is their effect on our well-being and circadian rhythm. Well-being and light pollution share negative correlation.

Light pollution consists of four components:

- Urban sky glow — The artificial brightening of the night sky
- Light trespass — Light overflowing where it is not needed or intended
- Glare — Light causing visual discomfort; resulting in decreased visibility
- Clutter — Excessive groupings of light sources

(Darkskiesawareness.org, 2018)

The following quote from a Campaign for Dark Skies local officer summarises how far the human race and technology has developed, yet how much we continue to damage and abuse our environment.

A sad paradox of modern life is the fact that our telescopes can offer stunning images of the near and far universe, and at the same time our lighting technology, if inadequately designed and installed, can steal our view of the stars above.

Bill Eaves, CfDS local officer (Eaves, 2018)

The Bortle scale was published in February 2001 (Bortle, 2001). It was created to help amateur astronomers. It is a 9-level numeric scale that measures the night sky's and star's brightness in a particular location, It can be used to determine the light pollution of a specific location. Light pollution comes from numerous sources, other than street lighting, for example: sports facilities, business and office buildings. The sky glow of Los Angeles is visible from 200 miles away. There was an evening when the power went out in Los Angeles, so many saw the Milky Way for the first time ever and reported a giant silvery cloud which would otherwise be obscured by light pollution. Sky glow is the result of light pollution being scattered by water droplets or particles in the air (Chepesiuk, 2009).

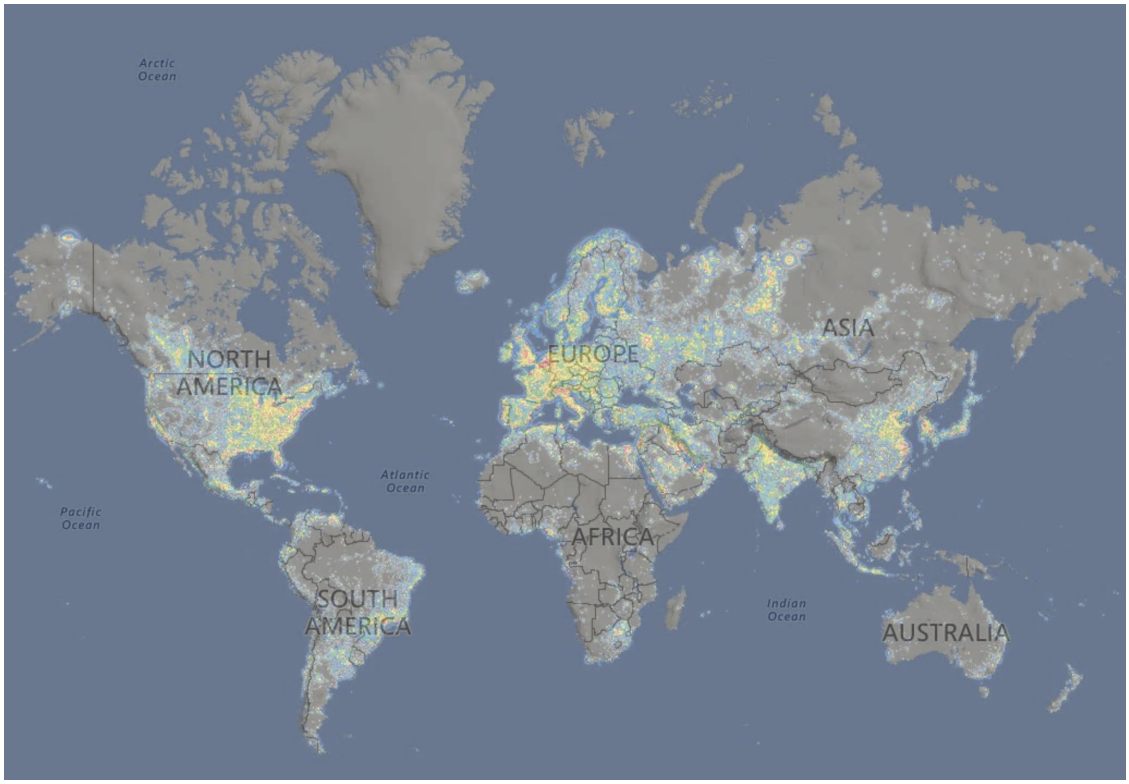


Figure 16. Global light pollution (Lightpollutionmap.info, 2018)

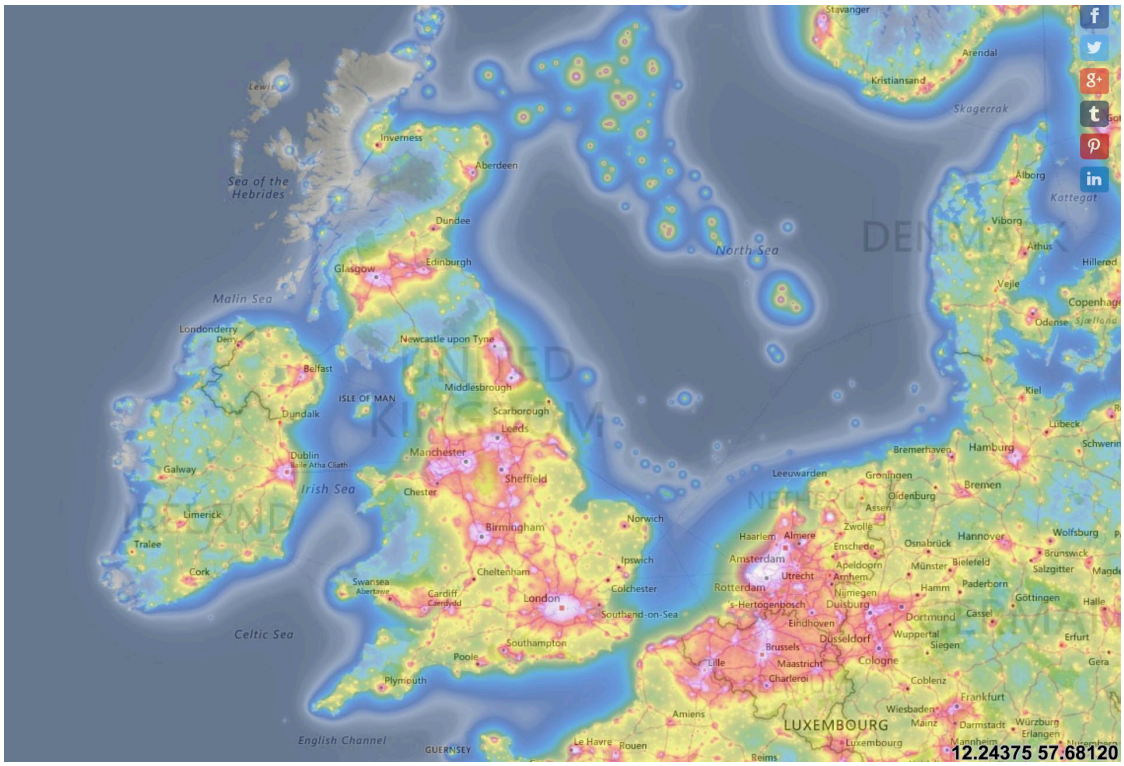


Figure 17. UK light pollution (Lightpollutionmap.info, 2018)

Figures 16 and 17 display light pollution. The red shows high and the blue shows low levels of light pollution. Europe and North America are the biggest culprits when it comes to light pollution. Despite Asia having several upcoming cities growing at exponential rates, it seems that they are taking into consideration the problem of light pollution when implementing new street lighting fixtures. The United Kingdom, despite several British Standards and lighting guidelines, is a significant participant in contributing to light pollution. It is clear to see that the majority of light pollution comes from city centres.

This is specifically coming from lights used for aesthetics and the advertising of premises open in the evenings such as bars, pubs and hotels. The lights are used in the hope of attracting customers and making more financial turnover. It seems that these businesses have overlooked the devastating effect they are having on the environment that surrounds them. The lights will only be reduced or eliminated if a formal complaint is written to the council and even then it may not comply as a statutory nuisance, meaning the council might disregard the complaint (Chepesiuk, 2009; Gov.uk, 2018).

There is light pollution coming from the middle of some oceans. This is from gas and oil platforms. Unfortunately, this will have very diverse effects on the surrounding wildlife both in the sky and in the sea (Kuestenmacher, 2018). Light pollution is a serious problem with implications for wildlife, human health, scientific research, energy consumption, global warming & astronomy (Gallaway, Olsen and Mitchell, 2010). A large amount of night lighting is purely aesthetic and this needs to be eliminated, though there is nothing to enforce this. The majority of what is built is illuminated at night. There are British Standard rules and regulations on street lighting, however, they are not strictly enforced and they are outdated by today's technology.

Lombardia (North Italy) is an example of managed light pollution. Over the course of 12 years of development and growth in Lombardia, the amount of external lighting has doubled across two sites. Yet due to strict rules and regulations, the artificial sky brightness of those areas has not changed over the last 12 years (Falchi et al, 2011). Only part of the total light pollution emitted originates from road lighting. However, for the sake of our planet, it is crucial that light pollution is taken seriously and adjusted to minimise the impact on the environment.

Councils are replacing older street lights with LED street lights as they have many benefits, with the main one being cheaper running costs. Of the UK's 7.4 million street lights, 2.32 million are scheduled to be replaced as they are well past their 25-year design life. They use less energy and require far less maintenance. However, if all the HPS lamps changed to metal halide or LED then the sky brightness would increase 2.5 – 5 times its current state. This is due to the fact these

technologies are more efficient and typically have a higher lumen output. The International Dark Sky Association recommends that no light is emitted above any light fixture, only level and below (Artificial Light in the Environment, 2009; Chepesiuk, 2009). It is key that any new installations are carefully planned and designed to ensure that they create the least amount of light pollution possible.

We need artificial light to carry on living our modern lifestyles by extending our working and leisure hours. However, we can all carry on our lifestyles, but decrease light pollution by:

- Implementing shields on light fixtures to prevent upward lighting
- Not using brighter lights than required
- Focussing illumination to the required area only
- Only switching on lights when required

(Falchi et al., 2011)

In 2017, Green Lane (Northwood) in London was illuminated by LPS street lights which emitted considerable light pollution. These lights have now been retrofitted to LED lights which have increased the visibility of the road, decreased light trespass and increased the safety of pedestrians. This has also eliminated the light trespass that used to flood through windows at night time.

3.8 Private land

On private land, landlords do not have any enforced guidelines to follow when installing external lighting. Often, they will go for a cheap, high luminosity flood lamp with emission above the horizontal plane to maximise output (Walter et al., 2011). This, of course, contributes significantly to sky glow and light trespass. For UK residents, there is some content regarding this on www.gov.uk/guidance/light-pollution, however, no specifics such as luminous flux or colour temperature are discussed. It is simply a matter of submitting a complaint and convincing the council that it is serious enough to be considered.

For the light to be a statutory nuisance it must:

- Substantially interfere with the use or enjoyment of a home or other premises
- Injure health or be likely to injure health

If it is found that a statutory nuisance is occurring, the council will serve a notice, whoever is responsible must stop or restrict the light. The notice will usually be served on the person responsible but can also be served on the owner or occupier of the premises (Gov.uk, 2018).

Searchlights, sometimes known as 20th Century Fox lights, were initially used for military purposes. They are now used for festivals, advertising and other non-military purposes. These lights shine so far that occasionally they are mistaken for UFOs. These searchlights can be purchased online by anyone and easily mounted and powered. Anyone can buy them, as no license is required to use or purchase such products. Once the lights are in operation a resident could complain in person or via the council with regards to the light pollution (Entertainment Effects, 2018). Other than a statutory nuisance, there is no legislation against private landowners mis-using powerful lights. Currently if a neighbour does not report it, then, unfortunately, the light pollution can continue, without the offender knowledgeable of the harm they are causing (Aa.quae.nl, 2018; Emftechnology.co.uk, 2018).

3.9 Benefits of light

3.9.1 Infrared

Light has numerous pros and cons even when it is at the extremes of the spectrum, such as infrared. Infrared light therapy is able to have very positive effects on your body, and it is now being used by doctors to treat numerous health conditions. It is a non-invasive treatment that can potentially fight cancer. It has already proved successful after eliminating cancer cells in mice (Organic Newsroom, 2018).

Infrared technology is also used in thermal imaging cameras and remote control devices. It used to be used for wireless data transfer but was quickly overtaken by the capability of Bluetooth.

3.9.2 Sunlight

Our bodies create Vitamin D from sunlight. We also consume it in several foods. We need Vitamin D for healthy teeth, bones & muscles (Nhs.uk, 2018; Hosie, 2018).

3.9.3 Blue light

Blue light has been proven to delay sleepiness and increase alertness. This can be advantageous to those trying to maximise their work efficiency (Breus, 2018; Jabr, 2018). White light of a colour temperature above 3000K has an increasing amount of blue light.

3.9.4 LiFi

Internet connections can now be streamed through flashing light, faster than our eyes can see. This allows communication of devices faster and more secure than previously (Zhou et al., 2018). This provides the opportunity to host the Internet from our street lighting network.

3.9.5 UV

There are three categories of UV light, all of which can be detrimental to our health:

- UVA

  Premature ageing, wrinkling of the skin, implicated in skin cancer

- UVB

  Skin cancer, cataracts, sunburn

- UVC

  Extremely dangerous, blocked by the ozone layer

(Wright and Weller, 2015)

Nonetheless, UV light does have its benefits. It can be used for sterilisation of surgical equipment and water to eliminate bacteria. It is used in tanning salons in sunbeds. It is used to speed up the process of drying paint. Insects are attracted to it, so it is used in fly killers. Security and POS will often have UV lights to check for forged notes or forms of identification (LightTechLightSources, 2018; Darvill.clara.net, 2018).

3.10 f.lux and sleep

Our body clock, also known as the circadian clock, is kept in sync by light. Exposure to light around sunset will delay the activity of a nocturnal animal and delay the inactivity of a diurnal animal (such as humans). Light exposure has numerous negative effects on our well-being. It induces suppression of melatonin, which also affects blind people. Light induces change in gene expression. High-frequency blue light can modify brain responses to completing a task (Dijk and Archer, 2009).

Software has been released called f.lux which tints your screen towards amber in the evenings, thus removing blue wavelengths. The concept has proved successful and Apple has now latched on to the idea and implemented ‘Night Shift’ in their new firmware update on both computers and mobile devices (Elliott, 2018).

A study was carried out which involved patients using amber-tinted glasses for three hours before going to bed. The theory behind this is that they remove the blue from the spectrum which prevents the circadian photoreceptor from being fired, thus preventing the sleep onset insomnia often caused by our screen-based devices which flood us with blue light. The results were:

- Improved sleep and mood with Bipolar patients
- Preserved melatonin levels even in a fully lit lab overnight
- Red tinted lenses that block wavelengths <600nm were found to decrease migraine pains within minutes

(Burkhart and Phelps, 2009)

LAN decreases pineal MLT production & secretion. Low MLT levels in the blood may encourage growth of some type of cancers. Of course, only a fraction of this is due to light pollution. Numerous people have bad habits such as using their phones or laptops late at night. There is a strong correlation between health problems such as breast cancer and high exposure to artificial light at night time (Chepesiuk, 2009). The public exposes themselves to all of the above risks on a daily basis. Before going to sleep many of us are exposed to screens, road lighting and other sources of artificial light that may be high in blue emission.

3.9 SAD

SAD (Seasonal Affective Disorder) is sometimes known as winter depression. In Ireland, it affects one in fifteen people between September and April (Mental Health Foundation, 2018). SAD is linked to reduced sunlight exposure. This disorder can affect the performance of the hypothalamus in the brain, possibly affecting the:

- Production of melatonin: Hormone that makes you sleepy
- Production of serotonin: Hormone that affects your mood, appetite and sleep
- Circadian rhythm: Your body clock

Studies show that the circadian rhythm controls 10% - 15% of our genes. Therefore, disruption of the circadian rhythm can cause numerous health issues. This is a good example of how important natural light is to our well-being.

(Chepesiuk, 2009; nhs.uk, 2018)

3.10 Wildlife

Artificial light creating a negative effect on one species can result in an advantage for the competitors or prey of that species. Migratory fish, birds and turtles are disoriented by artificial night light. Several newly hatched turtles never make it into the sea, but end up in streets where they are at risk. Each year just in New York City 10,000 migratory birds are injured or killed crashing into skyscrapers as they are distracted by light (Musters, Snelder and Vos, 2018; Chepesiuk, 2009; Hölker et al., 2010). Almost all bats are nocturnal. This means that they are ideal subjects for testing light pollution. When new lighting has been implemented it has been observed that bats will take an alternative route (Stone, Jones and Harris, 2009).

It is well known that artificial light attracts insects. A study has proven houses closer to road light were 1.64 times more likely to be infested with the blood-sucking insect Triatoma Dimidiat than those not close to road light. The Triatoma Dimidiat is one of the main reasons the Chagas disease is spread throughout South America. The insects are most attracted to blue light, therefore the implementation of any new high colour temperature LED lights could cause undesirable effects on the health of the population (Pacheco-Tucuch et al., 2012). Many insects have been observed to congregate around artificial light sources until they die of exhaustion. This can have consequent effects on the food chain (Hölker et al., 2010).

For centuries, fishermen have used lanterns to attract fish to their nets, however, light pollution penetrates deep into ocean environments. Many organisms in the sea rely on optic orientation, artificial light interferes with this. Most inhabitants of the deep ocean have extremely sensitive visual systems which are completely thrown off by light pollution (Depledge, Godard-Codding and Bowen, 2010) (Artificial Light in the Environment, 2009).

The technological development of the human race should take inspiration from nature and think more about the environment and the consequences of our actions. As shown in the examples above, the well-being of certain forms of wildlife is sacrificed for the benefit of the human race. Holiday destinations such as Greece and India rely heavily on their local wildlife for tourism. If the wildlife continues to be treated in this way then it will not be there for much longer. It is for reasons such as this that a new set of regulations must be enforced, as well as a better method of navigating through them.

3.11 Financial aspect

There are many pros and cons to recent developments in street lighting, as previously discussed. The advantages far exceed the disadvantages, with the largest being the financial aspect. Updating regular street lights (typically sodium) to LED can reduce energy usage by 50%, this reduction has the potential to change to 80% with the implementation of smart lighting with a CMS.

Street lighting is a crucial part of our towns and cities, yet it relies on technology that originates from 1960. Street lighting consumes approximately 40% of a city's electricity. Cities are keen to change from traditional street lights to LED as the systems will pay for themselves through reduced energy usage over a period of 5 - 10 years. £300 million per year is spent on electricity for street lights in the UK. The Green Investment Bank predicts that with LED street lights there is a potential saving of £200 million per year (Griffiths, 2017). 'Any lighting scheme should be affordable over the whole of its life cycle and a scheme is only affordable if its benefits outweigh the costs' (Franks et al., 2016).

Birmingham City Council has invested £70 million on Philips & Indal LED street lights across the city. This is currently the biggest single installation in Europe of its kind; it is expected to half the energy usage. The Birmingham highway team have calculated an annual saving of two million pounds (Kenber et al., 2019).

Improved street lighting reduces crime, resulting in:

- Fewer thefts
- Fewer properties requiring repair (from break-ins)
- Fewer insurance claims
- Less impact upon victims (people may take days off to deal with an incident)

(Library.college.police.uk, 2018)

3.12 Street lighting market and technology

Since street lighting has such large financial savings surrounding it, the product market is growing in response. Street lighting is a sector of the market which has huge potential. There is potential for modern-day street lights to operate as multi-purpose nodes; not only to illuminate our streets but also to monitor crime, parking, weather and much more. A well-structured city with smart street lighting and sensors could collect lots of data such as air quality, ambient light levels, temperature, motion, pressure, humidity, noise, radiation, precipitation and wind. This may become the norm in smart cities of the future. Parking could be live monitored, this data could be sent to car computers, smartphones and displayed digitally along with the price and size of the parking space. Parking offences could be detected by cameras integrated into the street lights, eliminating the need for parking wardens.

Light and Charge is a new project that BMW is trying to implement. It simply uses power from a street light to charge an electric vehicle such as the i3 or i8. This will eliminate the current hunt for charging stations that EV owners may endure at present. Light and Charge is already in practice, a few years ago EVs did not seem to have much potential, using the technology concept from a milk float was not well respected. However, today there are several practical and efficient EVs available from a choice of manufacturers including: Audi, BMW, Kia, Mercedes, Mitsubishi, Nissan, Porsche, Renault, Tesla and many more (Griffiths, 2017; Rolecserv.com, 2018; DeMattia, 2018). In China, the majority of bicycles and scooters are electric, many of these are retrofit applications. Traffic flow (intensity and speed) could be monitored through street lights via infrared sensors. This data could then be fed to navigation apps such as Google Maps and Waze. This could benefit motorists by offering routes with less congestion, helping them reach their destination in less time (Griffiths, 2017).

With a new cloud-based control system, diagnosis information could be sent periodically, alerting a control station of any necessary maintenance or faults that need attention. Traditional street lights would often suffer from LDD, this is where dirt accumulates on the twilight sensors which results in the lights staying on longer hours than intended (Rossi, Gaetani and Defina, 2016). Not only is this a waste of energy, but also an unnecessary contribution to our mass problem of light pollution. Gemma lighting (UK LED lighting manufacturer) offers numerous LED sodium replacements. They also offer LED bollards and globes which blend in with current street furniture, which is ideal in locations where a modern appearance would be undesirable. Most of these modern LED lights are very well designed and minimise upwards glare by restricting light emission above the horizontal, hence they keep light pollution to a minimum (Gemmalighting.com, 2018; Griffiths, 2017).

Smart lighting could dim after midnight when sensors have detected an absence of traffic, and could instantly re-illuminate when one of these sensors are triggered in enough time so it is effective for the user. There are several companies such as Silver Spring Networks, Telensa, Echelon and Philips that provide IoT services suitable for the smart street lighting solutions discussed. Many are already installed and being put to great use (Griffiths, 2017).

Recent news has shown increased public awareness about carbon footprints and energy conservation. Saving energy at home often means implementing expensive new products such as a more efficient fridge or boiler. Homeowners can apply for energy grants which can help with their fuel bills, help in making their homes more energy-efficient and installing a new boiler or thermal insulation (Gov.uk, 2018; Which?, 2018). Several banks are offering green loans which give individuals the opportunity to update and improve their infrastructure with money they do not have, on an interest rate that is lower than a typical loan. The cost of the loan is never greater than the cost of the energy saved. These loans can be used to finance the cost of upgrading to a more efficient LED lighting plan (Financer.com US, 2018).

3.13 Literature review summary

This literature review has increased awareness of how widely spread the issue of artificial light is. It affects species from all over the world, both in the sea and on land. Artificial light affects our environment, sleep and even our hormones. For the way our lives have evolved recently there is no shying away from the fact that we require artificial light at night. With so many different available technologies it raises the question: which light is most suitable?

Lights vary in brightness (lux), colour temperature (K), Colour Rendering Index and luminous efficacy. Different sources of light technology all have their pros and cons depending on their application. This thesis specifically focuses on street lighting in the United Kingdom. This narrows down the field, however, this is still a huge sector to analyse with so many variables such as pedestrian, cyclist and motorist usage, speed limits, residents, wildlife, hills, junctions and bends in the road.

It is obvious that white LED street lighting is the future. However, with that comes numerous questions.

- What colour temperature is best?
- What height is the most suitable?
- Should they be dimmed after midnight?

Blue light has become an ever-increasingly discussed topic. So much so, that the likes of Apple have even implemented a function to reduce blue light emission from their screens. The public is now aware that blue light is hazardous for their health. Therefore, in a residential area it is key to keep blue light to a minimum (Elliott, 2018).

The other side of the coin is that blue light has a shorter wavelength with a higher frequency which stimulates us far more than typical warm, white light. This results in faster reaction times, which is key for driving at night, when visibility may be reduced. By using light of a higher colour temperature towards 4,500K it is easier to recognise faces, thereby increasing security and preventing crime (Dong et al., 2017).

It is important to find the right balance of colour temperature. Not only for the safety and comfort of our streets but also to do the least amount of harm to the surrounding wildlife. The detrimental effects of light pollution influence more than just wildlife, it also disturbs astronomy, the food chain and more.

In non-residential areas such as carriageways and motorways (of a higher speed limit), 3000K white LED light should be installed as research has proven it decreases motor accidents. 3000K light is not too high a colour temperature that it will do significant harm to the surroundings, provided there are necessary measures installed to reduce light spill such as shades and baffles (Huaizhou et al., 2015). Highways England can confirm that road lighting reduces night-time accidents on motorways and dual carriageways by 10%. (Franks et al., 2016).

Light pollution can also be reduced by careful light planning before any of the infrastructure is implemented on a new road, this way the lights can be installed at heights and intervals that maximise road safety and visibility whilst minimising light pollution into the night sky. Careful planning is essential to take into consideration the need for extra lighting at potential hazards such as crests of hills, width restrictions and junctions.

In residential areas, the main uproar is regarding light trespass into people's properties which can be classed as a statutory nuisance. If reported to the council, they must take action and resolve the issue. Others may argue that the person reporting the claim should simply install blackout curtains (Gov.uk, 2018). In a residential area the speed limit is typically 30 mph. This means that the same amount of light for motorists is not as necessary as a motorway where the speed limit is 70 mph. However, motorways have continuous straight roads whereas a residential road will have: width restrictions, speed bumps, junctions, roundabouts and other things that require fast reactions. Motorists can still react in time and observe obstacles in light of a lower colour temperature than 3000K as they have done so for many years in the presence of LPS yellow street lighting. If these lights were to be replaced by LEDs it is only logical that light of a similar colour temperature is used (Huaizhou et al., 2015). This would take full advantage of all the LED benefits such as less energy usage and bulb replacement, whilst still maintaining the benefit of yellow LPS lights which is, the lower colour temperature having less blue spectra emission, resulting in a reduced effect on wildlife and our own sleep quality.

If this LED implementation were to occur, it would only make sense to install appropriate shades and baffles, to minimise light spill into unwanted areas such as homes. By doing this we could also be setting a foundation for preparing our streets for the next generation of technology.

Lighting engineers can now use software to simulate different mounting heights and the consequent effects of doing so (Roco, 2016). From a light pollution perspective, a lower mounting height is preferred as this reduces unwanted light trespass.

From a practical and urban planning perspective a higher height is preferred as it reduces the number of installations as the light is more dispersed (Artificial Light in the Environment, 2009) (BS 5489-1:2013, 2012).

Light should be dimmed to a lower illuminance level when possible, not only to save energy but also to reduce light pollution levels.

4. Analysis of literature findings

4.1 Introduction

The future of street lighting has much potential and will be host to a whole field of technology. There are numerous smart systems on the market and conceptual videos of how they will better our world. The following text will highlight the key points that must be taken into consideration when building the roads of the future.

4.2 Recycling guidelines

Some of the standards have very detailed explanations and specifics. They have been revised several times and are very useful documents. There are some points mentioned which are far more important than others although no hierarchy of importance is given within the documents. Specific points that must be enforced are as follow.

4.2.1 Illuminance

Street lighting should not just illuminate the road. Street lighting should also illuminate any potential hazard which may not be on the road at the time, for example, a fox crossing the road. It is also necessary to illuminate the pavements to make pedestrians feel safe. One thing that makes pedestrians feel vulnerable is shadows created by objects. Pavements are frequently over lit. This means the lighting could be dimmed or redirected. Over-lit pavements can result in greater contrast between bright and dark. Consequently, pedestrians may have poor recognition abilities, which could aid criminal activity. Luminance depends on the road surface and what aggregates it consists of. Road surfaces vary greatly and change over time with traffic polishing and weathering. When street lighting installations are in their development phase, it is key that the reflectiveness of the road surface and pavement are taken into consideration. Incorrect planning due to unknown reflectivity can lead to under or over lighting, possibly leading to unwanted light pollution and glare (Völker, Steblau and Buschmann, 2017).

As previously discussed the reflectiveness of a road and pavement will change over time. As a result, adjustments might be necessary after some use. New smart LED lighting systems provide the opportunity to remotely decrease the maximum light output of a single luminaire or a group. The traditional method of measuring reflectiveness of a road surface is to drill out a core and examine it in a laboratory. This is no longer necessary with the development of Gonioreflectometers such as Memphis and Coluroute (Figure 18).

Figure 18. The Coluroute device to measure reflectivity of road surface

(The Coluroute Device, 2009)

4.2.2 Spread

During the development phase of a street lighting installation, the spread of light must be considered. This is determined by a series of interlinked factors such as:

- Luminaire illuminance
- Luminaire spread
- Height of the luminaire
- Installation plan (staggered or symmetrical)
- The frequency of installation
- Obscuring elements, such as trees or road signs

(BS 5489-1:2013, 2012)

4.2.3 Light classification

The lighting specifics given in the current guidelines are vague. The range of lumens and colour temperature should be specified depending on the application. For example, in a residential area (30mph) where light trespass into people's properties is possible, the colour temperature should be no higher than 2000K. All new street lights should use LED technology, whether that be SMD or COB. The lumen output of a single luminaire would determine how many are required for a set area, which would also be influenced by their mounting height (Falchi et al., 2011).

4.2.4 CRI and colour temperature

It is necessary to have light of a high CRI. LEDs should not be installed with a CRI lower than 80. This is so that motorists and pedestrians can clearly distinguish objects in front of them and view hazards and signs.

In residential areas, a lower colour temperature LED is more desirable. A consequent effect of choosing a lower colour temperature LED is that the CRI will also drop.

Ideally, all lights should be 3000K as research has shown this is a good equilibrium and provides drivers with clear vision, giving them sufficient reaction times. This is particularly crucial on highways and motorways where speed limits can be up to 70 mph.

Light of a higher colour temperature has several drawbacks, such as:

- Poor fog penetration
- Poor colour perception and dark adaptation time for the human eye
- Producing strong sky glow pollution

In residential areas where the speed limit is 30mph and below, a colour temperature of 2000K should be enforced. This still gives drivers enough clarity to react in time, however, it removes some blue wavelengths from the visible emitted light, resulting in fewer negative effects, which is more of a concern in a residential area (Falchi et al., 2011). Reaction times are less of a concern as the speed limit is less than half of what it would be on a motorway. In addition to this the developed HID Bi-Xenon projectors now utilised in cars allow drivers to comfortably drive on roads where street lights are not present at all. Headlight range is being pushed further with LED headlights and the new development of white laser headlights. Some high-end cars such as Bentley, Mercedes, BMW and Audi even feature night vision. This allows the motorist to see further than your eye would be able to. It is feasible that with the development of technology this will be implemented in more commonly used vehicles in the near future (Howard, 2018).

4.2.5 Maintenance

No matter how smart our future street lights may be, they will always at some point require maintenance. Smart street lights could have integrated IoT systems to report any errors much like a check engine light (Smart City: Street light energy saving ideas, 2015; Rossi, Gaetani and Defina, 2016; Griffiths, 2017). This will result in a central management system sending out an engineer after receiving a report from the specific street light. However, there are only so many things that software can detect, hence routine inspections should still occur. Alternatively, a clear system for

the public to report errors could eliminate or reduce the need for inspections. Typically luminaires would be cleaned at the time of bulb replacement. New LED lights, however, have a life of many years. With a longer service interval, dirt will have more time to build up. This means that LDD is more likely to be an issue than previously. This issue could be solved with the use of a self-cleaning Ritec coating used on the lens (Non-Stick Glass Protection | Ritec International Limited | London, 2018).

Most street lights in the London borough of Islington each have their own plaque with a phone number and street light number. This allows pedestrians to report a faulty luminaire. Street lights must adhere to a maintenance program. This is to ensure their LDD is kept to a minimum. Engineers must inspect luminaires for things such as dirt accumulation and moisture ingress (Griffiths, 2017).

4.2.6 Positioning

The positioning of light columns is just as important as the light emitted from them. It is important to see far ahead when driving a vehicle. Sometimes this is not always possible with blind spots, hence the requirement for enhanced lighting on bends. The same applies to the crest of a hill. More often than not, however, when driving at night it is easy to see an oncoming vehicle on a narrow lane by the beam of their headlights and running lights, whether there are street lights present or not.

The pattern of street lighting for a residential road usually alternates sides in an attempt to create an even distribution of light. On a dual carriageway and motorway, sometimes the layout is symmetrical due to the width of each side. The street lights are set at specific intervals which may increase in frequency as a junction or bend approaches.

The typical height of a street column is 6m. In circumstances where light pollution is less of a concern such as a motorway, this can be higher. The advantage of a higher light is they can be further spaced out, resulting in the need for fewer installations and less running costs. In a residential area it is more desirable to have a lower height of less than 6m. This is to reduce light pollution and make the environment more comfortable and less urban.

Street lights positioned near trees can have several drawbacks:

- The tree's photosynthesis cycle will be disturbed
- The luminaire will accumulate dirt at a faster rate and require servicing more often
- The tree will need trimming more often as it may obscure the light emitted
- 'Continuous and long-term road lighting changes the circadian rhythm and the photoperiod of street trees which initiates some physiological behaviours, of the trees and even causes greater damage to them. Some studies have confirmed that intensity of 1 µmol / (m^2s) is enough to cause damage to plants photosynthetic organs.

(Artificial Light in the Environment, 2009) (BS 5489-1:2013, 2012) (The Safe Distance Between Road Lighting Fixtures and Street Trees, 2019)

4.2.7 Light pollution

Light pollution can be reduced with shades and baffles. A lower mounting height also reduces light pollution. There is not much that can be done regarding the light reflected off surfaces such as wet tarmac. However, reflections off the top of bus shelters could be eliminated with a matt black paint or something similar. The correct lens and focussing can ensure that there is minimal light trespass. New LED lights are more directional as opposed to sodium lights which emit light in all directions, which will aid the fight against upward sky glow.

4.2.8 Columns

The columns on which street lights are mounted have many possible configurations:

- Height: 5m - 15m
- Shape: Tubular, conical, octagonal
- Material: Reinforced concrete, polymer resin, steel
- Safety: Passive and non-passive

On the side of a motorway, barriers are present so any tall non-passive column would be appropriate. Columns tend to be at least 10m for motorway applications. These are mainly steel (BS EN 40-3-1:2013, 2013; BS EN 40-3-2:2013, 2013). For roads which have a speed limit of at least 40 mph with no barriers present on the side of the road, a passive street light could be used to minimise the damage and reduce impact in the event of a collision (Williams et al., 2007).

4.2.9 Weathering & windage

Any external installation will be subject to weather exposure, this includes a variety of temperatures, humidity and UV radiation. With the installations being very tall, some of which are 15m they must be able to withstand the wind and not oscillate in harsh conditions. This will now be easier to achieve as LED lights have a slimmer profile, making them more streamlined.

4.2.10 Road studs

As previously mentioned, vehicle headlights have significantly developed. So much so, that street lights are almost no longer required for vehicles. On roads where there is negligible pedestrian or cyclist usage, road studs should be implemented and street lights should be removed. This should also be done for environmentally sensitive areas and AONB. It is important for us to keep the sky as clear from light pollution as we can. At the same time, we will save our resources and reduce our carbon footprint by not installing and powering street lights in areas that do not require them (Griffiths, 2017).

4.2.11 Advertising

It is important that with any new street light installations minimising light pollution is the main concern. Plenty of hotels, bars and other late-night establishments over-illuminate the front of their premises in the hope of drawing in more business. There are regulations regarding the illumination of shop signage on GOV.UK. It breaks signage down into categories depending on their size and location. The illumination specifications are almost non-existent; for example:

'Advertisements must not exceed 1.55 square metres in area and a reasonable degree of illumination is allowed to enable the information or directions to be read in hours of darkness.'

'Class 4 permits the display of advertisements with either internally illuminated letters or characters on an unilluminated background or lit by 'halo' illumination. An advertisement permitted by Class 4:

- Must not have any intermittent light source, moving feature, animation or exposed cold cathode tubing
- Must not have more than one such fascia panel and one projecting at right angles
- In the case of a shop, illumination may only be displayed on the wall with a shop window
- Must be at least 2.5 metres high at its lowest point
- If a fascia panel, must not extend more than 0.25 of a metre from the wall
- If a projecting sign, must not exceed 0.25 of a metre between the two sides.'

(assets.publishing.service.gov.uk, 2019)

There are no specifics regarding lumen output, light pollution restrictions or colour temperatures. There needs to be stricter enforcement against the emission of sky glow from private enterprises. The MLO states that no up lighting should be allowed unless the building is of historic value and has a jurisdiction, this should be stringently enforced (Walter et al., 2011). Shops and clubs should explore other opportunities for advertising their businesses that do not involve light pollution, for example sponsoring or social media advertisements.

4.3 Planning ahead

Although we are unable to predict the future and analyse what our streets will look like in 20 years time, we can make an educated prediction. This prediction can be based on our growing population, current technologies, and how they might benefit us. The following pages list technologies associated with street lighting in order of importance, the most important first.

4.3.1 Dimming

Traditional street lights based on sodium technology do not take well to frequently being turned on and off, or being dimmed. LEDs, however, are far more suitable for this. On roads where motorists have not passed for a certain time period, the light could be dimmed to a reduced lumen output. In the event that a car, pedestrian or other is approaching, the sensors on nearby street lights could communicate and reactivate the necessary luminaires.

In the event of fog or haze, the lights could be sent a command from the CMS to reduce colour temperature and therefore increase fog penetration. In the event of snow, the lights could be dimmed to reduce unwanted glare which may reduce visibility to motorists.

If all the 5.5 million street lights in the UK were converted to LED, there would be a saving of 770 million kWh and 430,000 tonnes of carbon dioxide, resulting in the government reducing their energy bill by £77 million (Luxreview.com, 2018). Dimming street lights has been put into practice across a 5.5 mile stretch of road in Norway. When there is no traffic, the lights dim to 20% of their full power; when a car, pedestrian or other is detected, the lights instantly reactivate to 100% where necessary (Popular Mechanics, 2018). The Norwegian government has estimated an energy saving of 80% (Autofocus.ca, 2018). Therefore the UK energy saving of £77 million with LED street lighting could be substantially increased further with the implementation of a CMS that controls dimming during off-peak hours.

Dimming has several benefits:

- Road users, whether they are motorists, cyclists or pedestrians, will never see a dimmed light due to advanced planning of the intelligent system (which also measures speed)
- Energy savings due to more dimmed periods as opposed to full brightness periods
- Reduced light pollution
- Extended service life of luminaires and control hardware
- Reduced costs of labour and materials

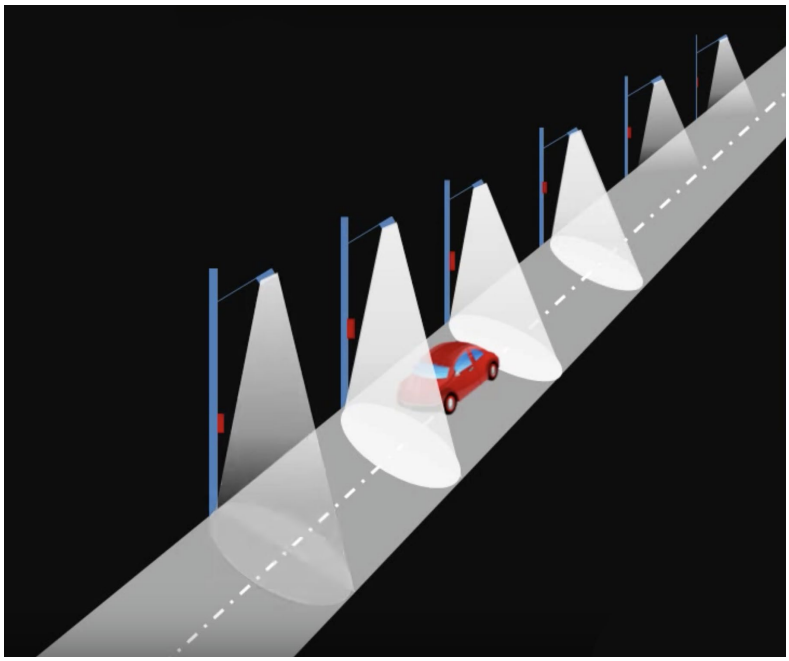


Figure 19. Illustration of dimming street lights

(Smart City: Street light energy saving ideas, 2015

Another possibility is psychological traffic calming measures, by reducing the speed at which the LEDs transfer from one to another. This would need further research before being implemented. One drawback of dimming is that the change in brightness could be disturbing for nearby wildlife and residents. To work around this issue it is key that light spill is kept to a minimum via the installation of shades and baffles.

If the lights increased and decreased in brightness smoothly (as shown in Figure 19), then this would have less impact on wildlife, as it would be less of a surprise. This would delay the process of which the lights turn to full brightness, which means the sensors must detect motorists or pedestrians in adequate time. This would be less of a concern when switching to the dimmed state from the fully on state.

In the event of an accident, the nearest street light could potentially flash or pulse, alerting people nearby. When emergency services are in pursuit with flashing blue lights this could be

synced with the street lights, increasing awareness of drivers and giving them more time to react and pull over. This could work by a pedestrian near the accident pressing an emergency button on the nearest street light.

Another factor that should be revised is the maximum brightness of a luminaire. A study showed that people who tripped on pavements during hours of darkness tripped for several reasons other than darkness, such as weather and uneven pavements. Cars have headlights, which are capable of allowing the driver to drive comfortably without street lights whatsoever. Therefore the brightness could potentially be reduced; further saving energy costs, carbon footprint and unwanted light pollution. Traditionally, lights would be dimmed by a decrease in power to the light. LEDs are SSL, meaning they can easily be dimmed remotely by the use of PWM. Dimming via PWM has many advantages over analogue dimming (Unwin et al., 2017; Analog.com, 2019).

4.3.2 IoT

Dimming could be carried out by means of IoT. IoT is being implemented everywhere we look. The implementation of new street lights provides a great opportunity to gather data on other useful information such as climate, parking and more via various sensors and cameras. Lights can communicate to a CMS via GPRS transmission, power line carrier transmission, or GSM. Parking can be monitored by cameras. This would eliminate the need for wardens. This could also gather data about the size of the parking space and cost. This data set could then be a feed which is sent to navigation systems, mobile apps, and live parking displays. Sensors could be used to gather data about air quality. The World Health Organisation states that more than 80% of people living in urban areas that monitor air pollution are exposed to air quality levels exceeding safe limits (Griffiths, 2017).

Security of WSNs is currently a concern, as they collect personal data which could be a breach of privacy and harmful in the wrong hands. Methods can be implemented to increase security, however, the following may occur:

- Increased memory usage
- Decrease in network lifetime
- Large increase in energy usage
- Increase in latency by up to 5 times

The technology is still in its early stages and there is always room for development. There is also the opportunity to develop an equilibrium for data of lower security risk such as air quality and climate (Alharby et al., 2018).

4.3.3 CCTV

As our street lights develop, personal safety remains a concern. Street lights are already at an adequate height for the mounting of CCTV cameras; this is an ideal opportunity to save on the installation of more support structures by integrating both CCTV and street lighting. Despite this, on Green lane, Northwood, HA6, the council has recently added CCTV cameras on independent aluminium columns as shown in Figure 20 and 21.

Figure 20. Green Lane, Northwood, unnecessary street clutter 1

Figure 21. Green Lane, Northwood, unnecessary street clutter 2

This results in unwanted street clutter. A much easier solution would be to mount the cameras on the neighbouring street lighting column. In the event that the columns are not strong enough to support the camera, possibly due to windage, then the whole column should be replaced with one that is adequate to support both the luminaire and the camera. In the long run, this will save the government money; the old column can be recycled and used elsewhere.

To upgrade the column, the mounting hole would require work, but the labour input would not be as significant as that required to create a new hole altogether. All of these jobs quickly add up in costs of labour and material. Before the go-ahead is given on projects like this, it is important to

have these decisions confirmed by people with an array of expertise such as lighting design and construction management. If this had been done beforehand then the area shown in Figures 20 and 21 would have less street clutter.

Figure 22. Holloway road CCTV column

Figure 22 of Holloway Road, London shows a symmetrical street lighting pattern with an independent column in the middle; solely for CCTV mounting. The symmetrical lighting pattern is typical for a road of this width as the beam of a single luminaire will not contribute much to the other side of the road. The CCTV camera is mounted in the middle for the best possible view however it is not one that rotates 360 degrees. When the time comes to update the lights or cameras they should be combined onto the same column where possible.

4.3.4 Light and Charge

Future smart cities will be filled with IoT technology. A key component in this concept is autonomous vehicles. EVs are a stepping stone in this direction. Light and Charge is the means by which EVs charge. There are EV charging points already implemented in London. There is no need to add street clutter and further narrow our streets when this can be smartly combined into the housing of a street light. As our reserves of fossil fuels continue to diminish, the move towards EVs will become one not just for the wealthy, but one for the majority, as the technology also becomes more affordable and available. EVs are already widely used throughout China by the general public and taxi drivers.

The sockets can be retrofitted into traditional street lights. The cost of parts and labour is £1000. The install time is 30 minutes. Residents of Hounslow, West London can request this installation if they provide a receipt of their EV and £500 to contribute. Light and Charge installations are only suitable for street lights mounted towards the kerb, rather than the other end of the pavement. This is so the charging cable is not a trip hazard. When installing a new luminaire and pole this is not a concern. To ensure the installation is sufficiently earthed, copper mats or rods would need

to be installed underneath the pavement to make the lamp post safe to use for EV charging (Griffiths, 2017).

Battersea Park Road has had EV charging points installed, however, they are independent units. There are already many things on the pavement such as trees, traffic lights, street lights, road signs and rubbish bins. EV charging points should be installed within street lights wherever possible, to minimise street clutter. The street lights on Battersea Park Road, London are mounted near the kerb making them ideal for an EV charging point retrofit.

4.3.5 Digital signage

In a smart city filled with IoT infrastructure comes a great opportunity to install digital signs that can be used for the following:

- Revenue: Companies can be given the opportunity to have their interactive advertisements displayed. This can help recover the costs of implementation of the smart street lights. Any upward illumination must be shielded to prevent additional light pollution.
- Information: This could provide the public with information on things such as weather, public transport or air quality.
- Emergencies: Alerts could be displayed on these screens to help emergency services navigate to them and for the public to avoid them. It is also possible that instead of calling 999 someone could merely interact with the screen to alert the emergency services. The screen would not have to be a touch screen, it could simply have a few buttons like our current cash machines, to make them more durable.
- Navigation & Traffic: Accidents could be displayed suggesting alternative routes, as well as directions to a major public event (Griffiths, 2017).

Many of the discussed future technologies such as digital signage are featured in Figure 23.

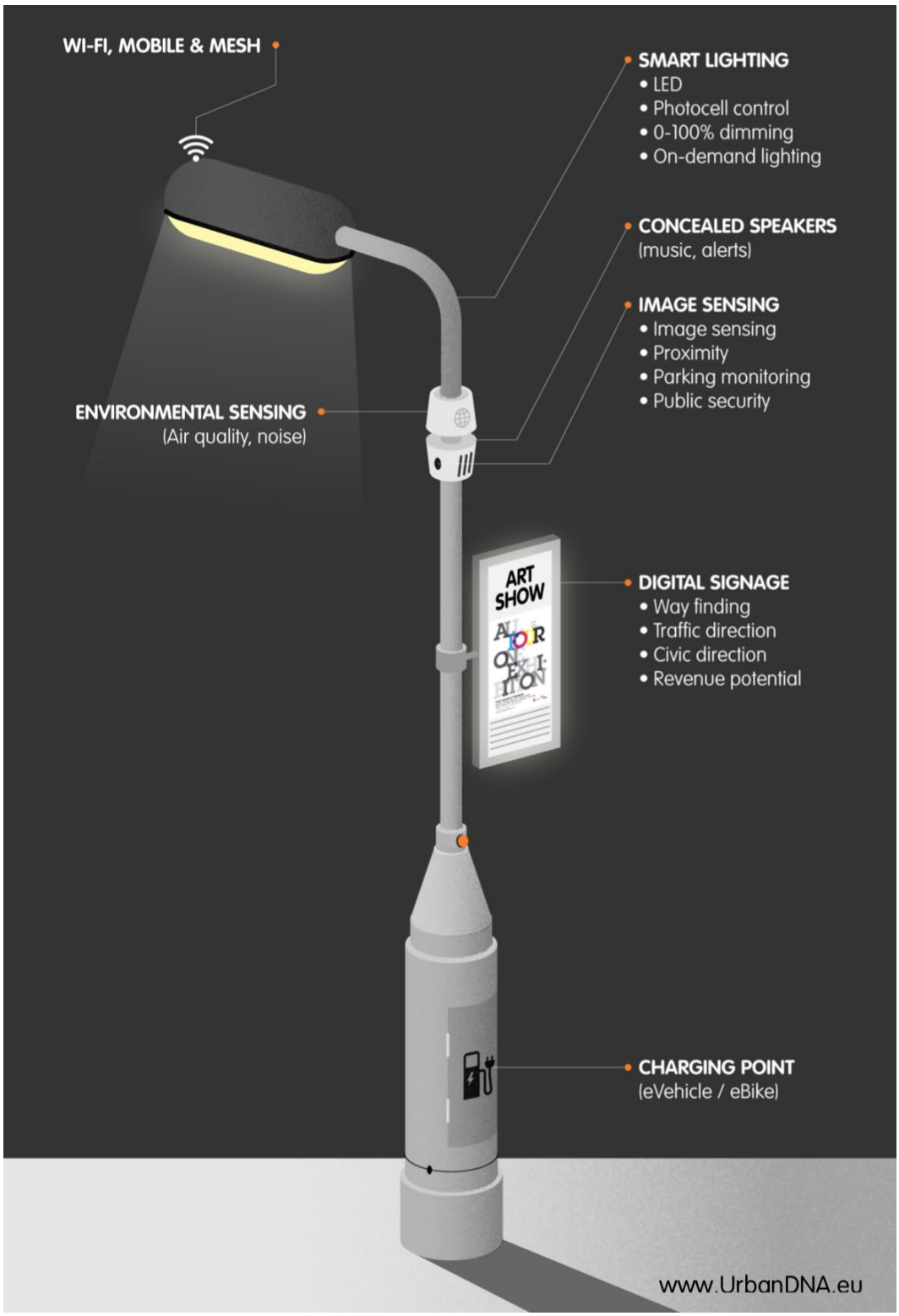


Figure 23. Conceptual future IOT street light (Urban DNA, 2016)

4.3.6 Solar

Smart cities sound great on paper, however, all of this technology increases the demand on our diminishing energy supply. The housing of new LED street lights tends to have a slim profile (as opposed to traditional cobra head or shoebox style lights) whilst maintaining a similar width and depth to previous street lights. This provides the ideal opportunity for the implementation of a solar panel above the light housing. LED street lights with solar panels are already available on the market. During daylight hours the photovoltaic cell charges a battery. This stored power is then used during non-daylight hours to run the LEDs. Since the light is LED, the current drawn is very low in comparison to other lighting technologies. This means they can be self-sufficient and off-grid. This can save massive costs by eliminating the need for grid power which would normally be provided by means of an armoured cable. The armoured cable is very costly and also a very laborious job to fish and route (Comber, 2019).

In some locations where solar energy is not feasible, it can be supplemented by the grid and run on a hybrid of solar energy and grid energy. This is still financially viable as street lights currently use approximately 40% of a city's energy. This is greatly reduced with the implementation of LED lights and it can be further reduced with the aid of solar panels.

4.3.7 LiFi

LiFi could potentially be the means of communication for future smart cities. It is still in its early stages; there is much to be developed. It has a few problems, such as difficulty operating in daylight. However with the current technological push, it is possible that LiFi will lead the way in how we connect to the World Wide Web in the near future. It is for this reason that we should consider integrating LiFi into our street lights. Street lights cover such a large span that they supply us with a huge network and could help us choose our routes, parking spots and far more. LED technology is well suited to LiFi as it can be turned on and off very quickly without much wear and tear on the components, unlike other lighting sources (Zhou et al., 2018).

An Ericsson Mobility Report states mobile traffic data is expected to grow 9 times by 2020. Current infrastructure is already struggling to accommodate this (Griffiths, 2017). Therefore, it is necessary to think outside the box. Even if LiFi is not a viable solution to the issue, then street lights are still a great platform from which to host WIFI.

4.3.8 Shotspotter

Shotspotter is a technology developed by GE. Using street lights with sensors, it can pinpoint the location of gunfire, immediately alerting the authorities. This is very useful when just 1 out of 10 shooting incidents are reported in the USA (Weaver, 2018).

Unfortunately, despite the potential that new technology gives us, there are still criminals on the street. Gun crime is on the rise. In 2017 there were 6,604 gun-related offences in England and Wales. (Weaver, 2018; Griffiths, 2017). This, combined with CCTV cameras, would greatly aid police work.

4.3.9 White laser

For the foreseeable future, it is clear to see that LEDs will lead the way in how we light our homes, offices and streets due to their many favourable properties. However BMW and Arizona State University have made breakthroughs with white laser technology. Arizona state university has combined 3 beams; of red, green and blue to generate a single white light. BMW, however, combines three blue laser beams, which are then converted to white by means of a yellow phosphor; this light is then scattered onto the road ahead. It is 30% more efficient than LED lighting. All new technology comes at a price, laser headlamps on the BMW i8 Supercar are a £7,995 optional extra (BMW Laserlight and BMW Selective Beam Glarefree High Beam Assistant - BMW Group, 2014; Whitwam, 2018). These white laser headlights have a range far exceeding that of a HID headlight. When a pedestrian is spotted, the car can detect this and will split the beam around them to prevent them from being dazzled (BMW Laserlight and BMW Selective Beam Glarefree High Beam Assistant - BMW Group, 2014; Whitwam, 2018). This technology could potentially be implemented into a street light. Due to the increased brightness and potential pedestrian tracking, fewer total installations would be required.

At an operating temperature of 80°C, the white laser headlight emits an average luminance of 560 cd/mm2 (cd = Candela). In comparison, high-power LEDs are in the range from 40 to 100 cd/mm2. The luminance enables an increase in light performance without having to accept compromises or disadvantages in other places. This enables implementation of a significantly more compact system, while simultaneously enhancing efficiency and light intensity. A smaller and more efficient optical system also allows for weight reduction. The white laser generates a light range of up to 600m (Werkstetter et al., 2014), double the distance of the current standard LED headlights (Osram.com, 2019). A camera-based high beam assistant controls the high beam function. This eliminates the possibility of other road users being dazzled.

The illumination range is linked to the vehicles speed; the laser booster is activated by the system when the vehicles speed exceeds 70 km/h (Werkstetter et al., 2014).

Traditional halogen headlights emit more light pollution due to their large reflective style; this results in more scatter and glare. Bi Xenon headlights have less as they are focussed through a projector lens. LEDs have even less as they are directional without a lens. The resultant glare levels for other motorists and pedestrians reduce as the technology used in headlights develop. Consequently, less light is scattered onto road signs. Many road signs rely on headlights at night for reflectance to ensure they are visible. This creates a new problem for motorists driving a vehicle at night with headlights that do not emit sufficient scatter above the horizontal plane.

Figure 24 shows the patent for:
'Hybrid illumination systems having a blue laser diode, dichroic mirror and yellow transmissive phosphor converter for generating white light' was obtained on January 16th 2018 by Texas instruments incorporated (Patents.google.com, 2019).

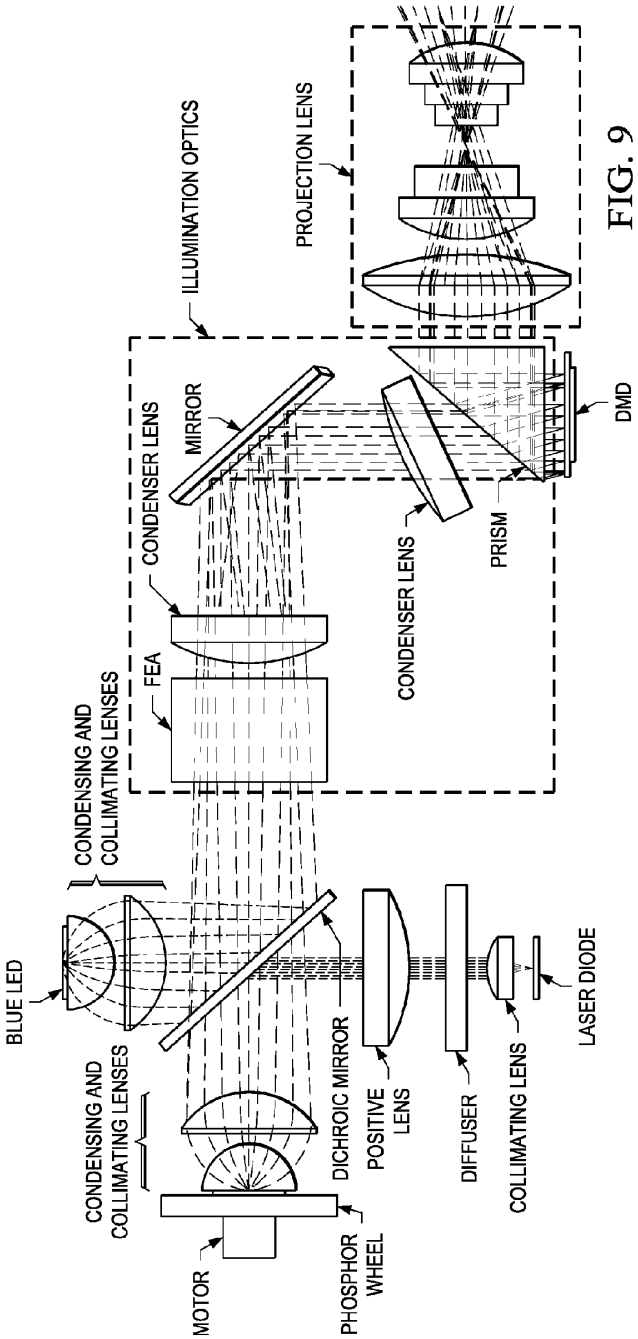


FIG. 9

Figure 24. White laser light patent (Patents.google.com. 2019)

5. Discussion

5.1 1-year potential technology push

LED street lighting is becoming the norm; the financial savings are too big for the government to miss out on. Local councils all over the country are developing mass plans to convert their old inefficient systems to more up to date, LED, connected systems (Wigan.gov.uk, 2018; Wokingham.gov.uk, 2018; Portsmouth.gov.uk, 2018).

Car manufacturers are always thinking of ways to make their vehicles safer. Audi has developed a traffic jam pilot. This gives users the option to drive hands free on less demanding roads up to a speed of 37 mph. Cadillac has also released a similar technology known as supercruise (Govtech.com, 2018). We have already seen the implementation of piloted driving by means of 'lane keep assist', adaptive cruise control and self-braking systems. Many of these new car safety features will become the norm for future everyday cars. Hence we should see a decrease in accident rates (Digital Trends, 2018).

It is now possible to purchase a simple device, which plugs into your car, turning it into a 4G hotspot. Many vehicles now come fitted with this option. This will further aid the world of IoT so that in the future it is possible that vehicles will use this technology to gather data on parking spaces, traffic and much more (Dunn, 2018).

It seems as though the future car market is led by EVs. They have several benefits; the global EV market is expected to reach £73 billion by 2019 (Business Green, 2015). If EVs lead the way in which we get from A to B, this will change the requirements of our street lighting. Currently, the factors putting people off from EVs include their range on a single charge, charging socket availability and the high initial purchase price (Innovations.harvard.edu, 2018).

5.2 5-years potential technology push

As well as the adaptation of older street lights, many new street lights have been designed for use with LEDs. In 2012, 10% of new public street lights were LED-based, this figure is predicted to rise to 80% by 2020 (Audentia-gestion.fr, 2018).

More than two-thirds of us will be living in cities by 2050. With the majority of us in such a dense urban landscape, it is key the world surrounding us moves as smoothly as possible. This applies to our transport network in particular. Road lighting plays a key role for motorists currently and it will continue to do so for some time (BBC News, 2018).

There will be many more advances in technology within the next few years. KGP concrete has been developed. It can store and deliver electricity. A six-metre tall street light constructed from a KGP column could store enough electricity to power itself for one evening. Previously off-grid street lights relied on rechargeable batteries. The most commonly used, being Lithium Polymer, which can explode easily and is difficult to recycle (Solar Street Lighting, 2018). These batteries could potentially be replaced by KGP concrete (BBC News, 2018).

Solar energy is currently the most commonly used source of renewable energy in cities. The cost was £3 per watt 10 years ago; it has now dropped to 40p per watt. Solar energy may become even cheaper in the future with the development of solar panels consisting of titanium instead of lead; this results in increased efficiency. Adding solar panels to the top of street lights is a more viable option than previously, and provides the opportunity for a street light to be off-grid (BBC News, 2018).

Tarmac roads could be replaced by alternative mediums in the near future. A public road in Cumbria has been constructed from recycled plastic aggregate. When compared against tarmac it is thought to have a much longer lifespan, lower carbon footprint and cheaper to repair. This different surface will affect how the light is reflected off, both from street lights and vehicle headlights. Factors include the colour of the plastic and how smooth or textured the finish is. This system may be less prone to potholes and puddles due to its less porous structure, hence light dissipation should be more consistent when compared with our current tarmac roads (Meonuk.com, 2018). The world's first solar panel road is already open to the public in Normandy, France. The solar energy that this road gathers should provide the locals with enough energy to reduce the local demand on fossil fuels. Just like the plastic road previously discussed this new road surface will affect how light is dissipated from its surface. It is important that motorists are not dazzled by reflections or subject to glare as a result of street lights and headlight reflections.

Contributing to local electricity supply is the main benefit of this system, however, it is still in its early stages. Many people are sceptical and doubt the road's efficiency when covered with vehicles, mud and snow. The road is also flat instead of directly facing the sun, meaning some of the light will be reflected instead of refracted. If this system proved successful it is quite possible that the road could power its street lights and have energy to spare (Meonuk.com, 2018; BBC News, 2018).

Free WIFI is already available on the streets of New York City. This is made possible by users agreeing to share their locational, personal, and behavioural data. This information is valuable to advertising companies and the data is used to better target their adverts on user's devices. Sharing locations helps to keep navigation apps up-to-date with information on congestion, parking and much more. These factors can be associated with street lighting, as the columns which street lights consist of provide ideal mounts for technologies such as cameras and routers (Griffiths, 2017).

5.3 10-years+ potential technology push

There are approximately 7.4 million street lights in the UK. Less than 10% of these are LED. With the business case becoming more solid than ever, the move to LED is expected to increase exponentially in the near future. It is expected that global penetration rates will reach 89% by 2026. Green loans are becoming more commonly used. Financers are providing funding packages into which all upfront costs are absorbed and repayments are made from energy savings. Typical payback periods range from four to twelve years. The Green Investment Bank has created the Green Loan for Local Authorities in the UK. This is a service, which can finance all LEDs and CMS capital expenditure including columns (Greeninvestmentgroup.com, 2018).

Car manufacturers such as Audi and Mercedes-Benz believe in 10 years' time autonomous vehicles will have developed enough for everyday life. If this is the case, then the requirements of street lighting will be completely revised. These vehicles will communicate with each other when meeting at junctions and roundabouts. They will be able to plan the most efficient method of passing each other with the least amount of braking. This means that people in these cars are no longer drivers, they are just passengers. Street lighting could then be more orientated on pedestrians and cyclists or reduced to help lower light pollution levels (Digital Trends, 2018; Daimler, 2018).

Norway is considering banning sales of new diesel and petrol cars by 2025 (Griffiths, 2017). Congestion is a growing issue in urban areas. A study from INRIX and the Centre for Economics and Business Research has found that between 2013 and 2030, the total cumulative cost of congestion to the UK economy is estimated to be £307 billion. The annual cost of congestion is expected to rise by 63% to £21.4 billion over the same period. Increased population and economy development will result in more vehicles being on the road and therefore a higher demand on street lighting and infrastructure (Ibtta.org, 2018).

Further development of Maglev and Hyperloop trains may mean that we depend on roads less. The Hyperloop train being developed by Elon Musk is nearing reality and plans to achieve speeds of 800 mph. This could prove to be a far more efficient method of transport when compared with driving. If these trains were installed across major routes, it could result in a reduced number of vehicles on our roads. This would allow for reduced street lighting, which would decrease our issue with light pollution (Fox News, 2018; The Independent, 2018).

Hollow plastic roads consist of modular blocks that drop into recesses, this makes them easy to install and replace. They have hollow cavities that allow for easy maintenance of pipes and cables. On paper, this hollow plastic system is easier to work with and maintain than tarmac roads. As previously mentioned these new road surfaces could change how light is reflected. If the surface was matt it could prove to have a more consistent light dispersion pattern than current tarmac roads. It would also be more durable and less susceptible to potholes and freeze-thaw action, due to its non-porous surface (Meonuk.com, 2018).

Piezoelectricity is a technology that is currently undergoing exploration. It provides the opportunity to make roads and pavements from quartz material. When this surface is compressed it transfers energy. Therefore, with every passing vehicle and pedestrian, electricity is harnessed. This could potentially gather more electricity than required to illuminate street lights for the length of the road, with the surplus being fed into the National Grid (BBC News, 2018).

Smart pavements can detect vehicles and determine their location in real-time. The WHO predicts that lack of road safety will be the 7th leading cause of death by 2030. The smart pavement system can detect when a car has mounted the pavement and will instantly alert authorities about it. This enables emergency services to react faster, providing a better opportunity to save lives. This information can be collected, so future changes to the roads infrastructure make it safer for everyone. Currently the cost is roughly $4million per lane per mile, however, this price is expected to go down as the technology becomes more commonly used and available (Van Hooijdonk, 2018).

As previously discussed there has been a breakthrough in the development of white laser light technology. Although LED technology has come a far way, it is no match when compared against white laser. White laser is more compact than an LED diode, it produces up to 1000 x more light and consumes 1/3rd of the electricity. It is already in use on the BMW i8 Supercar headlights.

It is quite possible that this technology develops and becomes a normal feature on everyday vehicles in the future much like parking sensors, Sat Nav, and DRLs have become. It is also quite feasible that this technology is implemented into street lights. BMW already has technology which splits the laser headlight beam around a pedestrian to prevent them from being dazzled. Street lights could be installed at less regular intervals due to the higher capabilities of white laser. To prevent over lighting and light pollution, the beam could then move so that it followed pedestrians and cyclists and nothing else (dmlights Blog, 2018; BMW Laser light and BMW Selective Beam Glare free High Beam Assistant - BMW Group, 2014; Whitwam, 2018).

6. Interviews orientated around a street lighting tool

6.1 Current Practitioner's Tools

Within a street lighting installation, numerous people from varying fields will be brought on board for their expertise and skills. Figure 25 illustrates an estimating process for construction.

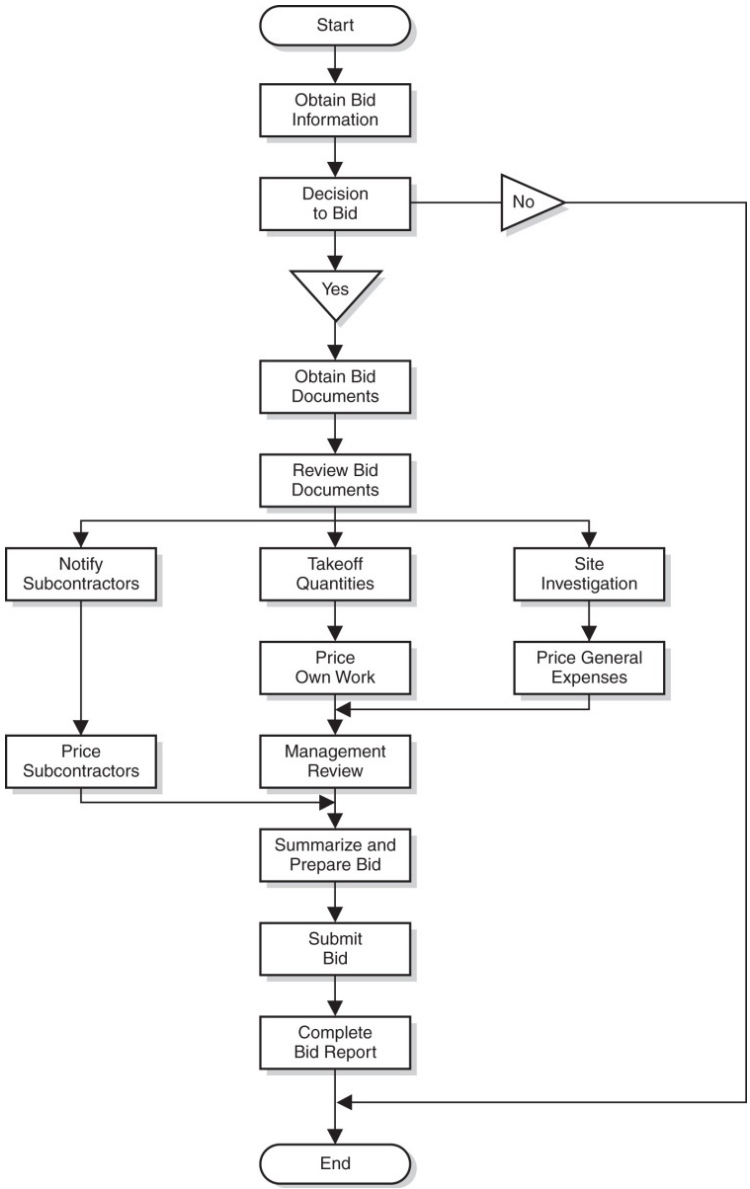


Figure 25. Estimating process for construction (Pratt, 2010)

This would be utilised by civil engineers. Most construction companies will subcontract parts of their project out to others to achieve a high-quality end product within a set time frame. A structural engineer may do calculations to ensure the columns are within specification. A wind surveyor would measure wind load, to ensure the columns are suitable for extreme conditions. A lighting engineer would specify colour temperature for LEDs to create the least amount of harm

for the environment and might measure current ambient lighting levels. A transportation engineer will assess the traffic speed and intensity. An architect may assess the impact of the installation and illustrate any intrusion of light pollution that may occur (What is Civil Engineering?, 2018; Agile Estimating & Planning, 2018).

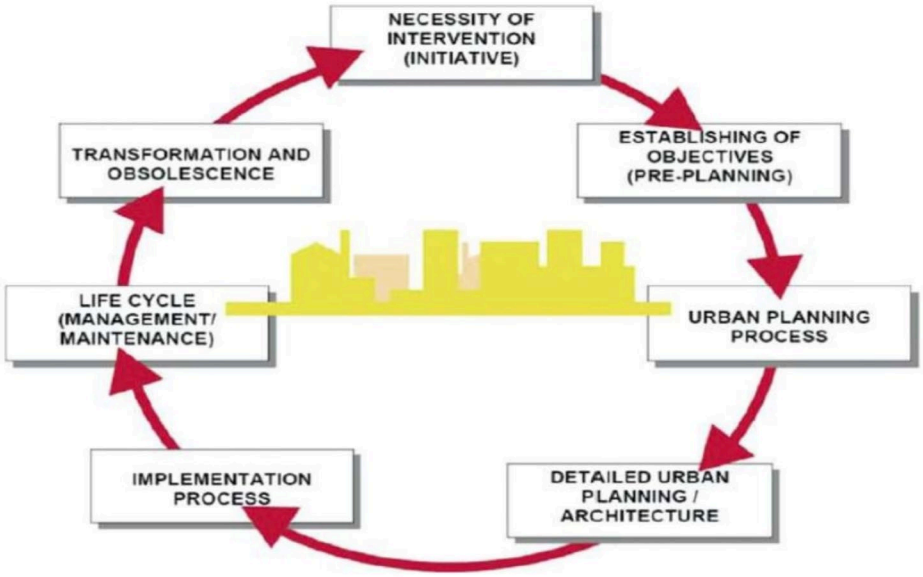


Figure 26. Urban planning flow chart cycle (Lighting design in urban spaces, 2015)

Figure 26 shows a cycle that an urban planner may utilise to oversee the progress of a project. This could involve an array of projects including renovating the street lights along a motorway. Within such a project there are many stakeholders, such as architects, lighting engineers, transport engineers, civil engineers, landscape designers and others. These professionals may end up collaborating on a single project as they all have their own area of expertise (Griffiths, 2017; Lighting design in urban spaces, 2015; Stephenson, 2018).

Figure 27 illustrates a more in-depth approach that an urban planner might follow. Urban planners must rely on and work collaboratively with key stakeholders to produce the best possible outcome and satisfy all parties, hence the numerous phases (Urban Learning, 2017) (IHS, 2013; Position Profile - Streetlight & Traffic Signal Technician, 2018).

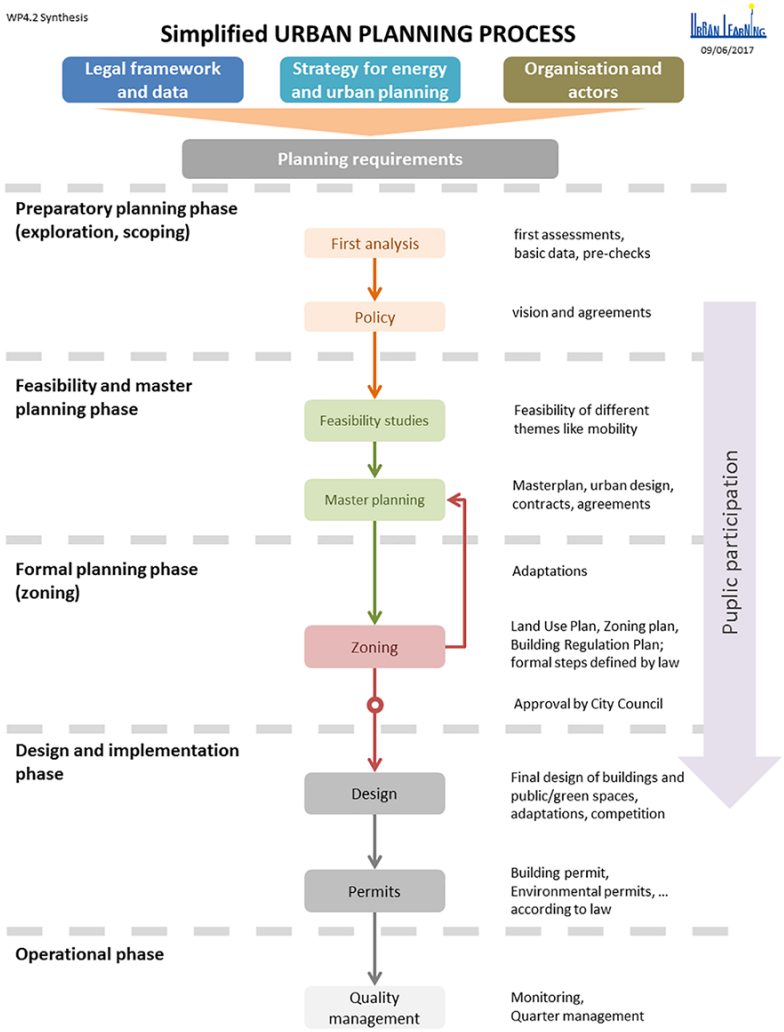


Figure 27. Urban planning flow chart cycle (Lighting design in urban spaces, 2015)

Figure 28. Adapted model from automated buildings.com, by Ajay Parmar,

(Smart building designer interactions, 2018)

Figure 28 illustrates the communications that a smart building designer will have throughout the course of a project. Although Figure 28 is not for street lighting design many of the communication routes overlap. With so many factors surrounding street lighting, it is important not only to meet regulations but also to make improvements and reduce negative impacts. Designs will go through several iterations before they make significant progress (Anixter, 2017; Automatedbuildings.com, 2018).

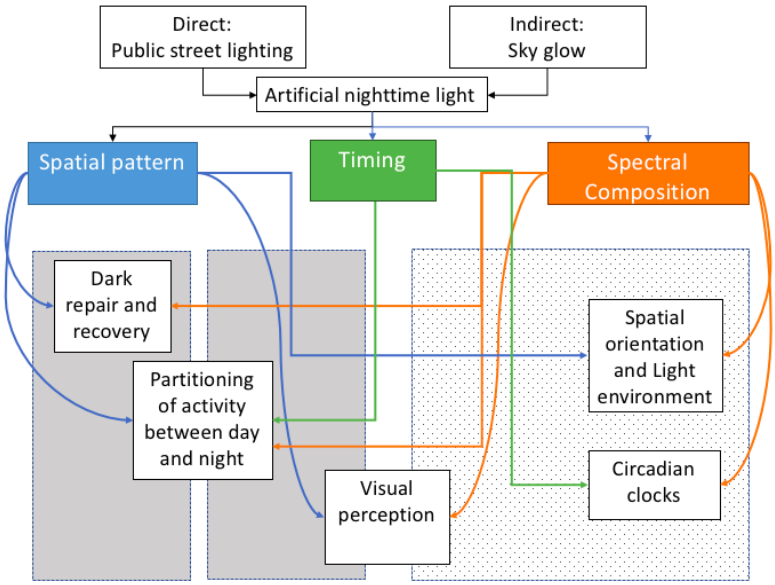


Figure 29. LAN impact on insects (Medium, 2018)

Figure 29 might be used by a biologist or conservationist. It displays how LAN impacts insects, however, the effects listed also apply to humans (Medium, 2018; Dijk and Archer, 2009). These consequences of LAN are considerations that an ecologist may highlight and a lighting designer must take into account when designing a new installation. Each application will be different depending on the surrounding wildlife, transport usage and homes (Pacheco-Tucuch et al., 2012).

Lighting engineers can now use software such as Dialux Workshop to build a virtual road system with street lights to help decide on column spacing, mounting heights and more. This is especially useful when it comes to corners and hills (Roco, 2016). Figure 30 shows a lighting plan for above a bridge. Figure 31 indicates the lux values on the road surface.

Specifications:

Luminaire: 2 x 400W HPS.

Column: 20m tall, with a double arm

Intervals: 40m

Mounting: On top of New Jersey side barriers

(Santiago, 2014)

Figure 30. Lighting plan above a bridge (Santiago, 2014)

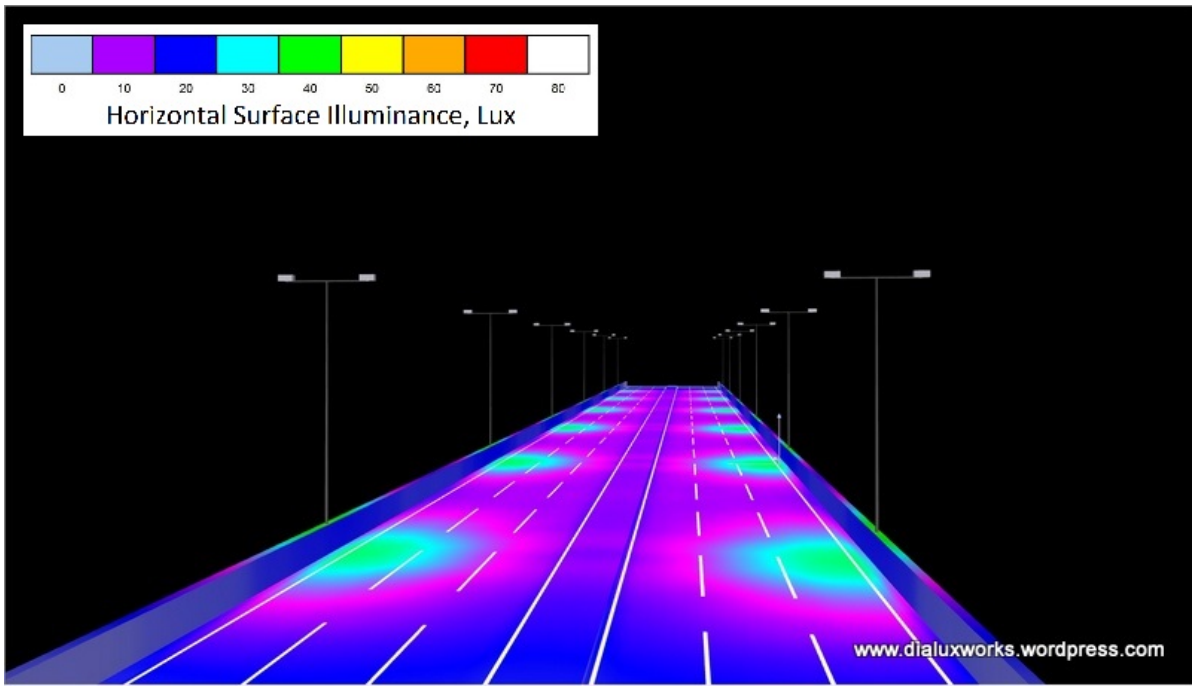


Figure 31. Lux values simulated for lighting plan (Santiago, 2014)

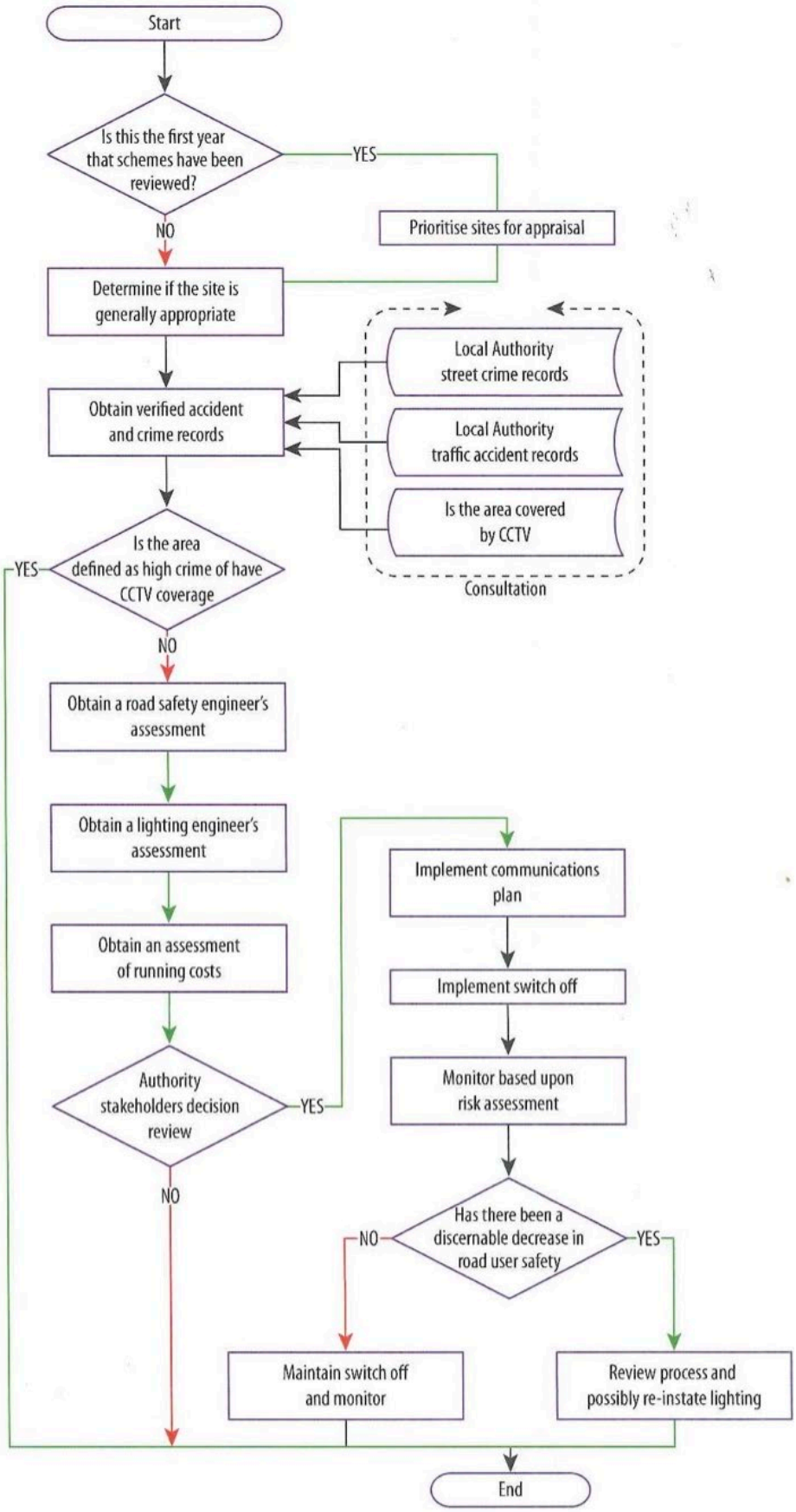


Figure 32. Assessing existing lighting for switch off/part-night lighting (Franks et al., 2016). This flowchart explores all aspects of switching off street lights entirely or for certain hours during the night.

This applies to new complete installations or the consideration of retro fit solutions to existing installations.

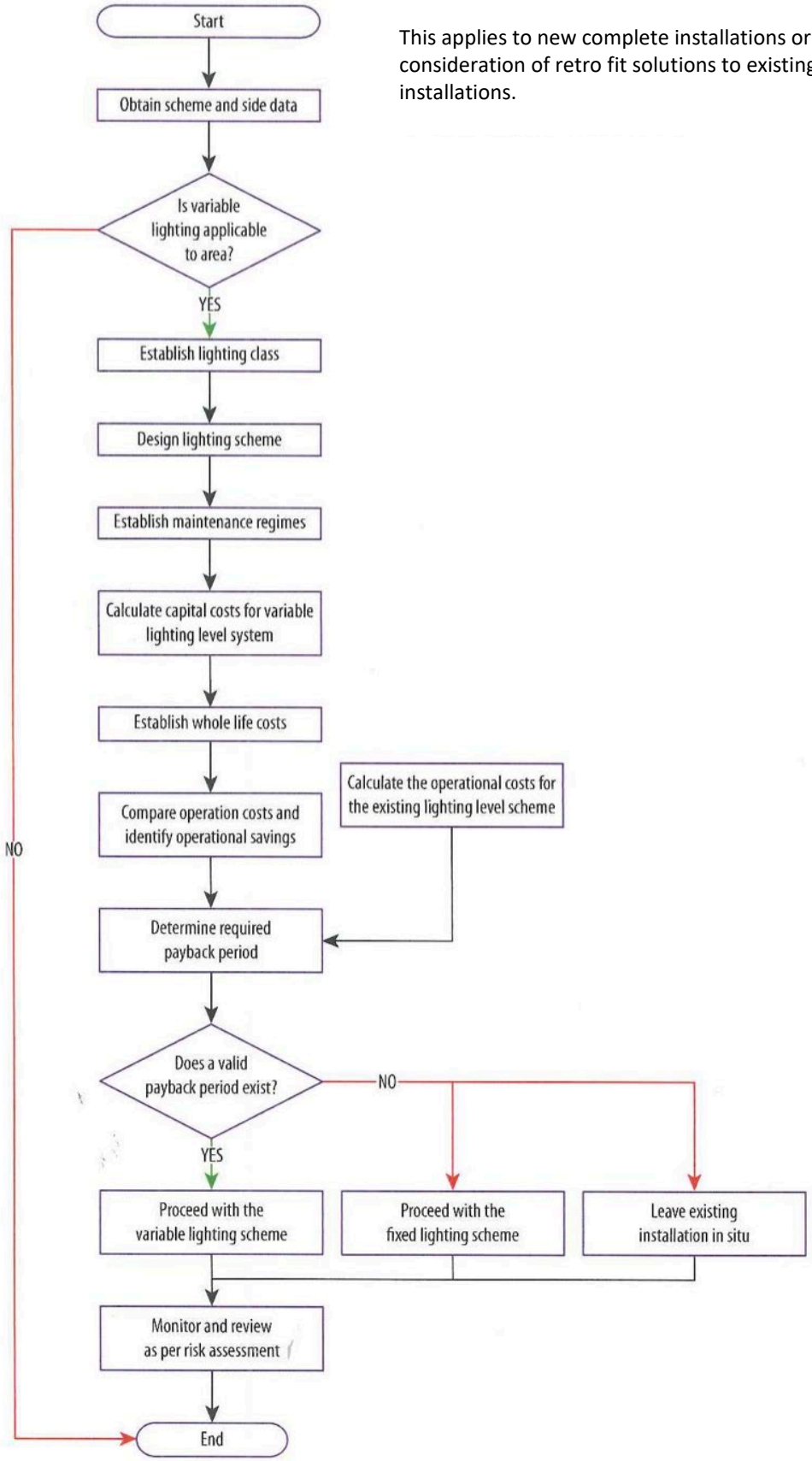


Figure 33. Adaptive lighting levels cost-benefit analysis (Franks et al., 2016). This flowchart takes into consideration all aspects of the payback period for an energy-saving street lighting installation.

6.2 Street lighting tool development

After conducting the in depth literature review of existing studies and navigating through the lighting standards it became apparent that certain aspects of a street lighting system are often left behind. Hence the requirement for a street lighting tool.

Harder states in *Development of Outdoor Lighting Regulations* a Dark Sky Association PDF, references to lighting are not practical to enforce or check for conformance due to incomplete or technically incorrect terminology (Harder, 2008).

Bain supports the above. He has been taking matters into his own hands and working alongside councils to improve and redesign proposed street lighting plans. As previously mentioned in chapter 3.8 residents can complain to the council if street lights are creating light pollution. Bain states that if residents complain, all they get back from their local authorities are 'cut-and-paste platitudes'. Bain states the only criteria anyone cares about is energy efficiency and they are failing to take into consideration other negative consequences such as light pollution. Not only is there a 'technical guidance void' on how best to use LED technology for street lighting, Bain says, there is also a 'policy void'. Bain states someone needs to put out some guidance. The following chapters create the foundation of this guidance offering professionals the opportunity to develop this further.

In one circumstance Bain disputed the colour temperature choice. The council responded and reduced the colour temperature by 40% from 5700K to 4000K. No technical information as to why they decided 4000K was discussed. Since councils are financially concerned they should implement dimming on current street lighting which still has years of life left as opposed to wasting more money on new LED installations. Bain has created such an impact in the world of street lighting; Cardiff council has invited him to discuss LED specifications, He is also assisting the ILP (Institution of Lighting Professionals) updating their guidance on LEDs (Bain, 2015).

The following diagrams show the progressive iterations made of the street lighting tool. Once the final diagram was made, numerous interviews were conducted with professionals and feedback was obtained on the diagram.

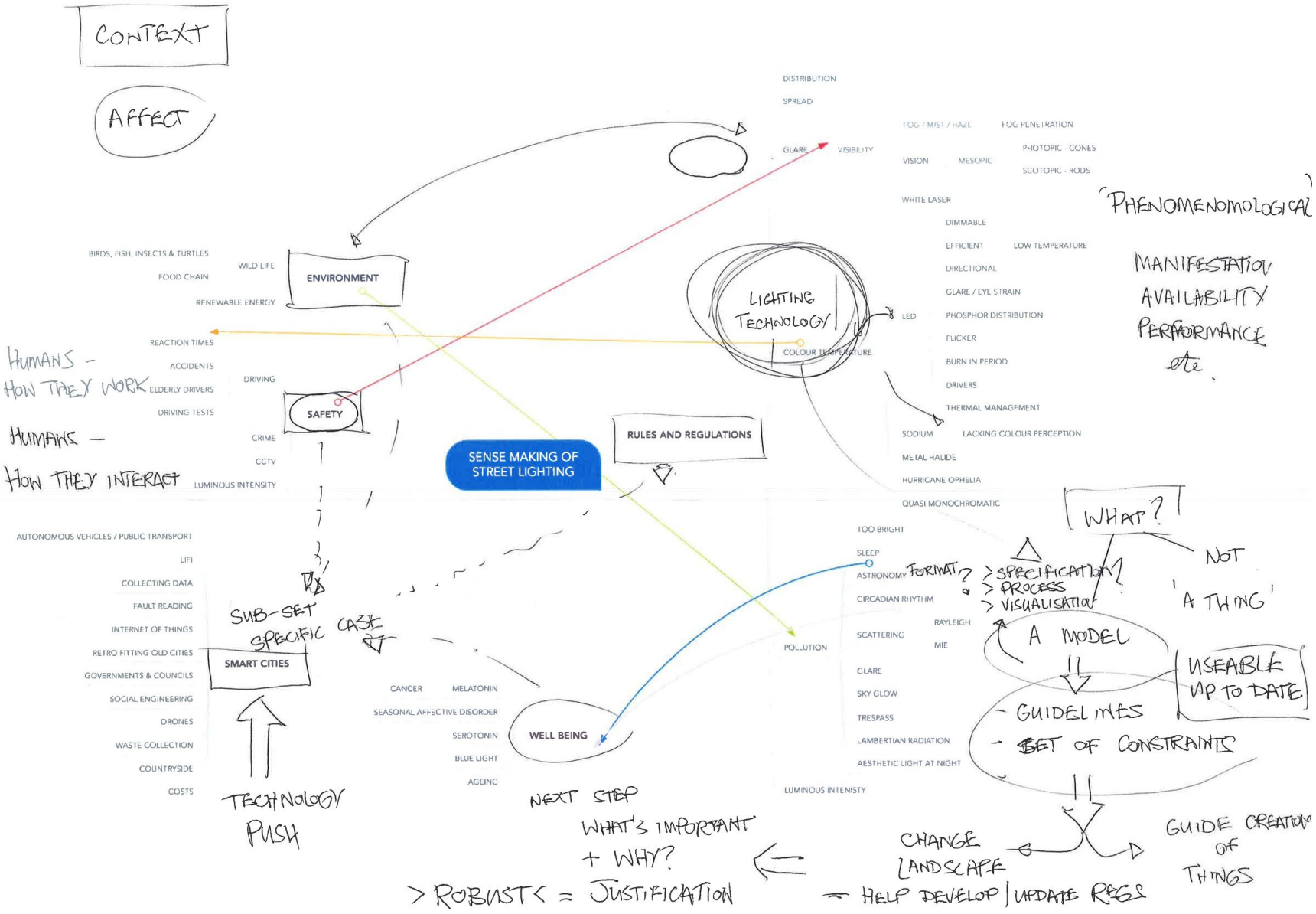


Figure 34. Sense making of street lighting, developed by Ajay Parmar, using www.mindmeister.com

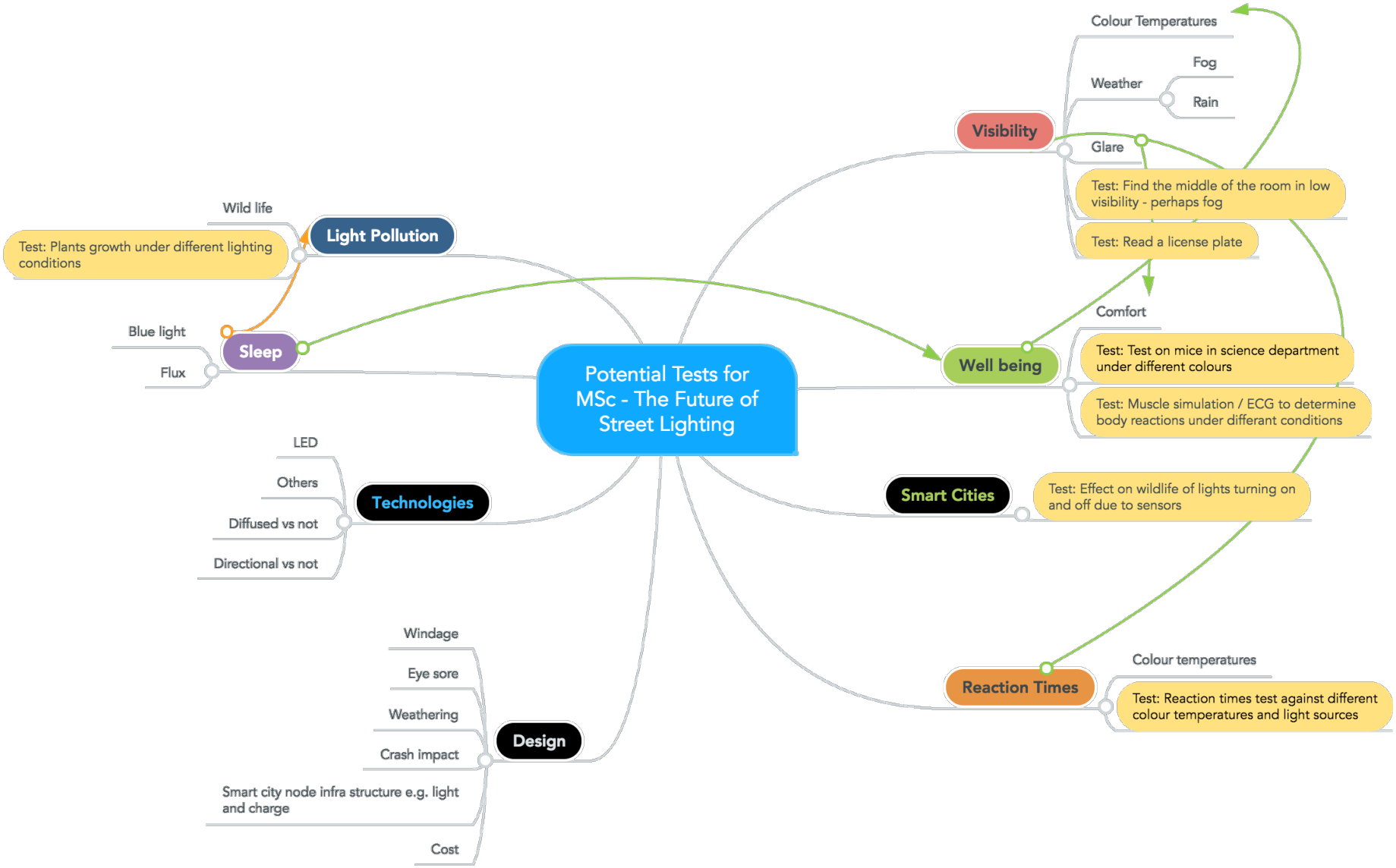


Figure 35. Potential tests for MSc, developed by Ajay Parmar, using www.mindmeister.com

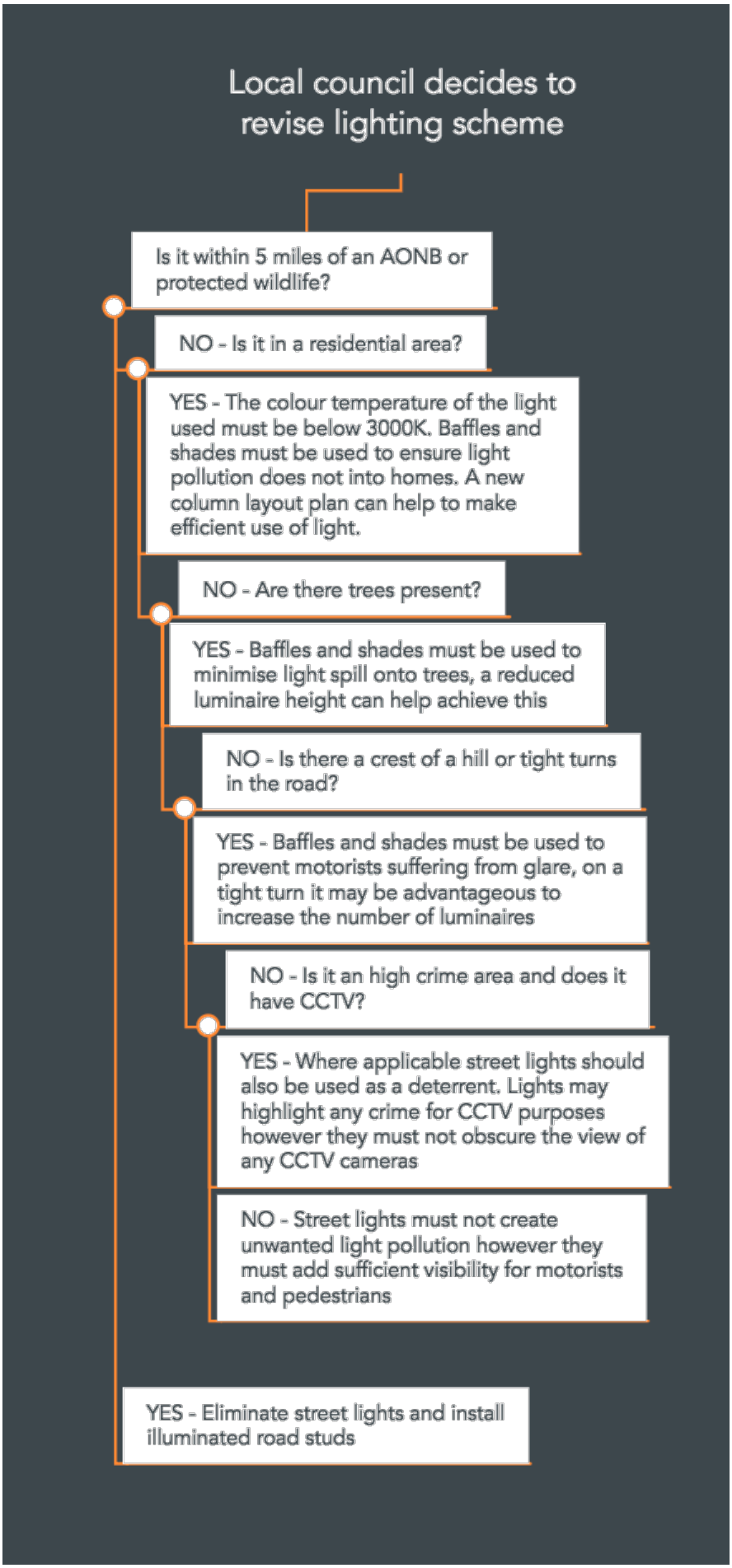


Figure 36. First flow chart iteration, developed by Ajay Parmar, using www.mindmeister.com

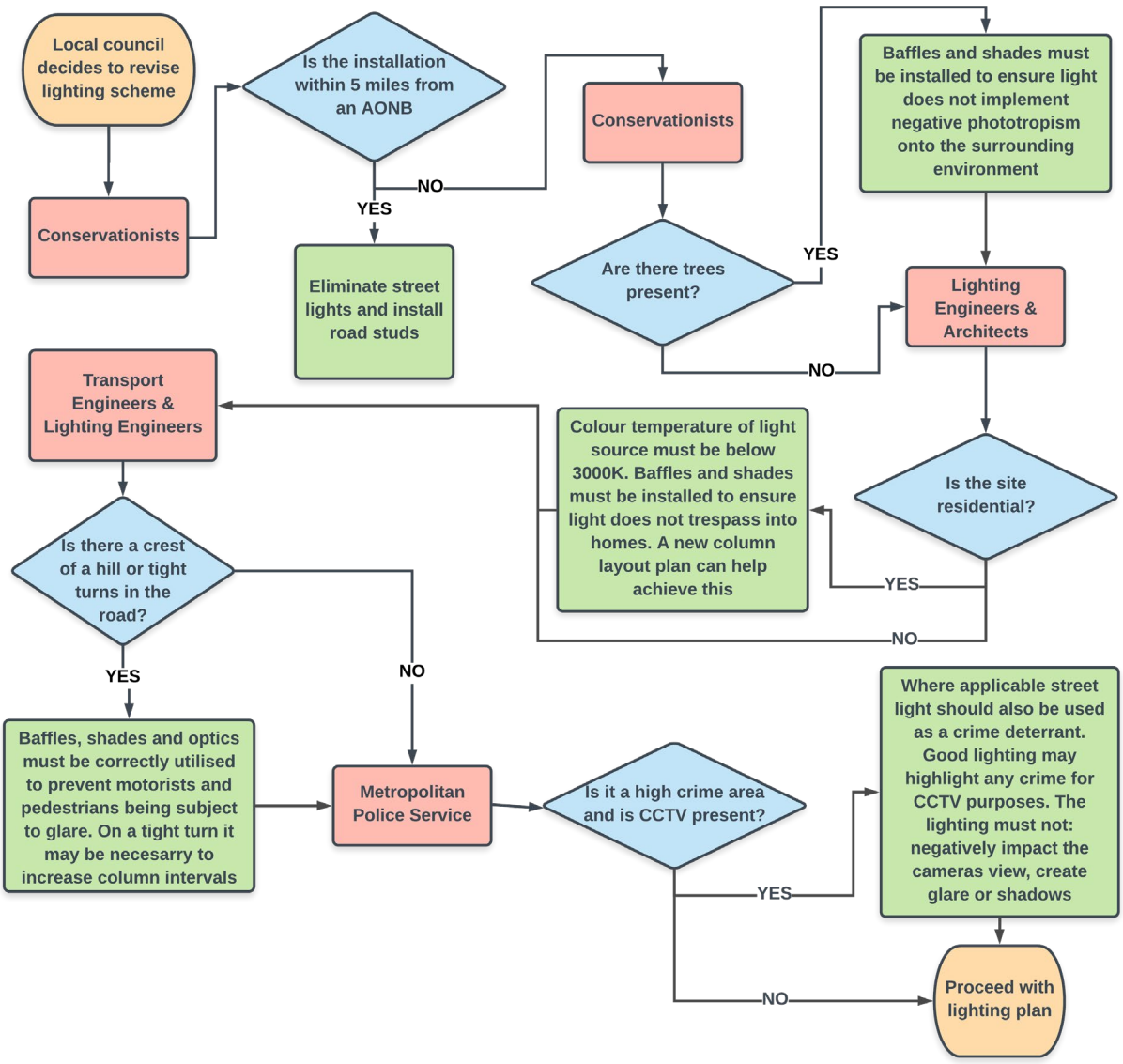


Figure 37. Street lighting tool, developed by Ajay Parmar, using www.lucidchart.com

Traditionally interaction designers developed user interfaces for desktop computers. This presented designers with the task of making the menus easy to navigate, and designing icons and dialogue boxes that are easy to understand and use. Advances in technology provide the opportunity to use handwriting recognition, speech recognition and more (Sharp, Rogers and Preece, n.d.).

A flowchart was chosen for the purpose of guiding professionals as it shows the complete process from start to finish, which is easy to follow. This could easily be printed and annotated perhaps with times and dates. It is easy to troubleshoot a project when using a flowchart by retracing steps backwards and identifying where the fault was (Smallbusiness.chron.com, 2019).

Figure 37 is a tool developed to help guide the two target audiences through designing a street lighting installation that will satisfy key criteria that currently are lost within the unorganised rules and regulations. It may also be used on existing light installations to highlight existing flaws. Research carried out on how to resolve these issues has been simplified for the purpose of the flow chart.

The Dialux software shown in Figure 30 and Figure 31 is a great tool to simulate the emission from luminaires across an environment. Figure 37 explores the considerations that a simulation would not cover. Figure 37 has gone through numerous iterations and has taken reference from various sources (Library.college.police.uk, 2018; Exterior Lighting Concepts, An Architect's Guide, 2018; Gov.uk, 2018; Manual for Streets, 2007; Painter, 1996; Griffiths, 2017).

6.3 Interviews

The following people are either existing contacts or have been suggested by others. A great deal of networking was carried out via lighting events, social media and LinkedIn. The following people come from an array of backgrounds providing a useful variation of insights. They were asked for their opinion on the flow chart developed (Figure 37) and for their views on the direction of this thesis. The conversation was led in a way that suited their unique expertise. I communicated with them in person, text message and via email. Some replies were in depth and others were not, hence they lasted two days as they were asked for more information and opinions. A lot can be learnt from professionals who utilise the lighting standards as part of their career. Some useful insights were gathered and are discussed in chapter 6.3.7. The subsequent sections introduce the professionals interviewed and offer their insight on both Figure 37 and the direction of this thesis.

6.3.1 Alvin Munzi

Alvin's career started with a Product Design degree from Middlesex University. On his placement year, he worked at Atkiva Lighting. This put him in great stead for his final year. After graduating and exhibiting his work at degree shows, he secured a product design engineer role at Light Projects, a lighting manufacturing company. He then went on to become a senior product designer at Lucent Lighting. Another opportunity arose and he became a product design engineer for DW Windsor, British designer and manufacturer of exterior lighting solutions. He has now been in the lighting industry over 10 years. Alvin currently works as a Product Designer for Current (part of GE). This role focuses on smart lighting systems and IoT.

Alvin states: 'Generally, 4000K 70CRI is used on exterior street lighting schemes, as it is more efficient and cost-effective. However, a move to 3000K is getting more popular as it is more comfortable, especially in residential areas, but there is a trade-off in efficacy. In areas where CCTV is used, higher colour rendering of 80CRI minimum is required, as footage can be used in court, so true colour rendering is needed. Lighting schemes play a major role in conservation areas, as dimming schedules can be programmed in, or sensors can help reduce light levels at times of prolonged inactivity. However, with IoT, local authorities now have complete control over schemes and can react to feedback instantly. One other thing for consideration is maintenance; just like above, local authorities will now be able to remotely increase light levels throughout a luminaires lifetime, as the LEDs burnout. The modularity of a luminaire is also a key factor, as road closures for maintenance is a nuisance as well as expensive to councils, so luminaire choice will also be based on the ease and speed of swapping out the whole Luminaire, or aspects of it. For instance the LED driver, is the most fragile part of a luminaire ecology, as the electronics in it are the most temperamental, or susceptible to peaks in input voltage or lightning strikes' (Munzi, 2019).

'I think the flowchart will be a useful tool for local authorities and lighting specifics on street lighting projects, as it covers the needs of both humans and animals alike.' (Munzi, 2019)

Many of the points Alvin has discussed, reinforce previous points discussed in this thesis, which have been illustrated in Figure 37.

6.3.2 Jeremy Comber

Jeremy has been a UK Power Network distribution supply technician for 12 years. He has wired up numerous luminaires over time. He states that before the council consider a new street lighting installation one of the first things they take into consideration is the current power routes.

Sometimes the council are fortunate enough to have sufficient power in the area. If this is the case, then UK Power Network may be contacted and people such as Jeremy may connect the luminaires with an inline 30 Amp cut-out fuse fed from a feeder pillar.

In the event that the existing available power sources are not adequate, the job becomes very expensive. The council may attempt to run cables themselves in an attempt to save cost. They may daisy chain from a single source to reduce costs.

Jeremy has worked on Gosforth Lane, Watford on more than one occasion. He states that due to the nature of the bend the street lights are frequently subject to being knocked over as a result of motorist accidents. Not only does this reduce the light output in the local area, but it also results in a cut out of power for the CCTV of the high street. This is a prime example of why such installations should be revised, as these daisy-chained systems are unreliable and outdated.

Figure 37 suggests an increase in the frequency of lighting installation on a tight bend. Perhaps if the bend was better lit, then motorists would have fewer accidents on the road (Comber, 2019).

6.3.3 Michael Rushe

Michael has been licensed as an architect for 35 years. He has been associate director at DEGW, Director at EEA (London & Rotterdam) and Director at ICE since 2004.

Michael has completed buildings in four European countries. Some of these include: Buildings for Great Ormond Street Hospital, The National Gallery (refurbishment), ING (Budapest), Art Galleries in Cork (Ireland) and MIMA in Middlesbrough, private residential developments in Prague, public housing estate regeneration in Telford and Stoke on Trent, refurbishment of listed buildings including at The University of Cambridge, and a children's activity centre in the New Forest and a Church in Vauxhall. Numerous small-scale residential developments for small sites and on individual houses including listed properties in London.

Michael's comments on the project are as follows:

"Light pollution - Painting the tops of bus shelters black would assist with reflection at night but a general trend in roof coverings is in the opposite direction and they are becoming lighter to reduce daytime solar absorption and thus reduce energy consumption for cooling which is only a seasonal problem in the UK but could become a larger consumer of energy if temperature forecasts for the UK are realised. In the long term, there could be a conflict between wanting reflectance during the day in low riser locations such as suburbia and not wanting reflectance at night.

Advertising - In our experience, the investment in external lighting for advertising varies significantly with the nature of the business and those that rely on passing traffic are unlikely to see social media or sponsorship as alternatives to the 'magnet' effect of bright lights on a cold winter evening. Other types of business such as hotels; particularly in rural areas see a dual benefit to floodlighting since it illuminates the approach and possibly the car park but also acts as 'advertisement' presenting a 'welcome in' message to a potential customer.

IoT - The potential for data collection devices in a single-pole is well set out in your document however more 'big data' increases energy consumption where ever it is stored and there appears to be a new resistance to user data collection, storage and retrieval following the Cambridge Analytica case. Having the tech may not mean using it.

CCTV - The street clutter of signage and street furniture is a frequently discussed urban issue since despite UK planning laws there is little active control or enforcement of signage by local

authorities. Transgressors often point to the mass of 'official' signage of the examples given including road signage to show that the Council's themselves do not abide by their own policies. Perhaps Figure 37 should include a test regarding the number of standards - either 'Will the scheme utilise fewer standards than the existing lighting' or ‘Can standards be combined with other services to reduce the number of standards'.

Street lighting tool - In my experience of residential design, crime prevention would figure in all schemes not just in areas of high crime. The Police have a programme of anti-crime measures (SBD), which are built into the design process and certified, usually for insurance purposes. The programme requires illumination on every elevation that has a door. All buildings can be assessed for SBD and so you should not exclude non-residential from your tool as these buildings have as much CCTV as residential.

The crime issue is broader than the relationship with CCTV and therefore should feature in your tool for both residential and non-residential buildings. There is also a decision to be made at some point between what lighting is to be provided close to or on a building and general way finding illumination. Street lights and of course these may be the same thing in private roadways or paths through a development”. (Rushe, 2019)

6.3.4 Paul Ferrari

Paul graduated with a degree in Land Economy (B. Land Econ) at Aberdeen University in 1980. Since then he has been a surveyor.

Paul states Figure 37 is a good checking algorithm however it looks oversimplified as it does not take into consideration urban conservation areas and parks. Paul is pleased that AONB and trees are considered however there are other aspects that should be taken into consideration:

‘Outside towns and cities, SSSI (Site of Special Scientific Interest), AoSP (Atmospheric and Ocean Sciences Program), country parks and local nature reserves are used for nature conservation and to protect animal and plant wildlife. There are more designations including National Parks and Natura 2000 for larger areas of England and, of course, UNESCO designates World Heritage sites. In some coastal areas, consideration would need to be given to whether lighting schemes could constitute a navigational hazard or if they affect an SMA’ (Ferrari, 2019).

6.3.5 Raj Jagtap

Raj studied an MSc in Urban Design at UCL. He now runs his own architecture company and is part of the Royal Institute of British Architects and Architects Registration Board. His company is a local partner with Brent council building control.

Raj states the following should be considered when designing a lighting installation:

- The kind of human activity for which lighting is to be provided
- The amount of light required
- The colour of the light as it may affect the views of particular objects and the environment as a whole
- The distribution of light within the space to be lighted, whether indoor or outdoor
- The effect of the lightened system itself on the user

Raj also states that the sequence of professional bodies involved in Figure 37 is correct. Raj concluded with 'The objective of lighting design is the human response, to see clearly and without discomfort' (Jagtap, 2019).

6.3.6 Renford Mulley

Renford has 40 years of experience in the lighting industry. He worked his way up from supervisor to manager and is now a Senior Lighting Engineer for Brent Council. A few years ago they upgraded all of the LPS street lights to HPS. Recently they have upgraded these same lights to LED whilst utilising the same columns.

Renford believes all of the necessary professionals have been correctly placed in Figure 37. As a universal street lighting tool to apply to lighting schemes it works well and he would not change anything on it. (Mulley, 2019)

6.3.7 Interview reflection

Alvin Munzi has some great insights into the lighting industry. He confirms the previously discussed statements regarding specific colour temperatures, the need for a lower colour temperature in residential areas and the need for a high CRI where crime and CCTV is concerned.

Paul Ferrari mentions that only wildlife and AONB have been considered, as an experienced surveyor he has knowledge of other protected areas where light pollution is a particular concern.

Michael Rushe's experience shows through his comments. Non-residential buildings were not overlooked; the secondary research simply showed that residential concerns were a higher priority.

Many people were interviewed and asked for their thoughts and opinions on both Figure 37 and the research topic to gain as many valuable insights as possible. The overall consensus is the flowchart is a useful tool for those in the field. However, it has much room for improvement. The main flaw being; if the user wants information on a specific topic it does not guide the user to a specific guideline or more detailed information.

The aim of Figure 37 was to improve efficiency of lighting designers and engineers implementing lighting standards and regulations. Taking on board all of the constructive criticisms from Michael Rushe and Paul Ferrari led me on to my next stage of primary research. It also clarified whether this course of action was felt necessary by professionals in the lighting industry.

7. Questionnaire

The majority of the data collected with the questionnaire was quantitative. This is data in the form of numbers or that which can easily be converted into numbers. Quantitative data analysis uses numerical methods to determine the size of something (Sharp, Rogers and Preece, n.d.). In this case, the questionnaire was designed to provide responses that would help to answer my research question:

What can be done to assist lighting designers and engineers to effectively and efficiently implement lighting standards and regulations?

This question is important as the lighting industry is evolving, as is the technology that surrounds it; such as IoT and dimming. It is crucial that: lighting designers and engineers can not only navigate the standards efficiently but also the content of what they are navigating covers all it should.

Once the questionnaire was finalised, a pilot run was carried out, then, as there were no issues, it was published on to Google forms. This was issued to existing lighting contacts, social media, LinkedIn and lighting groups such as the Society of Light and Lighting and Institution of Lighting Professionals. Appendices 13.2–13.7 shows some of the professionals who shared the questionnaire via LinkedIn and with their colleagues to reach and exceed the target of 50 questionnaire participants.

Participants were introduced to the thesis before answering any questions, see appendix 13.8. The next step was for all the participants to click a button providing consent for the data collected to be used within this thesis, see appendix 13.9. The following questions extracted information about the participant, the lighting standards they use and how they could be improved.

7.1 Participants

Q1. What is your email address?

An email address was requested so that:

- If the questionnaire was mis-filled it could be requested that is was corrected

(Fortunately this did not happen)

- If the results had shown an anomalous result I could contact the participant to discuss this

(This did happen, further clarification was required on a few responses from participants where they did not specify the exact number of the lighting regulation they use. For example specifying 'ILP' instead of 'ILP PLG08')

Due to GDPR and ethics, I have not listed the email addresses or names of participants, however, Appendix 13.1 shows the range of professionals that participated in this data collection.

Q2. Do you consent for me to use the data collected throughout this questionnaire in my thesis?

The target was to achieve 50 participants. Reaching out to people in the field was a slow process. Eventually, the communication moved at such a pace that 74 participants were obtained (see appendix 13.1). One participant out of 74 did not consent for their data collection to be used in this thesis, so those results have been excluded from the data collection. Once the data collection stalled again, the questionnaire was stopped. The results were analysed trends were identified. Not all questions were compulsory, hence some data collections will not have a complete total of 73 participants.

Q3. What is your job role?

The most common job role of the participants was lighting designer (25/73, 34.2%) followed by engineer (20/73, 27.4%). The variation of job roles was larger than anticipated. This is due to the way in which the questionnaire was issued. It was issued by means of posts on LinkedIn lighting groups and word of mouth within the street lighting community. Job roles have been grouped together for ease of data analysis and reading the pie chart (appendix 13.10). I have grouped the following roles under education: 'Photometrist and educator', 'teacher', 'astronomer and science teacher' and 'researcher'.

Q4. What is your involvement in street lighting?

Although this overlaps with the previous question, sometimes it does not. In some circumstances, the participant's job role has nothing to do with street lighting but they might be involved with it

and vice versa. In addition to this, by asking a similar question twice, it can extract additional information that was not extracted the first time. For example one participant stated his job role was an Asset Manager; but followed this up by stating his involvement was: Condition and operation inspection. Once again similar job roles have been grouped to help with data analysis (appendix 13.11). Question 2 results showed more lighting designers than engineers. Question 3 shows a reduced number of lighting designers (19/72, 26.4%), as, for this question they have been more specific in describing their role, which in some circumstances has put them under a different category.

Q5. What is your age?

The perspective and results of each participant will vary depending on their age, career path, and education. The largest age group was 51 – 60 (22/73, 30.1%), followed by 31 – 40 (15/73, 20.5%). Both of these age groups indicate that the participants will be of a mature age and probably have experience in the field. Therefore the data they provide will be of higher value (see appendix 13.12).

Q6. What is the highest educational qualification you hold?

The majority of participants have a postgraduate degree (27/69, 39.1%); the second largest group was undergraduate degree (17/69, 24.6%). The majority of participants have a postgraduate degree, this further adds value to this data collection (see appendix 13.13).

Q7. How long have you been in the lighting industry?

The majority of participants have been in the lighting industry for over 21 years (30/73, 41.1%). The second-largest experience group is 11-20 years (21/73, 28.8%). These results reinforce the remaining data; as it shows it is obtained from people who have experience in this particular field (see appendix 13.14).

7.2 Lighting standards

Q8. Do you refer to the lighting standards as part of your role?

The majority of participants (65/73, 89%) refer to lighting standards as part of their job role. The others may do it as a volunteer, enthusiast or not at all (see appendix 13.15).

Q9. How do you navigate through the lighting standards?

The main focus of this questionnaire is the lighting standards; hence it is key to learn how professionals are viewing and interacting with them. The majority of participants view these online (39/72, 54.2%), which is best practise, as it would normally mean the user would be

notified if the document were to be withdrawn or updated. There are still a large proportion of participants that view these in paper form. Upon further inspection the British Standards are not viewable online. I contacted three of the participants that stated they viewed the British Standards online and they clarified that their organisation downloads them from the British standards website, they then view them as a PDF saved on their local server or hard drive (see appendix 13.16).

Q10. How much time do you spend a week navigating the lighting standards?

The majority of participants (36/71, 50.7%) spend 0 – 1 hour a week navigating the lighting standards; the next largest group (29/71, 40.8%) was 2 – 5 hours. With just these two data sets this equates to a minimum of 52 hours annually per participant (see appendix 13.17).

Q11. Do you see any problems with the lighting standards?

Although the current lighting standards have worked for years, this does not mean there are not issues with them. This questionnaire aims to explore any potential issues and suggest a solution for further development and improvement. The majority of participants (50/71, 70.4%) did see problems in the lighting standards. For example lighting levels in "BS EN 13201-2:2015 - Road lighting. Performance requirements" not being based on scientific data (see appendix 13.18).

Q12. Do you know about all the standards relevant to your role?

Whether or not users are aware of the standards relevant to their role, will help to illustrate how publicly accessible and well known they are. Fortunately, the majority of participants (54/72, 75%) answered yes to this question (see appendix 13.19).

Q13. Which lighting standards do you utilise?

Question 13 obtained a significant collection of data. Appendix 13.20 displays all of the standards and guidelines that the 73 participants use. The participants are split into various categories, which have corresponding colours as displayed in the key. To make more sense of the data collection, Appendix 13.21 only displays standards that 5 or more participants use. This removes anomalous results such as TSRGD and UNI 11248. Unfortunately some participants did not specify which standard(s) in particular they use. They may have entered the generic category such as British Standard or ILP.

Trends identified:

- Engineers most used: BS 5489 (6 participants)
- Engineers second most used: BS EN 60598 (4 participants)
- Lighting designers most used: BS 5489 (13 participants)
- Lighting designers second most used: BS EN 13201 (9 participants)
- Managers most used: BS 5489 (7 participants)
- Managers second most used: BS 13202 (4 participants)

No trends were identified amongst the rest of the participants. Appendix 13.21 illustrates that the most commonly used standards of the participants were British Standards and ILP. The data collected shows BS EN 5489 and BS EN 13201 to be the most commonly used amongst participants. These standards are further divided into categories, which unfortunately have not been specified in the data collection. An example of this, is a participant stating they use BS 5489, instead of specifying BS5489-2:2016). Fortunately some of these subdivisions are no longer in use, this clarifies which ones are active. The same applies for the ILP collection, although not specified it is likely most of the ILP entries are for ILP PLG 08. Below is a brief description of these standards:

- **BS 5489-1:2013**

  Code of practice for the design of road lighting.

  Lighting of roads and public amenity areas
- **BS 5489-2:2016**

  Code of practice for the design of road lighting.

  Lighting of tunnels
- **BS EN 12464-1:2011**

  Light and lighting. Lighting of workplaces.

  Indoor workplaces
- **BS EN 13201-2:2015**

  Road lighting. Performance requirements
- **BS EN 60598-1:2015**

  Luminaires. General requirements and tests
- **ILP PLG08**

  Guidance on the application of adaptive lighting within the public realm

Appendix 13.21 still had a vast array of participants, some of whom were not lighting designers or engineers. The street lighting tool was aimed to assist lighting designers and engineers. Hence why appendix 13.22 further filters down this data collection to professionals from only these two backgrounds.

7.2 Room for improvement

Q14. Do you feel the British Standards covers all the content needed in terms of road lighting and future factors?

If it is apparent that the British Standards already covers all the required content from practitioners; then there is no need to consider iterating them, however as appendix 13.23 shows the majority (49/73, 32.9%) believe this is not the case.

Q15. In the standards you use or are familiar with, do you believe the correct units of measurement have been used?

When reading through various papers alongside lighting standards it is apparent that there are many units in the world of lighting. Some overlap each other and are superseded by new ones much like metric and imperial. The majority of participants answered yes (54/73, 74%); however, there is still a considerable amount of participants that stated they do not believe the correct units have been used within the standards they use (see appendix 13.24). This question should have been better worded to extract this information from the participants regarding what units in particular, and which is preferred.

Q16. Do you feel concerns of LED lighting , health and glare are covered adequately in lighting standards?

It is clear that LED is lighting the way of the future. It is not clear to see this in the British Standards, however. Hence why the majority (17/73, 23.3%) of participants answered no to this question (see appendix 13.25).

Q17. Do you think developing technologies such as 5G; IOT and street light dimming should be mentioned in the standards?

This thesis highlights future technologies that could be incorporated into street lights. The majority of participants (57/73, 78.1%) believe this would be a good addition (see appendix 13.26).

Q18. How about more established topics like blue light emission?

Blue light emission is a growing concern that the public is being made aware of. The problem is growing with the public being surrounded by more lights and screens on a daily basis. Yet the lighting standards do not go into depth about how blue light emission should be dealt with or avoided. Most participants (58/73, 79.5%) stated this should be covered within the standards (see appendix 13.27).

Q19. Do you think an interactive tool guiding users based on their profession to the location of standards; further information and additional guidance would be useful?

The majority of participants (94.5%, 69/73) would support this concept, as it is likely to make their jobs easier and also reduce paper waste (see appendix 13.28).

Q20. What would suit you best?

If an interactive tool would be useful to professionals, it is necessary to know the format in which users would utilise it. Most participants (43/71, 60.6%) chose website. Regardless of whether the user is on a phone or computer, the website still could be accessed (see appendix 13.29).

Q21. What do you think should be stated in regards to these topics?

Topics such as 5G and street light dimming have a large amount of content surrounding them. It is necessary to know if professionals feel these should be discussed within lighting standards. The data collection for this question is qualitative. By using thematic analysis the responses have been grouped for data analysis purposes in appendix 13.30. This question was not compulsory; hence some participants left it blank. Some participants wrote a response that covered more than one of the slices shown in appendix 13.30. The following three groups were equal with participant responses: Blue light, keeping up-to-date and standards defined. Insights summarised from this question are stated below:

- **Blue light** (10/47, 21.3%) – Participants state that more guidance is required on blue light emission and the implications it has on people's health.
- **Keeping up to date** (10/47 21.3%) - Many new technologies are being used and implemented such as CMS, however, this is not discussed in lighting standards, which it should be. Any new and developing technologies should be discussed for future-proofing purposes. Dimming is implemented in numerous areas, however we are yet to see a methodology on how these dimming levels have been determined.
- **Research / referencing** (7/49, 14.9%) – Lighting guides should be supported by background research. Most things are not referenced for example the process of selecting class of lighting. It should be stated what is mandatory and what is advisory. Existing research is already out there in ILP guides. We need to know what is 'good lighting for vision'; this is difficult to define using lux or cd/m^2.
- **Environment / Health** (6/49 12.8%) – More information should be provided in terms of the harmful effects of light pollution on our health such as circadian rhythms.

The remaining slices of appendix 13.30 did not have useful qualitative data attached.

Q22. Thanks for participating in this questionnaire. Your time is much appreciated. If you feel there is anything you wish to add, please do so below.

Just like question 20, this is also a qualitative collection however by using thematic analysis the responses have been grouped for visualisation purposes in appendix 13.31.

- **Guidance** – Most of the lighting standards and guidelines are expensive and not affordable by some volunteer or charity organisations (5/21, 23.8%). The following points need adding into future guidelines: glare, blue light, guidance on introducing lighting into unlit roads, consideration for seasonal changes and how lighting requirements may vary.
- **LED** – The implementation of LED information in guidelines is long overdue hence why many LED installations are flawed (2/21, 9.5%).
- **Survey** – A few participants mentioned that some of my questions should have had extra options for NA or a box for their own answer. A few also mentioned they are happy to be contacted in the event I wanted to discuss their responses further (4/21, 19%).
- **Other** – These did not have anything in common with each other. The most valuable one was: 8 million street lights in the UK, very soon all of which will be LED. The standards are not catching up at the same pace (4/21, 19%).

In some circumstances, funding is not available for new lighting systems. This results in authorities taking cheaper options, which do not comply with standards. This is often the cause of over-lit or under-lit areas. Local authorities do not have the technical knowledge on specifying a lighting plan, which would comply with regulations.

The data collected illustrates the majority of participants are lighting designers and engineers aged between 31-60 (more so towards the 51-60 category). The majority of these professionals have a postgraduate degree and have been in the lighting industry for over 21 years. These professionals refer to the standards online and spend between 0-1 hour weekly using them. This is a considerable amount of time when viewed from an annual perspective; even more so when the number of professionals using these standards is considered. If something could be implemented to reduce this time it would be very useful. The most commonly used standard throughout the data collection was BS 5489. This spanned a few different professions including lighting designers, engineers and managers. The majority state that the British Standards does not cover all content needed in terms of road lighting and future factors.

By carrying out this data collection new research questions have arisen:

Q1. What are lighting designers looking for in the standards?

A1. Lighting designers are looking for:

The most relevant up to date information concerning the topic of the project they are working on. The standards should be easy to navigate and would benefit from being digitalised into an interactive website (Question 19) guiding them based on their profession to the location of standards, further information and additional guidance (Question 21).

Q2. What are the current flaws in the lighting standards?

A2. The current flaws in the lighting standards are:

The participants are aware of all the standards relevant to their role and state they are flawed in some way. The following topics need to be discussed further within the standards:

- The impact of lighting on health
- Glare
- Blue light emission
- New technologies such as 5G, IoT, CMS and dimming
- Where figures are stated these should be supported by research. Where lighting levels are stated, methodologies should be given to show how the lighting levels are determined.

The above answer has been concluded by analysing the complete data collection, in particular:

- Question 17
- Question 18
- Question 21

8. SLSNF

As a result of the primary research carried out (interviews, questionnaire) and secondary research (literature review) carried out the Street Lighting Standard Navigation Framework (SLSNF) was designed and evaluated.

The comments and data received from the 73 participants of the questionnaire directed the thought process for the design of Figure 38, SLSNF Sketch. After some discussion and user testing this was then developed on 'draw.io' shown in Figure 41; this is the research outcome. By allowing users to immediately search for the topic or phrase required should eliminate the process of navigating a complex British standards contents page.

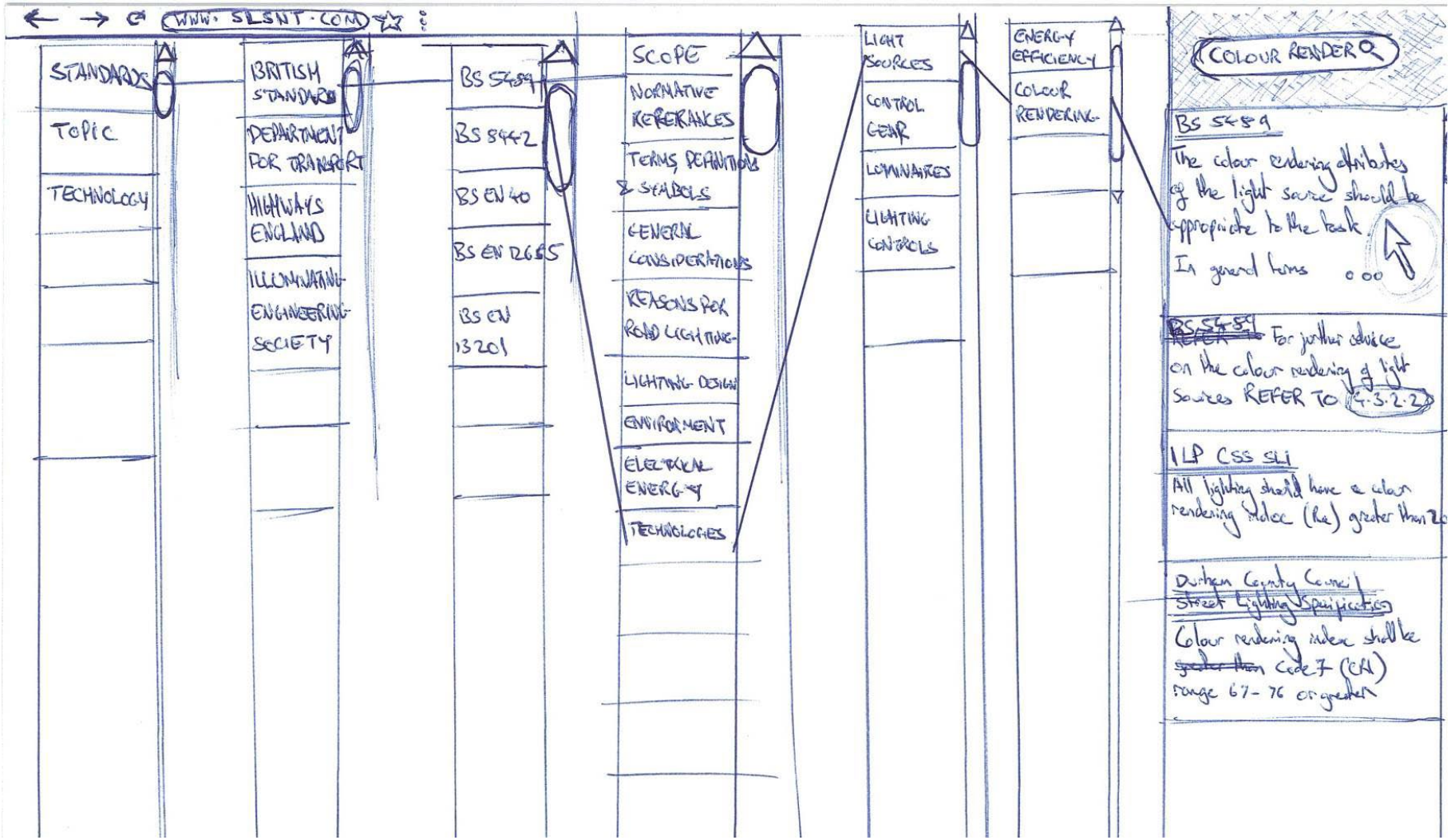


Figure 38. SLSNF Sketch

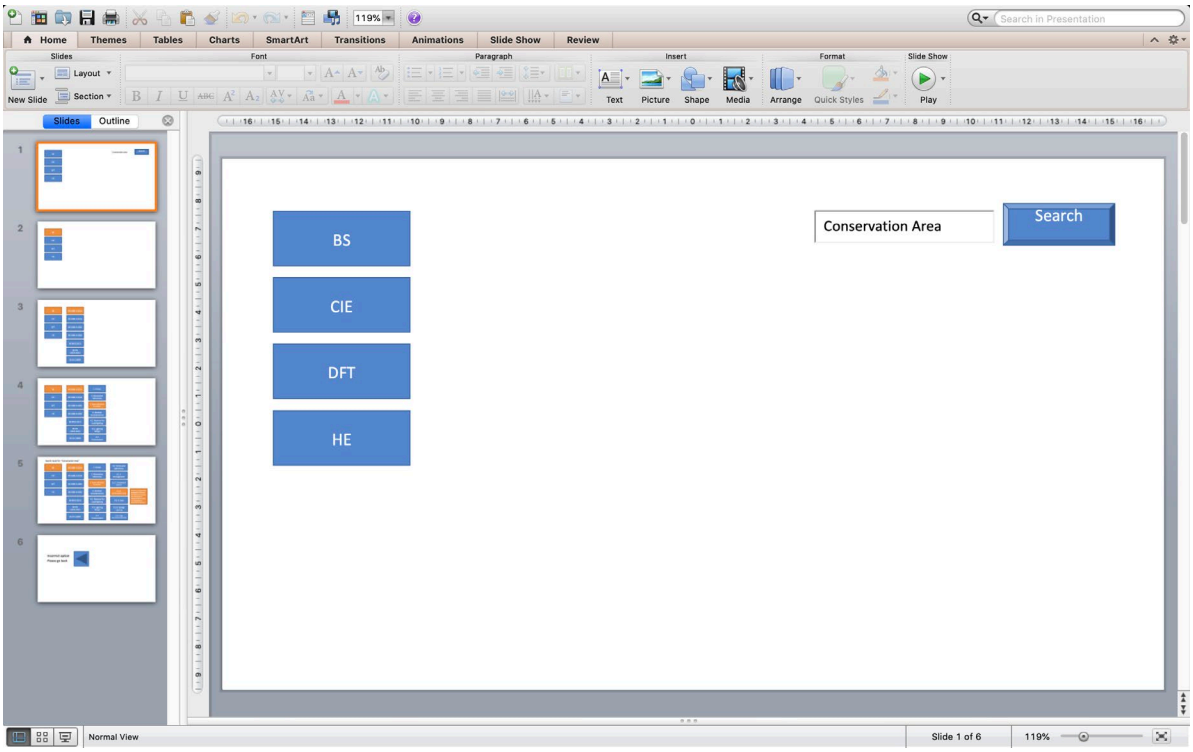


Figure 39. SLSNF Powerpoint 1

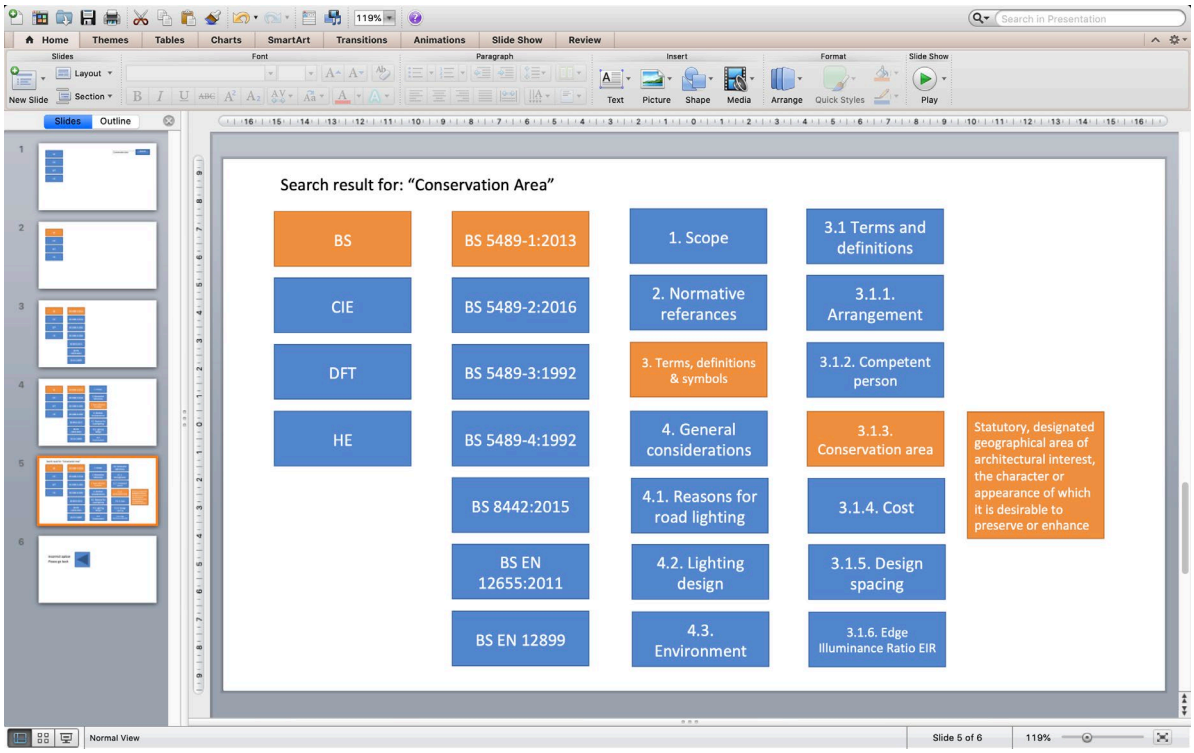


Figure 40. SLSNF Powerpoint 2

I tried to develop a basic interactive framework in Microsoft PowerPoint using buttons and slides. I realised it is impossible for a search function to work as desired. All searches would land on the same page. To overcome this problem I developed a paper prototype using draw.io.

To evaluate this tool, I asked volunteers to use it. Three participants were asked to complete the three tasks below. First, they were asked to complete it by means of PDF British Standards on a computer of their choice, following that they were asked to complete it by means of the SLSNF.

- At low light levels, what S/P ratio gives improved performance?
- What unit is used to measure the average road surface luminance?
- Define: EIR

They were timed and observed during both exercises in controlled conditions. They were asked the following questions once they had completed their tasks.

- How do you feel about Street Lighting Standards Navigation Framework (SLSNF)? Please explain your answer
- If this was developed into a usable website, would you prefer to use the website or refer to the lighting standards as you did previously? Please explain your answer
- What could be made better about this tool besides the fact this is a paper prototype? Please explain your answer

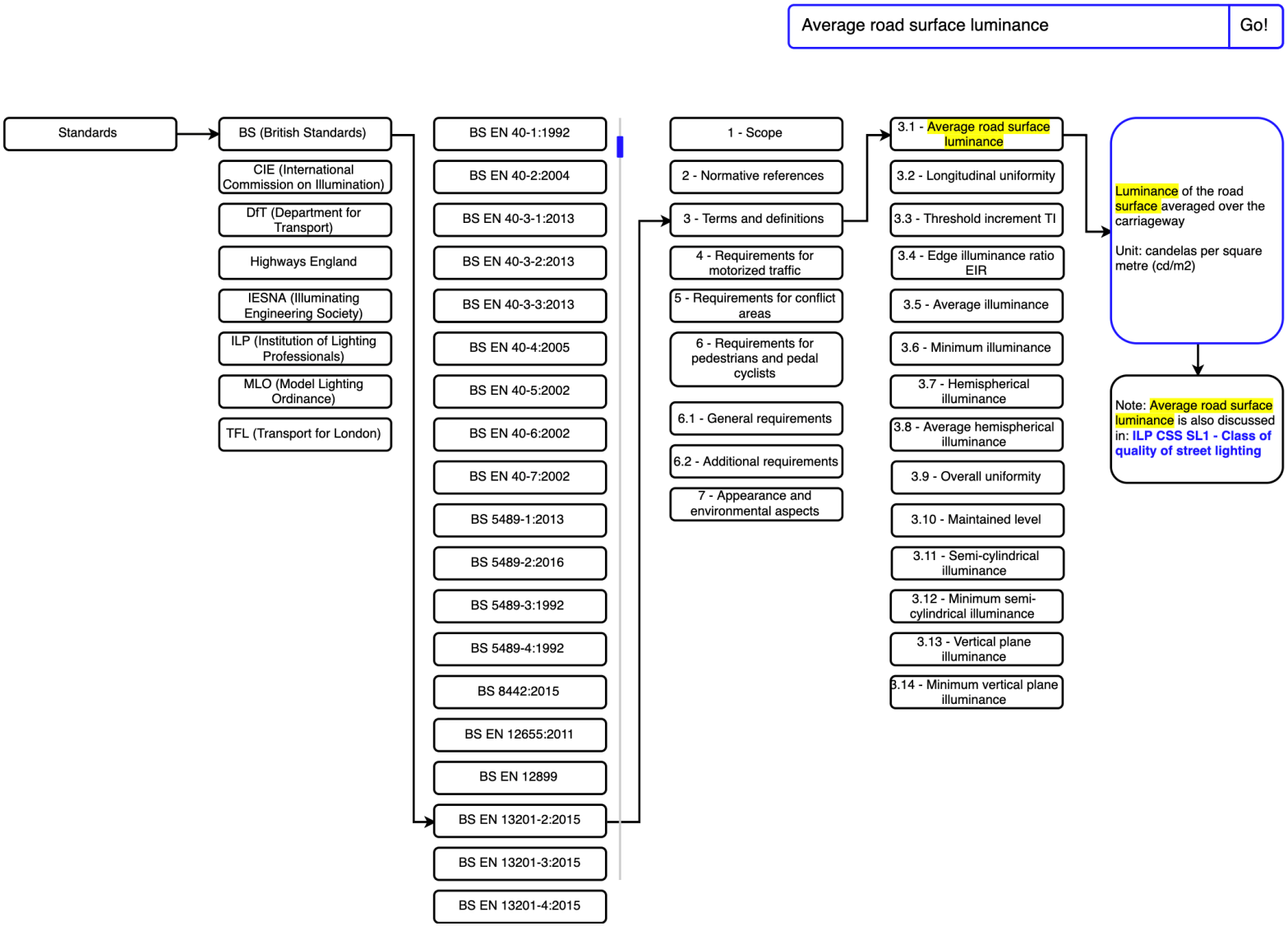


Figure 41. SLSNF - developed on draw.io

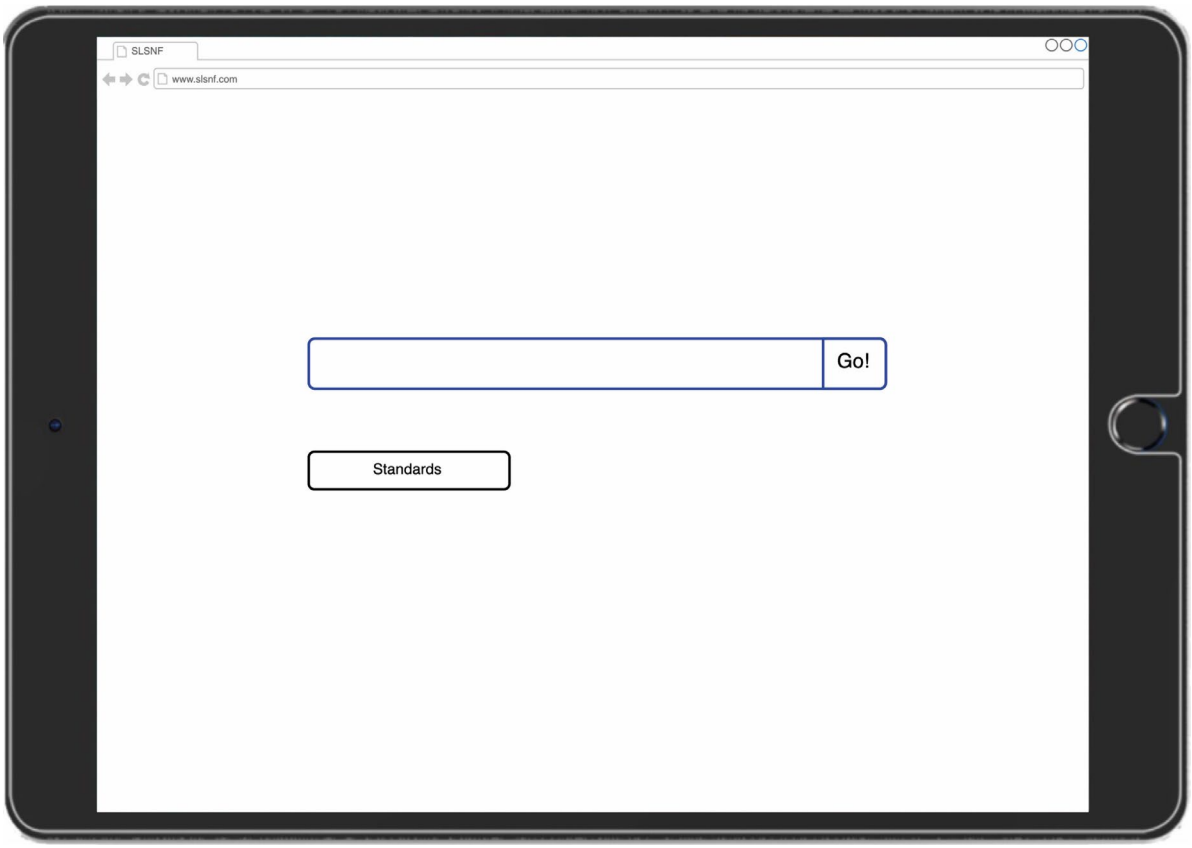


Figure 42. SLSNF – Home page

Figure 43. SLSNF – Home page with keyboard

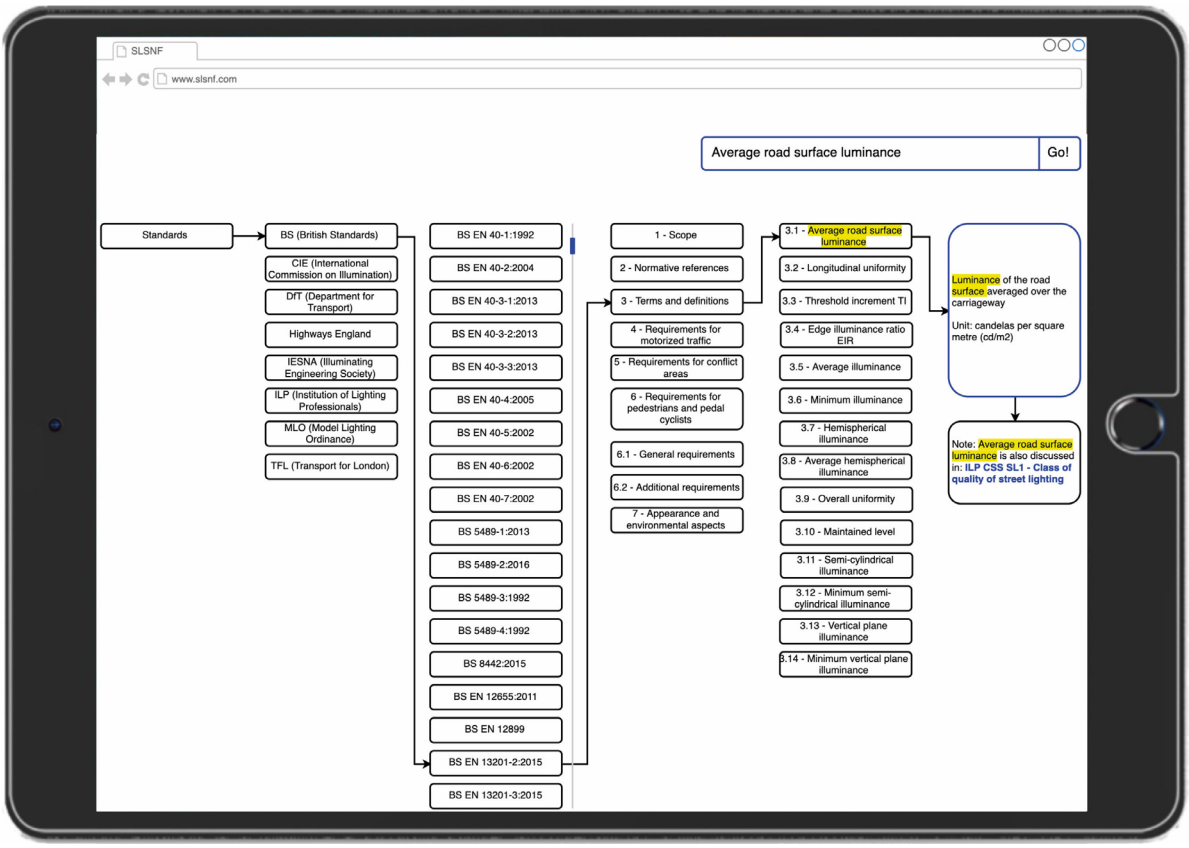


Figure 44. SLSNF – Search: Average road surface luminance

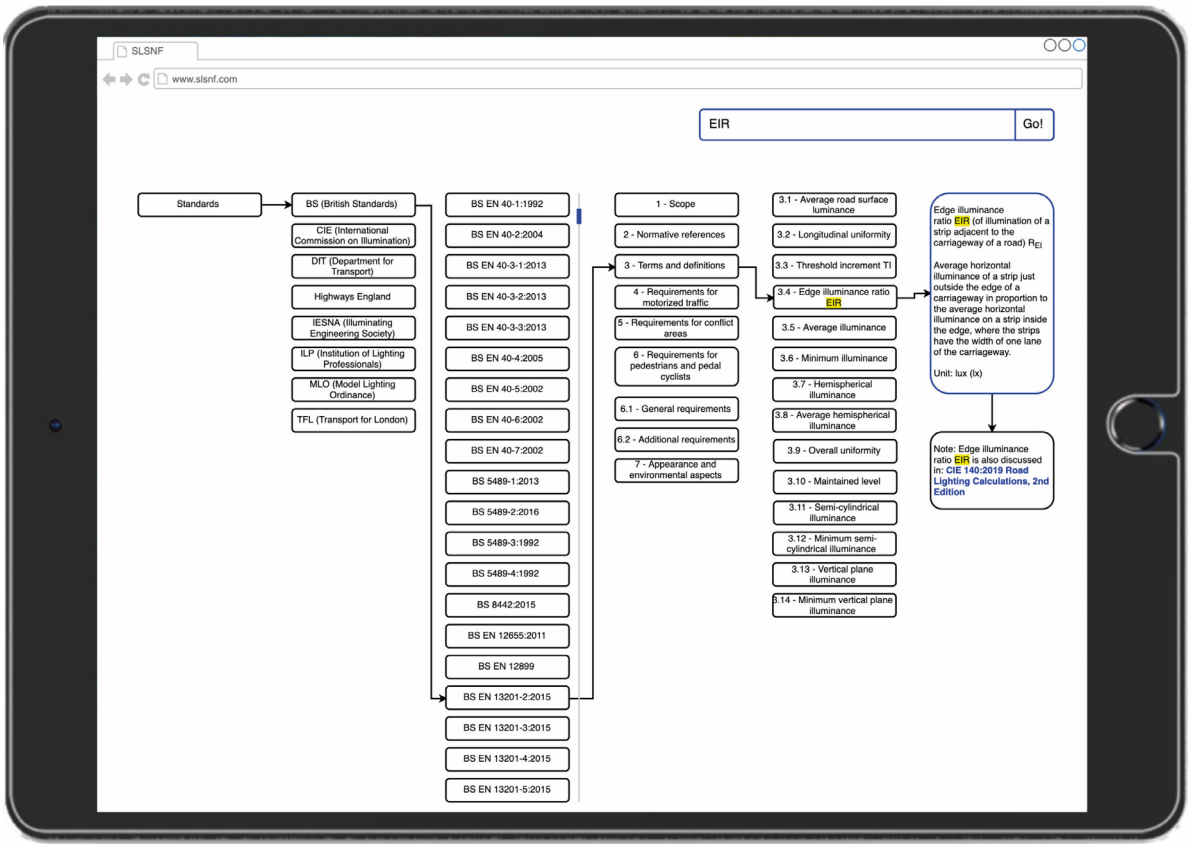


Figure 45. SLSNF – Search: EIR

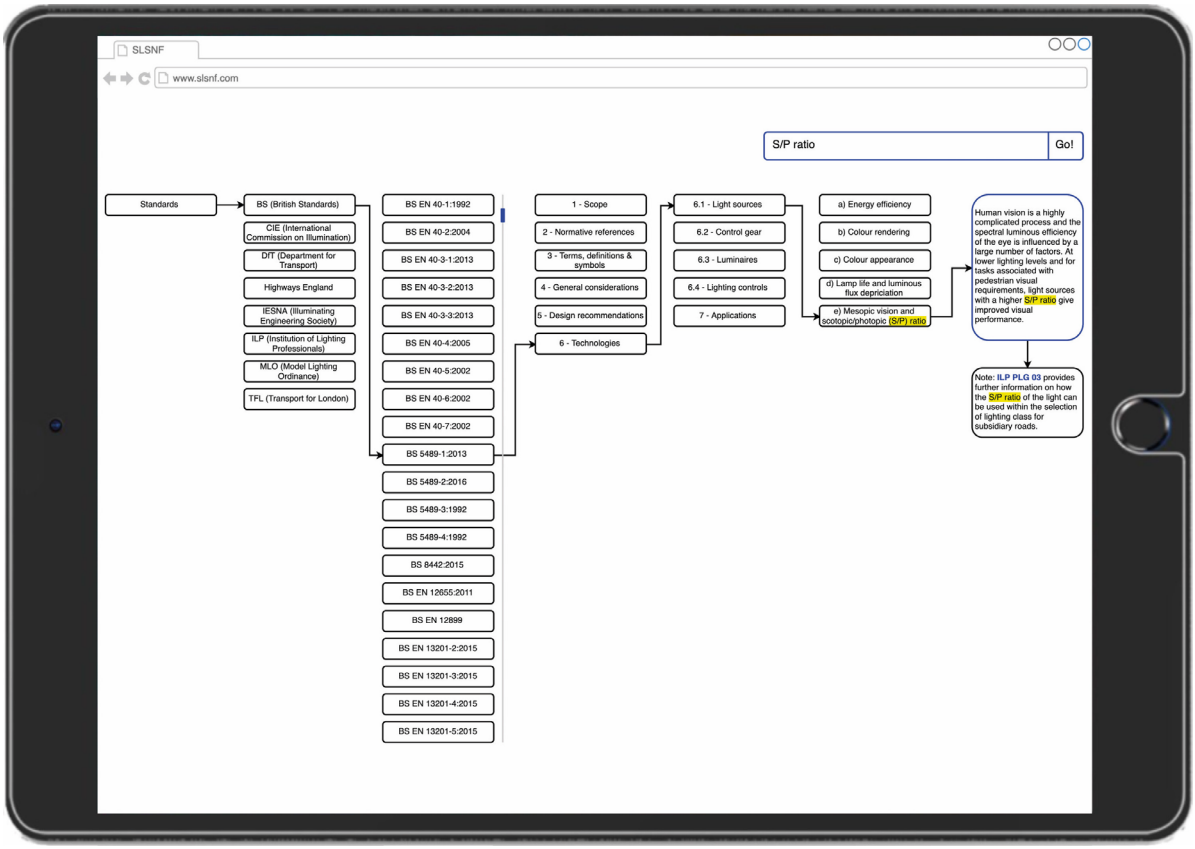


Figure 46. SLSNF – Search: S/P ratio

8.1 SLSNF Testing

Three participants were asked to evaluate the SLSNF. For the evaluation to be as useful as possible, it would involve the lighting designers and engineers involved in street lighting who fall into the majority categories from my questionnaire. Unfortunately this was not possible. The next closest group of people available were post-graduate degree participants that teach electronics or computer science. All of these participants have a good understanding of LED technology, blue light and IoT. They all have a basic understanding of street lighting and the standards that surrounds them.

Participants were timed using a stopwatch and were given a brief explanation of how they could navigate through the PDF standards, and how they could navigate through the SLSNF.

The results shown in Figure 47 confirm that there are better ways of navigating to key bits of information regarding street lighting than the current method. The SLSNF shows an improvement in navigation time compared to British Standard PDFs in all circumstances.

8.1.1 Participant 1

Task 1. At low light levels, what S/P ratio gives improved performance?

BS. Participant 1 opened the first British Standard on the list in front of her, which was BS 5489-1-2013. She scrolled through and did not find what she was looking for. By complete luck, she was in the right British Standard document. She searched 'S/P ratio' within the body of the text and did not return any results.

SLSNF. Participant 1 was stuck on the home page for at least 20 seconds. If this were an actual iPad instead of a paper prototype, the delay would have been less. Eventually she touched the URL instead of the websites search bar. The timer was stopped at this moment. As she was not supposed to divert from the SLSNF.

Task 2. What unit is used to measure the average road surface luminance?

BS. Participant 1 had a much better understanding of the website and the BS PDFs now. She searched the key term 'average road surface luminance' within BS 5489-1:2013, which received zero results. She opened her search to just the term 'luminance' which again received zero results.

SLSNF. I quickly explained that all the information required is within SLSNF and that she should not divert from that web page. She understood and searched the question 'what unit is used to measure the average road surface luminance'. Because the full text does not appear in the standards, zero results were returned. She then opened her search up to 'average road surface luminance' and landed on the correct page.

Task 3. Define: EIR

BS. Participant 1 entered the letters EIR in windows explorer which reduced the number of PDFs. She clicked on the first one which was BS5489-1-2013. The text within this document is not searchable so no results were found. She went to the next PDF which was BS 13201-2:2015, searched EIR and landed on the correct page.

SLSNF. She typed the letters EIR and quickly landed on the correct page.

Question 1. How do you feel about Street Lighting Standards Navigation Framework (SLSNF)?

It seems like a useful tool for those who would use it on a daily basis.

Question 2. If this was developed into a usable website, would you prefer to use the website or refer to the lighting standards as you did previously?

Website in the hope of keeping up to date and saving time.

Question 3. What could be made better about this tool besides the fact this is a paper prototype?

Some instructions are needed; it is not obvious the search bar is how to navigate. Also, the website should have a logo and title on the home page.

8.1.2 Participant 2

Task 1. At low light levels, what S/P ratio gives improved performance?

BS. Participant 2 clicked on a random British Standard, which did not have the information required. After a lot of persistence, he eventually found the relevant page.

SLSNF. Participant 2 understood how to use the website. He searched the term ratio and immediately landed on the correct page.

Task 2. What unit is used to measure the average road surface luminance?

BS. Participant 2 searched 'average road surface luminance', which did not remove many PDFs from the results. He searched the term road surface within BS5489-1-2013, which did not return any results.

SLSNF. Participant 2 searched 'road surface', this landed on the right page and highlighted the units are cd/m^2.

Task 3. Define: EIR

BS. Participant 2 searched the term 'e i r' first, which returned zero results. He then searched 'eir'. This search found a few BS standards. He clicked on BS5489-1-2013, searched 'eir' found no results. He proceeded to click on BS 13201-2:2015 and searched 'eir'. Again no results were found. He was frustrated and clicked on the last PDF - BS 13201-3:2015. He searched 'eir' and found that it stood for Edge Illuminance Ratio.

SLSNF. Participant 2 searched 'eir' and was taken to the correct page.

Question 1. How do you feel about Street Lighting Standards Navigation Framework (SLSNF)?

The SLSNF appeared good and easy for me to read. The tabled layout is easy and quick to grasp and follow.

Question 2. If this was developed into a usable website, would you prefer to use the website or refer to the lighting standards as you did previously?

I think the SLSNF is easier to read. It is more user-friendly.

Question 3. What could be made better about this tool besides the fact this is a paper prototype?

The addition of an index for abbreviations used would help as the table descriptions by their very nature have to be brief to fit in small boxes.

8.1.3 Participant 3

Task 1. At low light levels, what S/P ratio gives improved performance?

BS. Participant 3 searched 'S/P ratio', this returned a few results. After a few minutes of scanning, he managed to find the required information.

SLSNF. Participant 3 searched 'S/P ratio'. This immediately landed on the correct page.

Task 2. What unit is used to measure the average road surface luminance?

BS. Participant 3 searched 'road surface'. This returned too many results to scan through. He narrowed his search by entering 'average road surface luminance'. Still, there were over 20 documents. He searched: 'average road surface luminance unit', this returned over 20 results. After seeing it was not in the first PDF he clicked on, he gave up.

SLSNF. Participant 3 searched 'average road surface luminance'. This landed on the right page and highlighted the units are cd/m^2.

Task 3. Define: EIR

BS. Participant 3 searched the term 'EIR'. This returned 3 British Standard PDFs. He clicked on BS 13201-2:2015. He searched EIR within the PDF which returned zero results. He went back to windows explorer and opened BS 13201-3:2015. He searched EIR within the document and found the abbreviation Edge Illuminance Ratio.

SLSNF. Participant 3 searched EIR into the search box. This brought up the relevant standard and the abbreviation.

Question 1. How do you feel about Street Lighting Standards Navigation Framework (SLSNF)?

It is more direct and less time consuming

Question 2. If this was developed into a usable website, would you prefer to use the website or refer to the lighting standards as you did previously?

I would use the website as it less time consuming

Question 3. What could be made better about this tool besides the fact this is a paper prototype?

I believe users would benefit from a video tutorial. When SLSNF shows zero results, there should be a prompt saying 'try to be less specific' or some keywords. It would be great if you could ask the app any question and it could decipher it just like Google.

8.2 SLSNF Summary

	P1 BS	P2 BS	P3 BS	P1 SLSNF	P2 SLSNF	P3 SLSNF
Task 1	DNF	45s	300s	DNF	10s	13s
Task 2	DNF	DNF	DNF	16s	8s	9s
Task 3	35s	50s	123s	11s	8s	4s
Mean Averages	35s	47.5s	211.5s	21.5s	8.7s	8.7s
Summarised Mean Average	BS: 294s			SLSNF: 38.9s		

Figure 47. SLSNF – Search: S/P ratio

Figure 47 shows that the SLSNF is over 7 times faster in extracting information from the British standards as opposed to navigating PDFs. However further testing is required. These participants are not lighting professionals. This testing can be viewed as a pilot run to test the tools usability. Further testing should be carried out on the SLSNF with professionals from the street lighting industry that frequently use the lighting standards.

If this testing was carried out it is likely there would not be any case where the participant did not finish (DNF). Street lighting professionals rely on the standards as a part of their job.

They would also be faster at navigating to the information by means of PDFs. Hence SLSNF would still be faster, but not as great an extent as 7x.

At this stage, SLSNF is only a paper prototype and would require further website based development with buttons and pages.

SLSNF has received positive feedback from users and also an improvement in navigation times. Most people find it problematic navigating through the British Standards. By developing SLSNF provides the opportunity for the public to navigate these standards and also allows a reduced time in navigation for professionals. A common problem found when using the British Standard PDFs is that sometimes the body of text is not searchable, other times it is. Hence even if the information is in the PDF, if it is searched for; it is not always found. SLSNF relies on a body text and would be developed in a way so that every term within the body of text is searchable.

Discussions with the SLSNF participants can be summarised in the following bullet points; development of the SLSNF would benefit from:

- Some instructions, perhaps a video tutorial
- Development of the search function so it can be asked any question, even if the text in the standards does not have all the text entered in the question. For example: 'How many lumens should a street light emit?'
- An index for all abbreviations
- A logo and some branding (This was deliberately not included in the prototype)
- Voice recognition

9. Synthesis

Evaluation is essential to the design process. Collecting information on user experiences when interacting with the SLSNF will clarify the areas that needed improving to develop its design. A common mistake of designers is: for them to design for themselves. By evaluating opinions from others, this tells us if the tool suits the wider population. Evaluations typically involve observing or measuring the performance of participants.

For this evaluation, the method of controlled cooperative evaluation was used. Participants were in a controlled setting so they could be observed and timed as they navigate through the (SLSNF Figure 41). This is a proven successful method (Sharp, Rogers and Preece, n.d.). It is best for this scenario as it reduces outside influences and distractions.

The first step of qualitative data analysis is to understand an impression of the data and begin to identify patterns. Once the data becomes more familiar themes and patterns will emerge. It is important to check and double-check that these trends or patterns are not viewed with bias and that the data supports them sufficiently (Sharp, Rogers and Preece, n.d.).

Appendix 13.20 illustrates the data collection for question 13: 'Which standards do you utilise?', showed a vast data collection of a variety of standards and professionals. This was filtered down in appendix 13.21. From appendix 13.21 it has been observed that 36 of the 73 (49%) participants are either lighting designers or engineers. Therefore any further primary research should be aimed at lighting designers or engineers to ensure its validity. I needed to contact some participants that did not state which in particular British Standard or ILP guide they meant. Appendix 13.22 further filtered down these results by only showing entries from lighting designers or lighting engineers (as these professions were the target audience).

There are currently standards and guidelines from numerous bodies including the British Standards, ILP, DFT, IESNA and more as explored throughout the literature review (chapter 3.2.2). When reading these standards and guidelines to build the literature review it became apparent that a navigation tool would be of great use. This is reinforced by the feedback provided on Figure 37 by means of interviews (chapter 6.3). This view is further built upon by the questionnaire data collection in chapter 7.

The majority of the professionals who participated in the questionnaire (36/71, 50.7%) spend 0 – 1 hour a week navigating the lighting standards; the next largest group (29/71, 40.8%) was 2 – 5 hours. This is a vast amount of time when the number of professionals using the lighting standards is taken into consideration. Hence if it were possible to reduce this time even fractionally by means of a navigating tool this would be highly beneficial. The data collected from question 19 shows that 43/73 (60.6%) of participants would prefer this interactive tool to be based on a website.

Data collected from question 21 states it is difficult keeping up to date. By the time technology is released and implemented, lighting standards are often out of date. It was also mentioned that it would be beneficial to see how the standards from different organisations tied together; which is where a tool or framework would be beneficial over a collection of PDFs. Lighting professionals want to know about lighting implications on health and blue light regulations. A colour coding system could be implemented to identify which points are advisory and which are mandatory.

The British Standards are only available as PDFs or paper copies, there is no online browser. This reinforces the demand for an online street lighting standard navigation tool. From the insights gathered a framework should be developed as opposed to a tool. The difference being is that a framework is an open-source item and allows others to contribute helping to populate it much like an ncyclopedia.

The secondary research carried out throughout the literature review (chapter 3.2.2.) highlighted that there are some missing aspects within the current lighting standards and regulations. An example of these are: colour temperature and light pollution. This was reinforced in chapter 6.3 by Alvin Munzi and Michael Rushe. Further insights arose from the questionnaire data collection in chapter 7, which highlight these gaps of knowledge in the lighting standards and regulations.

The data collected throughout the interviews clearly reinforces that a tool to help navigate through this would be beneficial to all professionals. The same can be concluded from the comments on Figure 37 achieved by means of interviews. The SLSNF had positive feedback and achieves the task it was developed for; increase the efficiency of lighting designers and engineers navigating the lighting standards and guidelines.

10. Conclusion

There are many organisations and governing bodies who all have their unique views on road lighting or a specific aspect of it, some of which conflict. The International Dark Sky Association works to protect the night sky from light pollution, however, the British Standards, for example, enforces that light must be emitted in certain locations to ensure motorists, pedestrians and cyclists have sufficient visibility.

This thesis has highlighted some essential factors that must remain, no matter what the future of road lighting holds. It has discussed potential new technologies that can help to better our lives. Initially, the aim of this thesis was to develop a framework for the future implementation of street lights. After extensive research, it became apparent that there are several governing bodies all with their own individual frameworks focusing on specific areas. Instead of repeating existing work, SLSNF was developed as a result of the questionnaire data collection. The user testing shows positive results, with a decrease in navigation time when compared against the traditional method of navigating through the British Standard PDFs.

Do designers and engineers efficiently navigate the current standards in place regarding road lighting?

No, the reason being is that there are over 50 documents from an array of different organisations, it is difficult to navigate to a single regulation if needed. The questionnaire results clearly show that users would benefit from an interactive navigating tool to find key terms. With the development of the SLSNF, the street lighting regulations and guidelines are easier to navigate, search and keep up to date. Professionals such as urban planners and lighting engineers must work together on projects such as a large street lighting installation. By doing so the work will progress at a productive rate and be of a higher quality (Mind the Product, 2018; Marinov, 2018).

This research project has unearthed many topics for discussion. Road lighting is intertwined with an array of subject areas. Writing this thesis has put me in good stead to be a more active member in the field of lighting and potentially lead me to a career in lighting design.

11. Recommendations

All of the aforementioned governing bodies, despite their different locations and various backgrounds, share a common interest: combatting light pollution.

This thesis has raised key elements which should be highlighted for current and future installations of any street lighting; as well as future elements to take into consideration.

It would, however, be highly beneficial for governments, designers and engineers all over the world, if the IDA, ILP, BS, IESNA and DfT and other organisations associated with lighting (these are mapped in Figure 48), united to develop SLSNF as a user-friendly up to date website accessible to all.

Duplicate and unnecessary terms should be removed and made easier to understand, such as 'Surround Ratio' and 'Edge Illuminance Ratio', T_{cp} and colour temperature (K). An agreement should be made so that the same units are used throughout, to eliminate unnecessary confusion. Reference to existing established units should be used when possible; such as candelas, lumens, lux and kelvins.

As stated in chapter 2.4, the SLSNF has been proved successful in terms of its usability; however to confirm its industry value, a data collection should be carried out with lighting professionals testing it.

With so many experts in the field (see Figure 48) and such a great collection of knowledge (see Figure 49), it provides a great opportunity for unification, collaboration and the adherence to individual mission statements with the development of one concise framework stating specifics and technical data on all of the factors mentioned in this thesis.

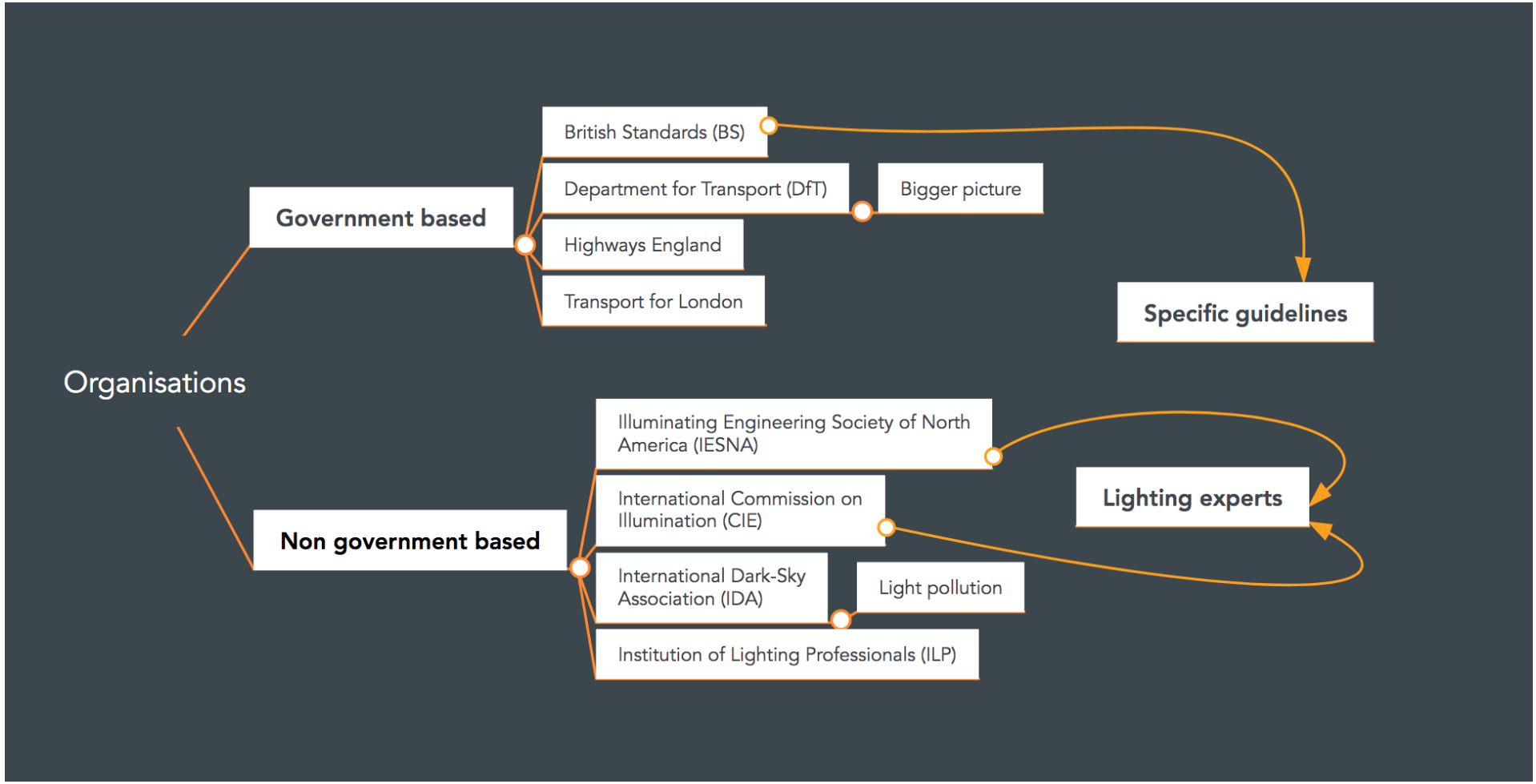


Figure 48. Governing bodies, developed by Ajay Parmar, using www.mindmeister.com

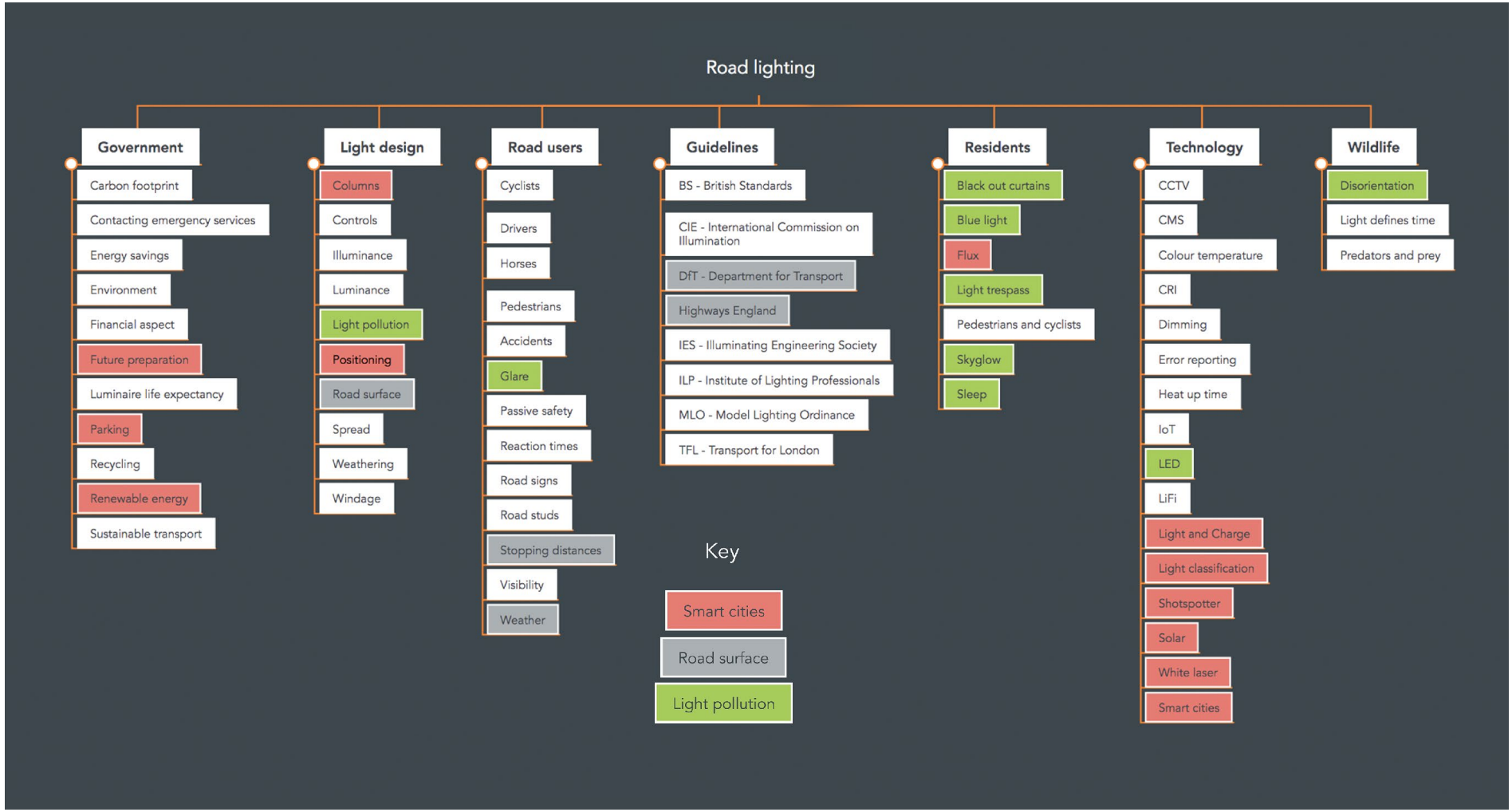


Figure 49. Road lighting and associated factors overview, developed by Ajay Parmar, using www.mindmeister.com

12. Appendix

- Akira Yamanaka Architects
- Anglia Ruskin University
- Ansell UK, Is a recognised market leader in the design and manufacture of high-quality luminaires for the commercial, domestic, industrial and architectural markets.
- BuroHappold, An international, integrated engineering consultancy. Delivering creative, value led building and city solutions for an ever-changing world
- CIBSE, Chartered Institution of Building Services
- CIE, International Commission on Illumination
- Citylum, Nature-friendly and human-centric approach with the latest smart technology for street lighting applications including features for Smart City integration
- City of London
- CU Phosco, Leader in high mast lighting
- Design for lighting, Lighting Design Consultants
- Dundee City
- DW Windsor Lighting, A service-led British manufacturer of exterior lighting
- FDD Studio, Creative Design Experience
- GFZ German Research Centre for Geosciences
- The national research centre for Earth Sciences in Germany, and is part of the Helmholtz Association of National Research Centres
- Hackney council
- Hampshire council
- Hoare Lea, Engineer consultants
- Hounslow highways, The highways service provider working on behalf of the London Borough of Hounslow
- ICE Architects
- ILP, Institution of Lighting Professionals, the UK and Ireland's largest and most influential professional lighting association
- Innovision Design, An international design company providing value-driven light, water and space solutions for built environment.
- Kent council
- Kingfisher lighting, Provided superior exterior lighting solutions for various applications, for over 30 years.
- LBHF, London Borough of Hammersmith & Fulham
- LIA (Lighting Industry Association), The largest trade association in Europe dedicated to serving the UK Lighting Industry and its supply chain
- Lumicom, The UK's leading independent not-for-profit WEEE Compliance Scheme set up to specifically serve the lighting industry
- Newham council
- Pamplona Planetarium, Spanish planetarium known for its educational focus, offering immersive audiovisual productions & workshops.
- Portsmouth council
- Ramboll, Structural and civil engineering
- Signify, Signify is the new company name of Philips Lighting.
- Skanska construction, Skanska AB is a multinational construction and development company based in Sweden
- Suffolk Highways, the highways service provider working on behalf of the Suffolk county council
- TRT Lighting, Thorlux Road and Tunnel Lighting
- Vodafone, 2018 Mobile Network of the Year

Whitecroft Lighting, Whitecroft Lighting is one of the UK's largest manufacturers of commercial lighting solutions

Appendix 13.1. Background of questionnaire participants

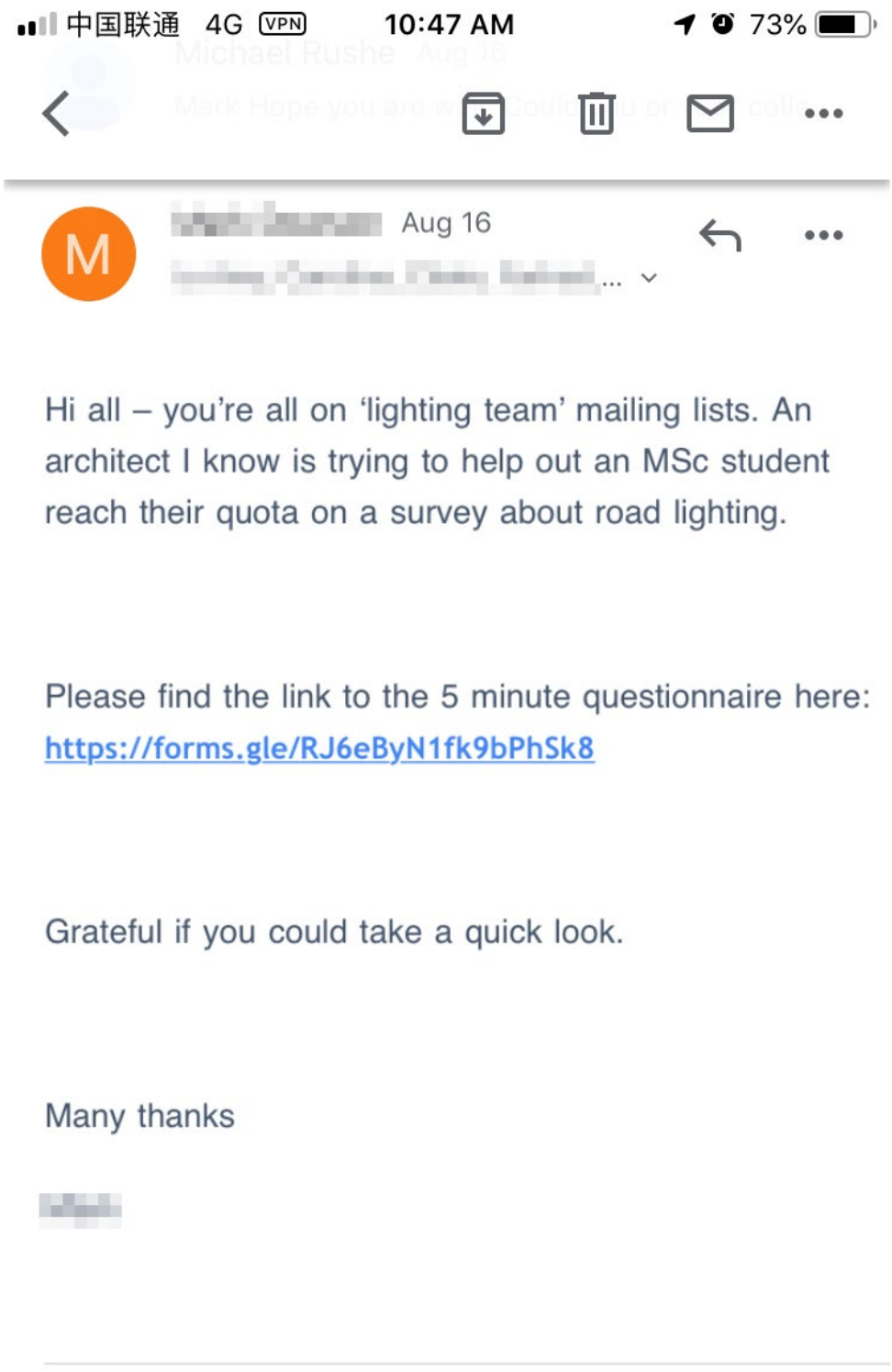
Your membership helps us deliver better lighting for the future. View this email in your browser

Since your last ILP newsletter, we have welcomed a new member of staff to the team, arranged several local CPD sessions, decided to offer part of the Exterior Lighting Diploma as a stand along week long course, and planned a new event!

The Institution of Lighting Professionals and Arup are organising an event on the evening of Monday 30 September. **The Art and Science of Light** is an event for people to learn and feel inspired about how different skills combine to produce light which benefits the public. The Illuminated River will be used as an example of this, with lighting designer Jonathan Gittins one of the speakers. Elettra Bordonaro of Light Follows Behaviour, co-founder of the Social Light Movement, will speak about the importance of this issue. We will also hear from younger members of the lighting profession. Aimed at communities of lighting, art, design and the public realm, this is free to attend and all are welcome. Booking will open later in August – for now, please save the date. If you'd like a notification when booking opens, please let Karen Suggett know. This CPD event will take place at Arup London, with refreshments sponsored by Signify.

One of our members has been in touch hoping for people to complete a masters dissertation questionnaire on road lighting standards. If you are a lighting designer, researcher, architect, engineer or similar, and could volunteer a few minutes to complete this and help a fellow lighting professional, please let us know.

Appendices 13.2. Questionnaire feature in ILP newsletter



Appendices 13.3. Reaching lighting participants

Chris Ackers FSLL • 1st
International Sales Manager at DW Windsor
1w

To all my connections can you help **Ajay Parmar** with his thesis any help would he greatly appreciated

#Thankyou

Road lighting and future factors
docs.google.com

5

Appendices 13.4. Chris Ackers, LinkedIn post

James Miles • 1st
Technical Manager at Kingfisher Lighting
1mo

If my Street lighting connections would be so kind as to fill out this questionnaire for Ajay's dissertation he would be eternally grateful **#streetlighting**

Ajay Parmar
CAD Designer at Fleetwood Architectural Aluminium Ltd
1mo

Hi there

I am an MSc by Research student
The title of my thesis is:
Road lighting and future factors
I would be very grateful if you could fill in my questionnaire if you work with street lights or the standards that surround them - **https://lnkd.in/grkn4xv**

Thanks very much

#lightingdesign #lighting #msc #fill #thesis #britishstandards #streetlighting #ledlighting

Appendices 13.5. James Miles, LinkedIn post

Carl Williams • 1st
Street lighting KAM at ASD Lighting PLC
2w • Carl's connections

Please let's help this guy 👍🏻

Ajay Parmar
CAD Designer at Fleetwood Architectural Aluminium Ltd
1mo

Dear all,
If anyone knows of Architects, Lighting Designers, or anyone involved with street lighting please kindly share or ask them to fill this questionn ...see more

Appendices 13.6. Carl Williams, LinkedIn post

Alex Brothwood • 1st
Business Manager at Lumicom Limited
3w

For my contacts who work in and around street lighting, could you please take a few minutes to fill out the linked questionnaire, I'm sure Ajay will be very thankful
#Streetlighting

Ajay Parmar
CAD Designer at Fleetwood Architectural Aluminium Ltd
1mo

Dear all,
If anyone knows of Architects, Lighting Designers, or anyone involved with street lighting please kindly share or ask them to fill this questionnaire in, it would be much appreciated.
Hope you all have a great weekend.
https://lnkd.in/geStY4n
#lighting #britishstandards #highwaysengland #iot #ledlighting

Appendices 13.7. Alex Brothwood, LinkedIn post

Road lighting and future factors

This questionnaire is to gather insights on how professional practitioners utilise and interact with the current lighting standards.

Abstract from my thesis:

This thesis maps the conflicting factors in the future of road lighting, to aid professional practitioners such as: lighting designers and engineers. Street lighting is currently a growing market with numerous technological developments. By exploring these technologies, a tool will be developed by means of a flow chart throughout this thesis. It will offer guidance when reviewing a new street lighting system. A summarising model will also be developed to illustrate all of the considerations surrounding road lighting as a domain. For new projects to develop efficiently, good collaboration amongst the various practitioners is required. The tool to be developed will highlight possible oversights of a street lighting installation at an early stage.

Your name and details will not be shared in my thesis and are not collected by default. If my results show a certain trend then I may feel the need to contact you.

Please comment on the last box if you are happy for this to take place. If so then please leave a name and email address or phone number for me to contact you on. Your personal details will be stored safely and never shared. If you wish to withdraw your consent to this data being collected please email me.

Any data collected will not be shared. Any data collected from this thesis will be stored safely for a maximum of 3 months. It will be deleted once I have written my conclusion.

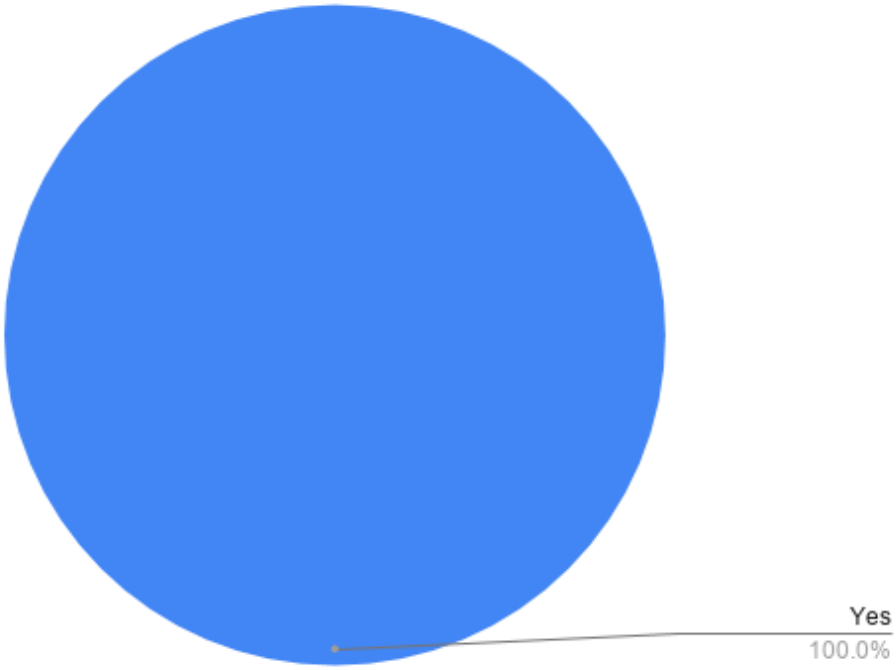
Thank you for participating
Your time is much appreciated

Ajay Parmar

* Required

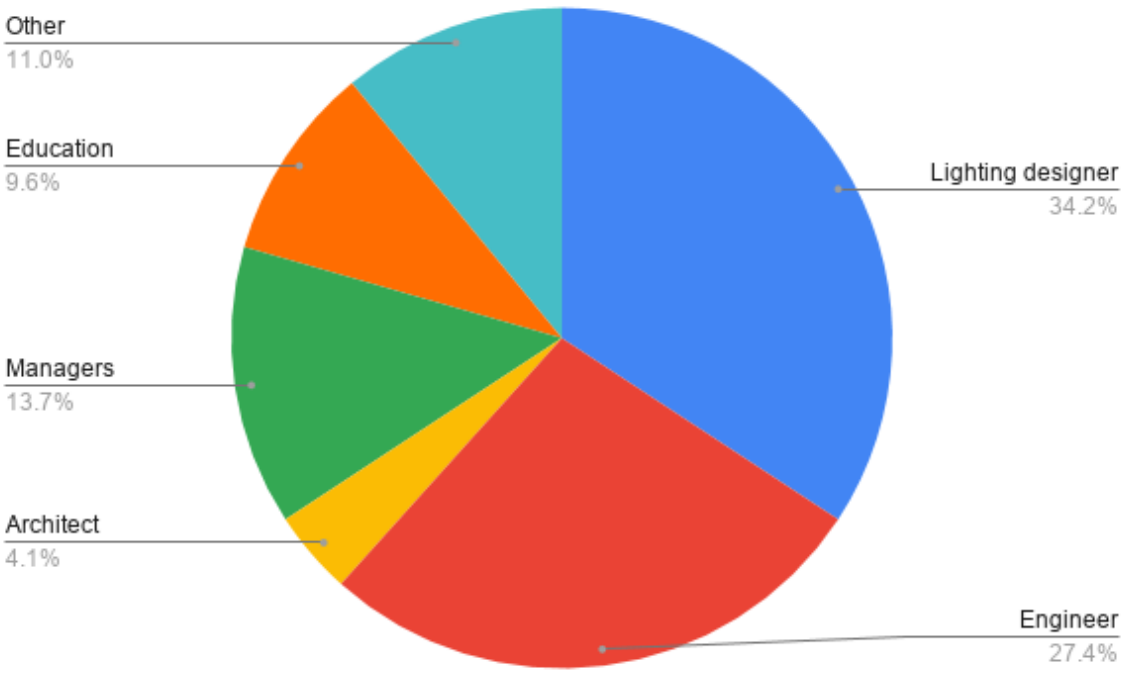
1. **Email address** *

Appendices 13.8. Questionnaire introduction



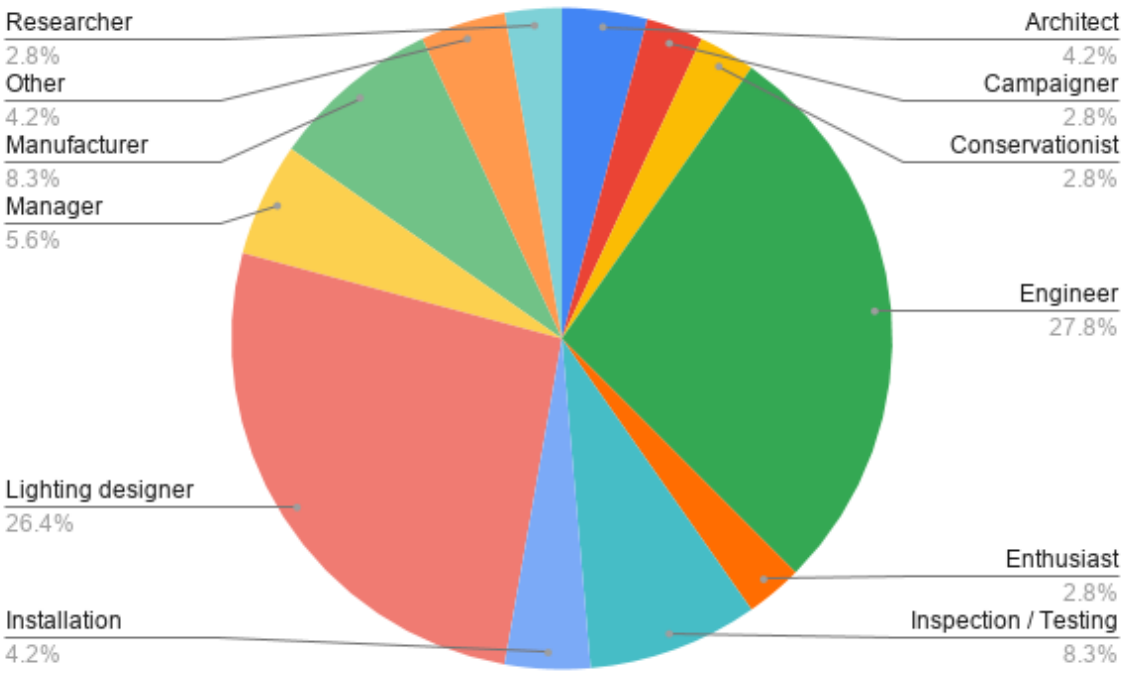
Appendix 13.9. Question 2 data collection.

Do you consent for me to use the data collected throughout this questionnaire in my thesis?



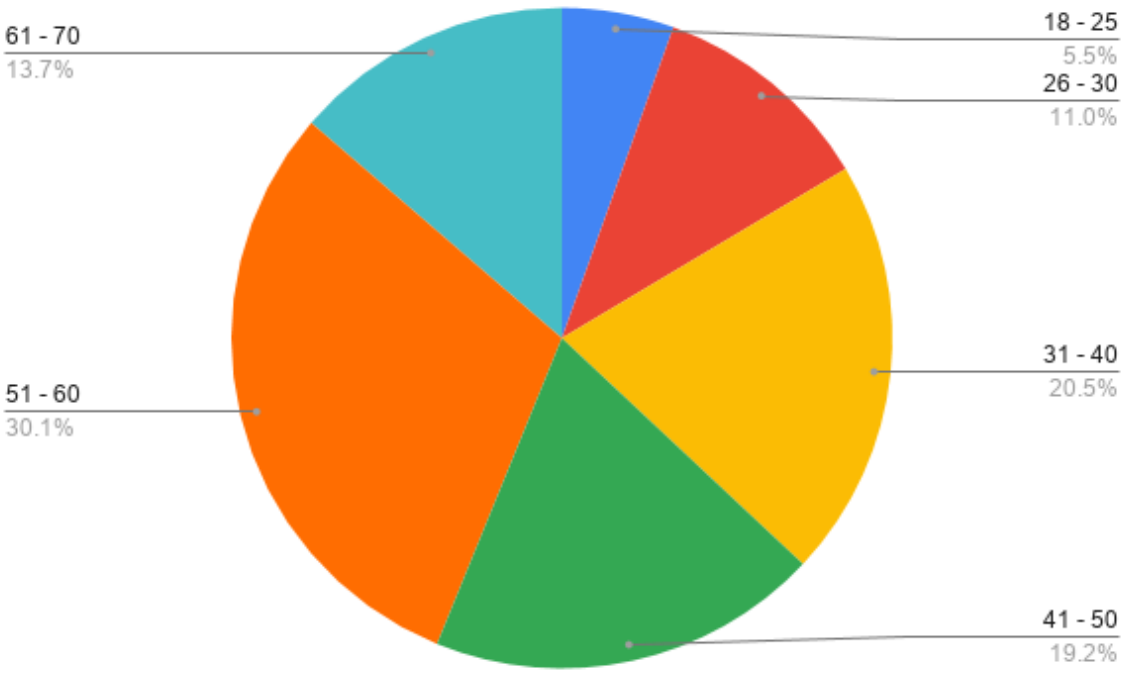
Appendix 13.10. Question 3 data collection.

What is your job role?



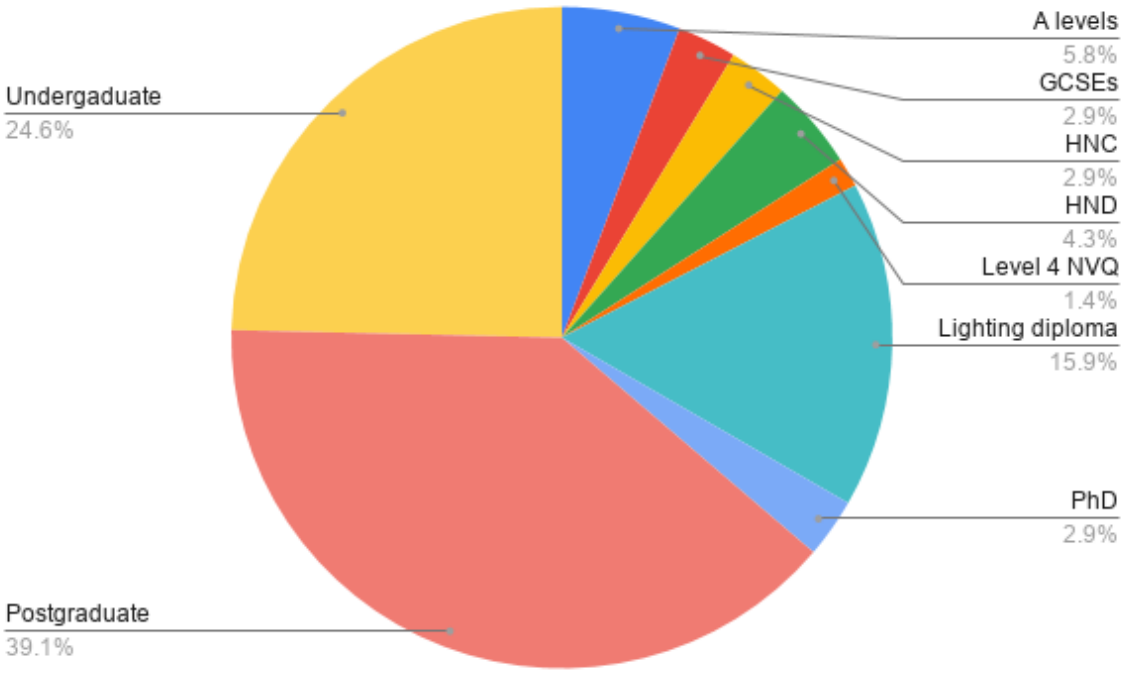
Appendix 13.11. Question 4 data collection.

What is your involvement in street lighting?



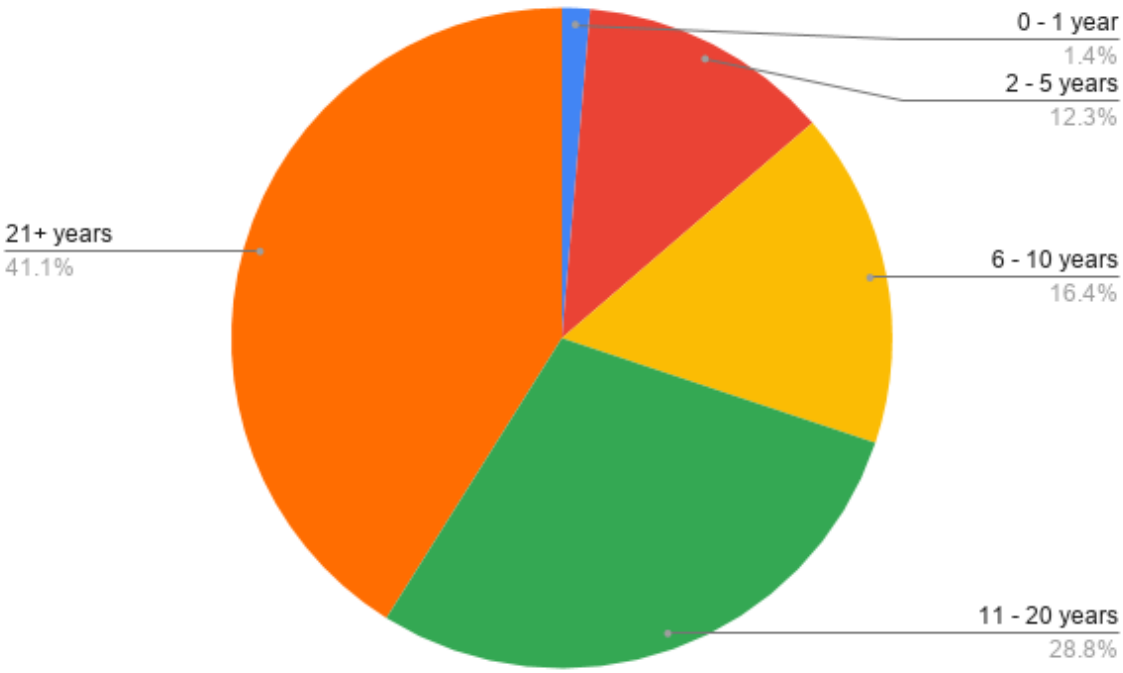
Appendix 13.12. Question 5 data collection.

What is your age?



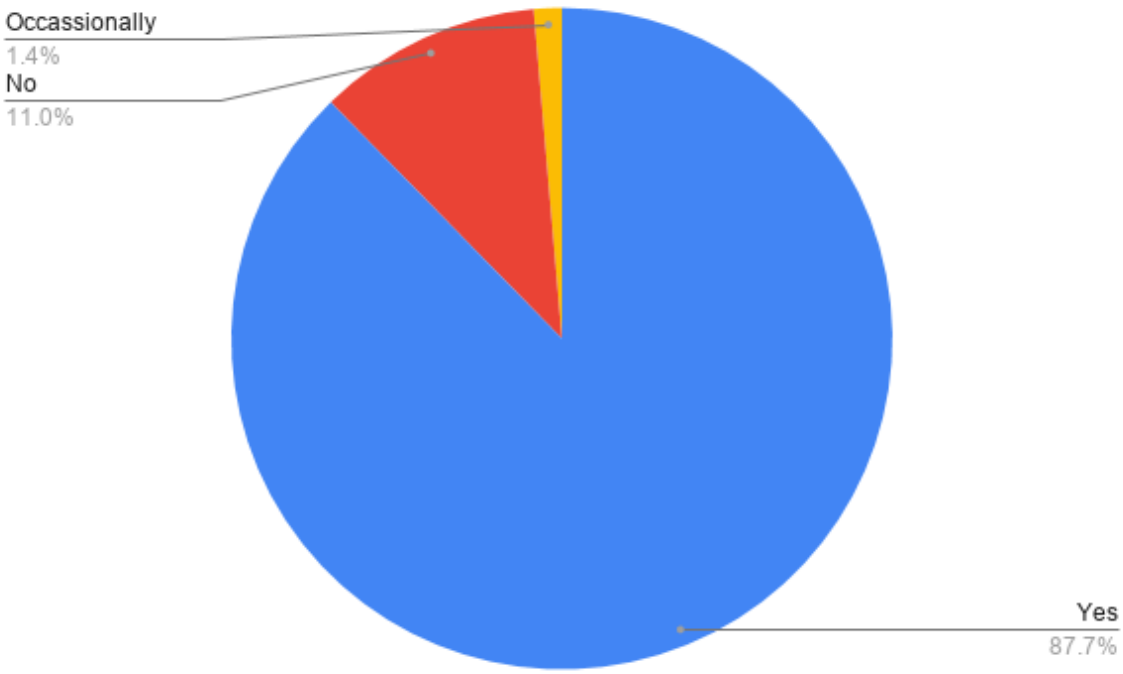
Appendix 13.13. Question 6 data collection

What is the highest educational qualification you hold?



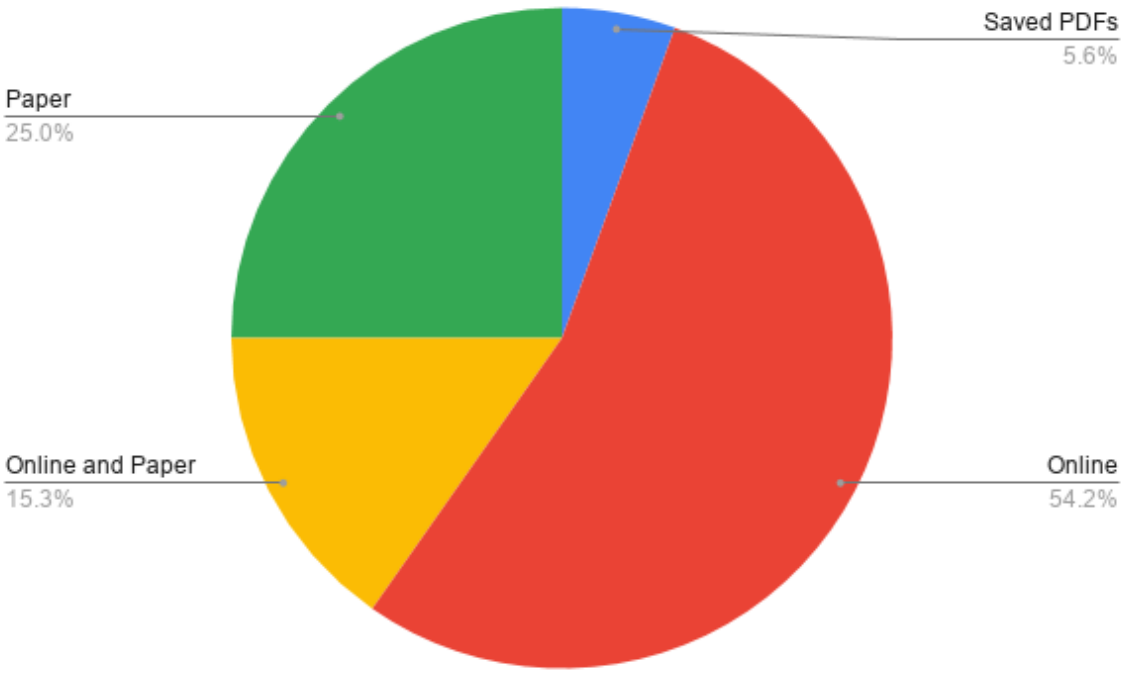
Appendix 13.14. Question 7 data collection.

How long have you been in the lighting industry?



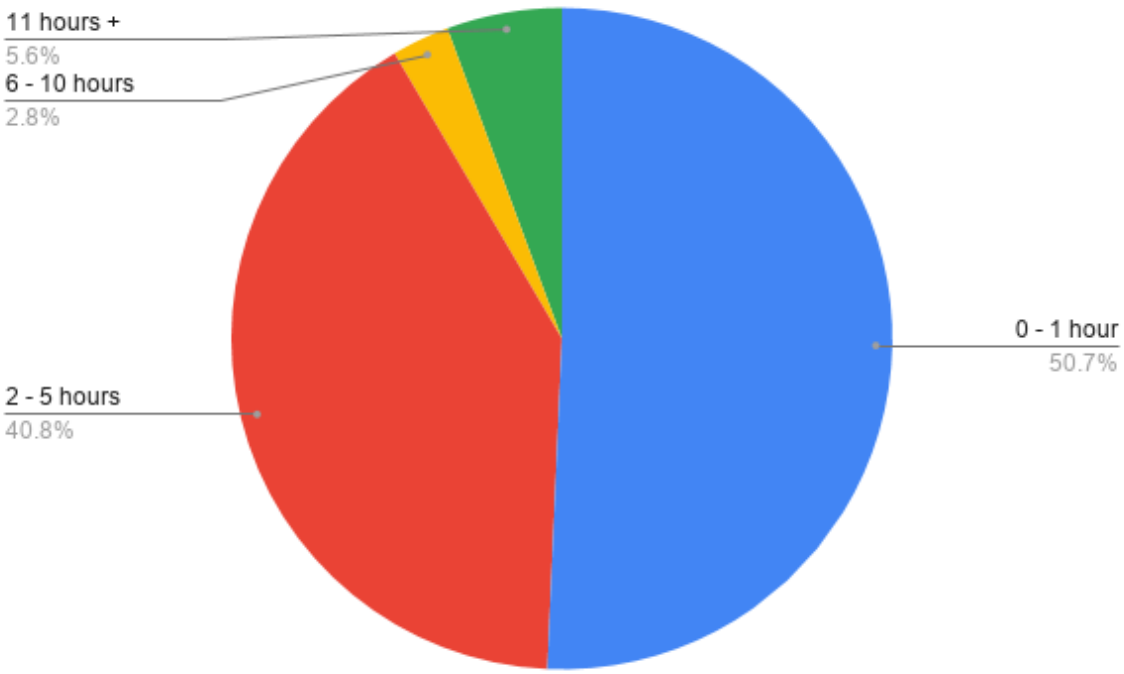
Appendix 13.15. Question 8 data collection.

Do you refer to the lighting standards as part of your role?



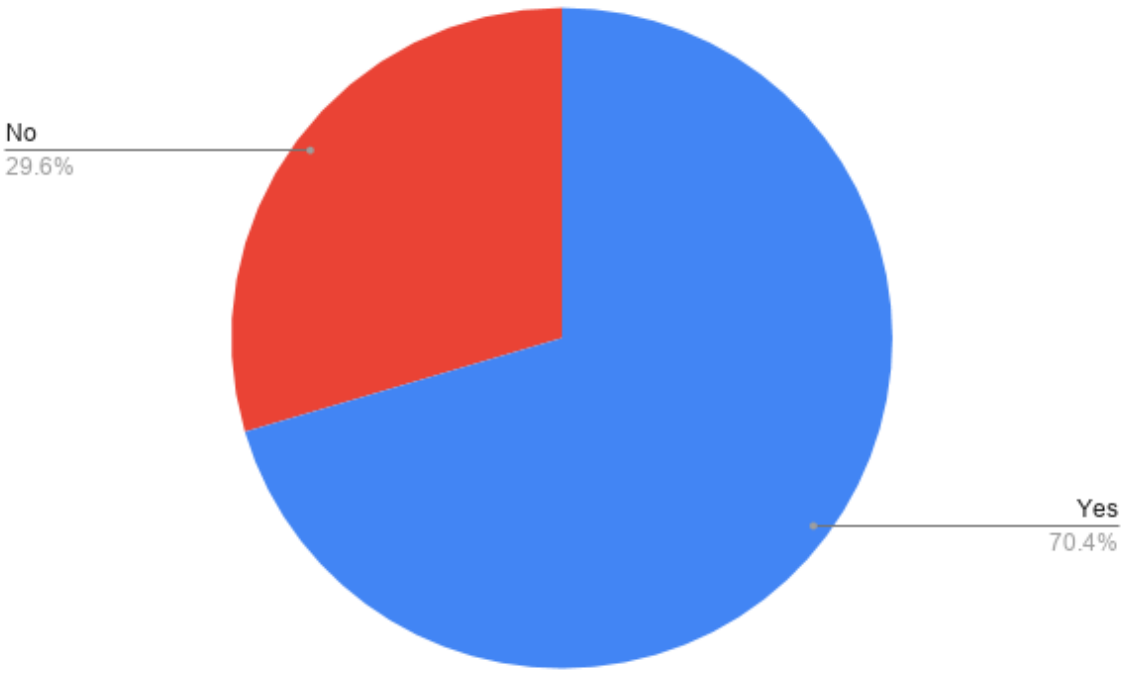
Appendix 13.16. Question 9 data collection

How do you navigate through the lighting standards?



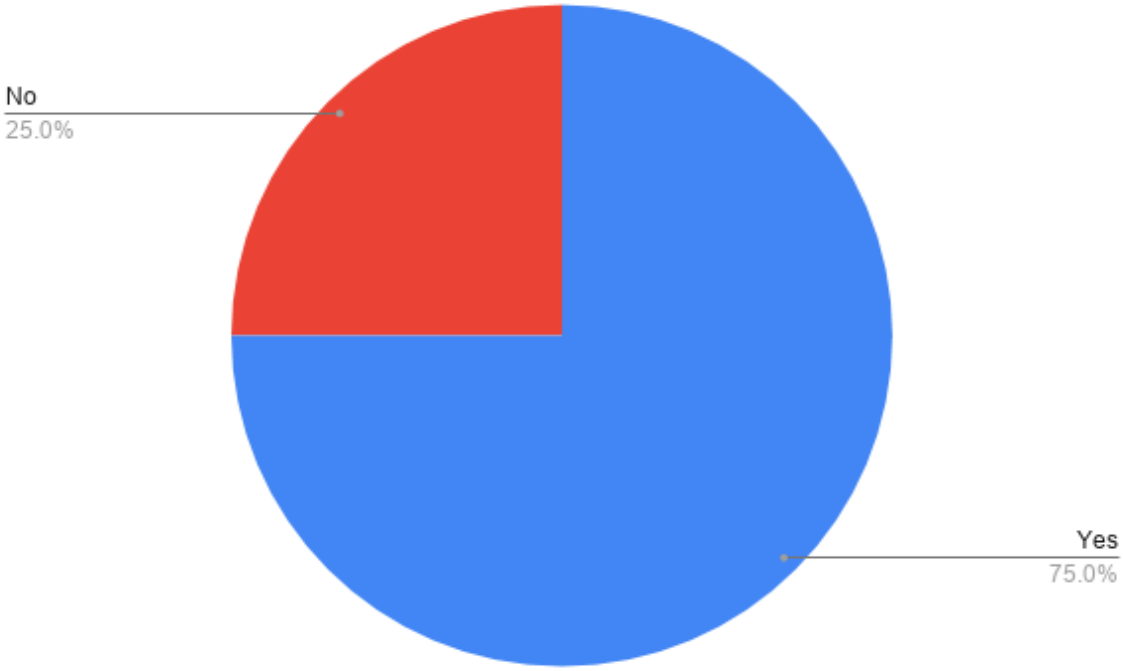
Appendix 13.17. Question 10 data collection.

How much time do you spend a week navigating the lighting standards?



Appendix 13.18. Question 11 data collection.

Do you see any problems with the lighting standards?



Appendix 13.19. Question 12 data collection.

Do you know about all the standards relevant to your role?

Lighting Standards Used	A1	A2	AM1	AM2	AHM	C	CA1	CO	DM1	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	ET1	ET2	F	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20	L21	L22	L23	L24	LR	M	MA	ME	OM	P	PM	R1	R2	S	T	Total
AS-NZS 1158																																																																	2
BR 209																																																																	1
British Standards																																																																	8
BS EN 115																																																																	1
BS 5266																																																																	2
BS 5489																																																																	29
BS 8300																																																																	1
BS EN 12193																																																																	2
BS EN 12462																																																																	1
BS EN 12464																																																																	10
BS EN 12767																																																																	1
BS EN 12899																																																																	1
BS EN 13032																																																																	2
BS EN 13201																																																																	16
BS EN 13202																																																																	4
BS EN 17037																																																																	1
BS EN 60598																																																																	5
BREEAM																																																																	1
Building Regulations Part L																																																																	1
CAP 128																																																																	1
CEN																																																																	1
CIBSE																																																																	3
CIE 30-2																																																																	1
CIE																																																																	4
CIE 115																																																																	1
CIE 129																																																																	1
CIE 140																																																																	1
DMRB																																																																	1
European Standards																																																																	1
HSE																																																																	1
IEC Guidelines																																																																	2
IEC 60598-2-22:1990																																																																	1
IESNA																																																																	4
IESNA LM79-08																																																																	2
IESNA LM80-08																																																																	1
IESNA RP-8																																																																	1
IESNA TM15-11																																																																	1
ILP																																																																	10
ISO																																																																	1
JRC 115406																																																																	1
LG4																																																																	1
LG6																																																																	1
LG10																																																																	1
NBR 5101																																																																	1
PLGs																																																																	2
PLG 02																																																																	1
RD1890																																																																	1
SLL																																																																	3
Time saver standards for UD																																																																	1
TR12																																																																	1
TSRGD																																																																	1
UNI 11248																																																																	1
UNI EN 13201																																																																	1
WELL																																																																	1
Total	1	2	1	1	1	3	1	2	3	1	1	1	1	1	3	3	1	1	1	1	1	1	3	3	2	3	2	1	1	1	2	1	2	2	6	5	2	4	2	7	1	1	1	1	4	5	1	1	4	12	2	4	2	1	1	1	2	1	4	3	3	3	2	2	

Key

A Architect

Education

T Astronomy and Science Teacher
P Photometrist and Educator
R Researcher

Engineers

E Engineer
ET Test Engineer

L Lighting Designer

Managers

AM Asset Manager
AHM Assistant Highways Manager
DM Lighting Technology Development manager
M Manager of client and contractor
ME M & E Manager
OM Operations Manager
PM Performance Manager
S Street Lighting Manager

Other

CA Campaigner
CO Certification Officer
C Coordinator for SLL
LR Lighting Recycling
MA Manufacturer
F Supplier of lighting and urban furniture

Appendices 13.20. Question 13 - Data collection. Which lighting standards do you utilise?

Lighting Standards Used	AM1	AM2	C	CA1	CO	DM1	E2	E4	E5	E6	E7	E8	E10	E11	E12	E13	E14	E16	E17	ET1	ET2	F	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L14	L15	L16	L17	L19	L20	L21	L22	L23	L24	LR	M	MA	ME	OM	PM	S	T	Total
British Standards																																																					8
BS 5489																																																				29
BS EN 12464																																																				10
BS EN 13201																																																				16
BS EN 60598																																																				5
ILP																																																					10
Total	1	1	3	1	2	3	1	1	1	3	3	1	1	1	1	1	3	2	3	2	1	1	2	1	2	2	6	5	2	4	2	7	1	1	1	4	5	1	4	12	2	4	2	1	1	1	2	1	3	2	2	

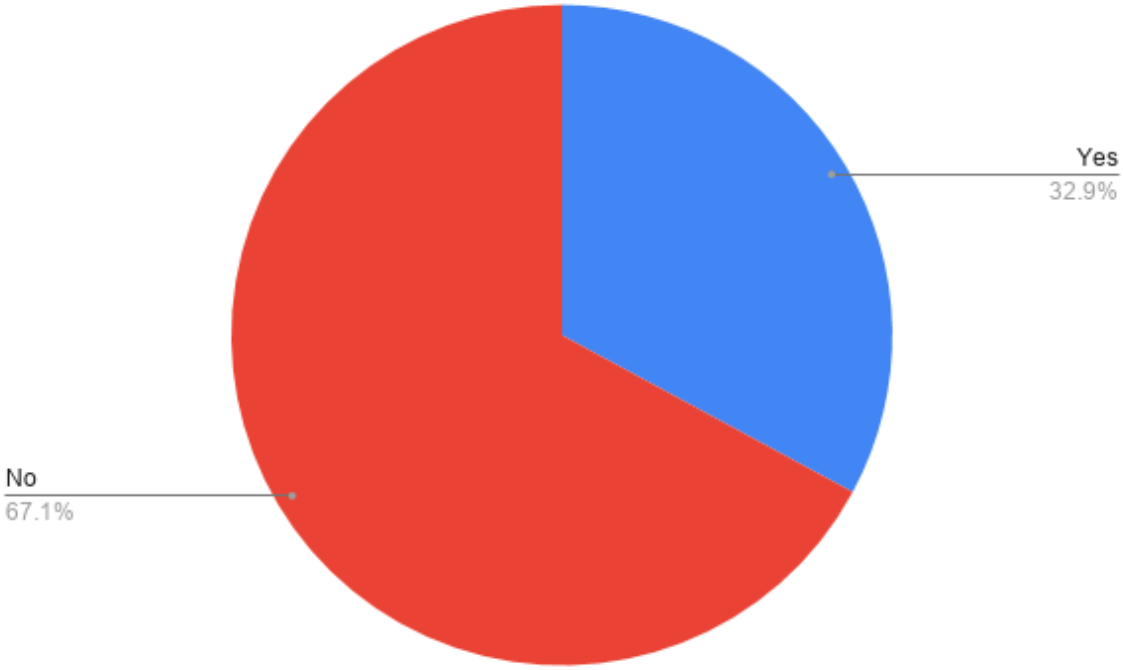
Key	
	Education
T	Astronomy and Science Teacher
	Engineers
E	Engineer
ET	Test Engineer
L	Lighting Designer
	Managers
AM	Asset Manager
DM	Lighting Technology Development manager
M	Manager of client and contractor
ME	M & E Manager
OM	Operations Manager
PM	Performance Manager
S	Street Lighting Manager
	Other
CA	Campaigner
CO	Certification Officer
C	Coordinator for SLL
LR	Lighting Recycling
MA	Manufacturer
F	Supplier of lighting and urban furniture

Appendices 13.21. Question 13 - Data collection filtered 1.0. Which lighting standards do you utilise?

Lighting Standards Used	E2	E4	E5	E6	E7	E8	E10	E11	E12	E13	E14	E16	E17	ET2	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L14	L15	L16	L17	L19	L20	L21	L22	L23	L24	Total
BS 5489																																				25
BS EN 12464																																				12
BS EN 13201																																				13
BS EN 60598																																				4
ILP PLG 08																																				9
Total	2	1	1	2	2	1	1	1	1	1	3	1	1	1	2	1	1	2	2	4	1	2	3	3	1	1	2	2	3	2	3	4	1	3	1	

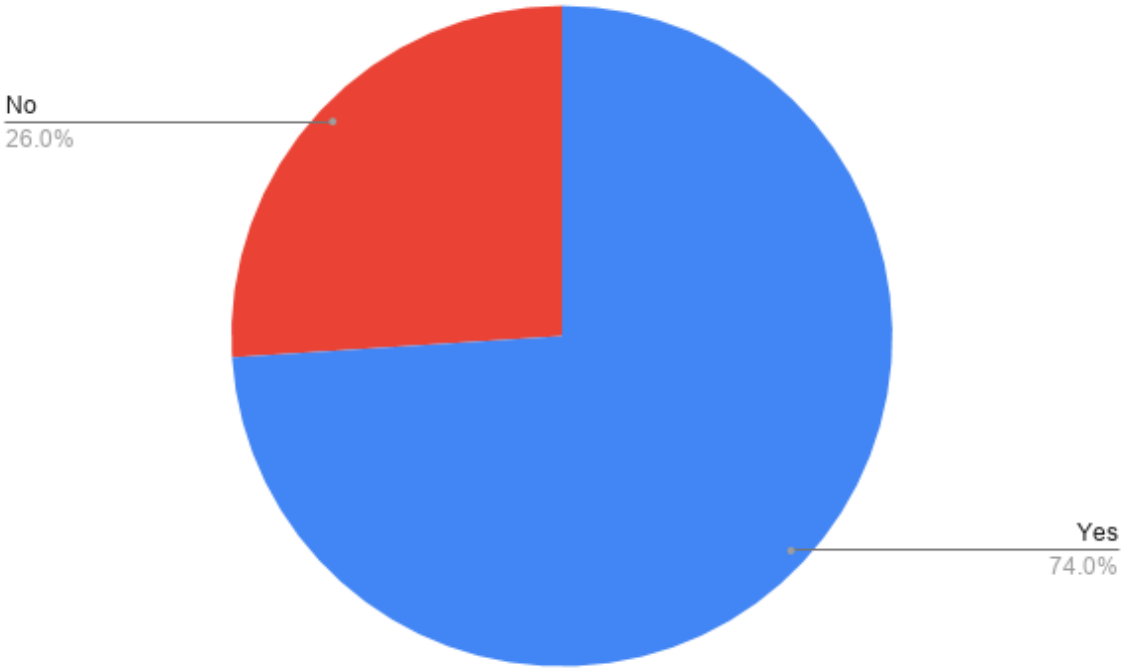
Key	
E	Engineer
ET	Test Engineer
L	Lighting Designer

Appendices 13.22. Question 13 - Data collection filtered 2.0. Which lighting standards do you utilise?



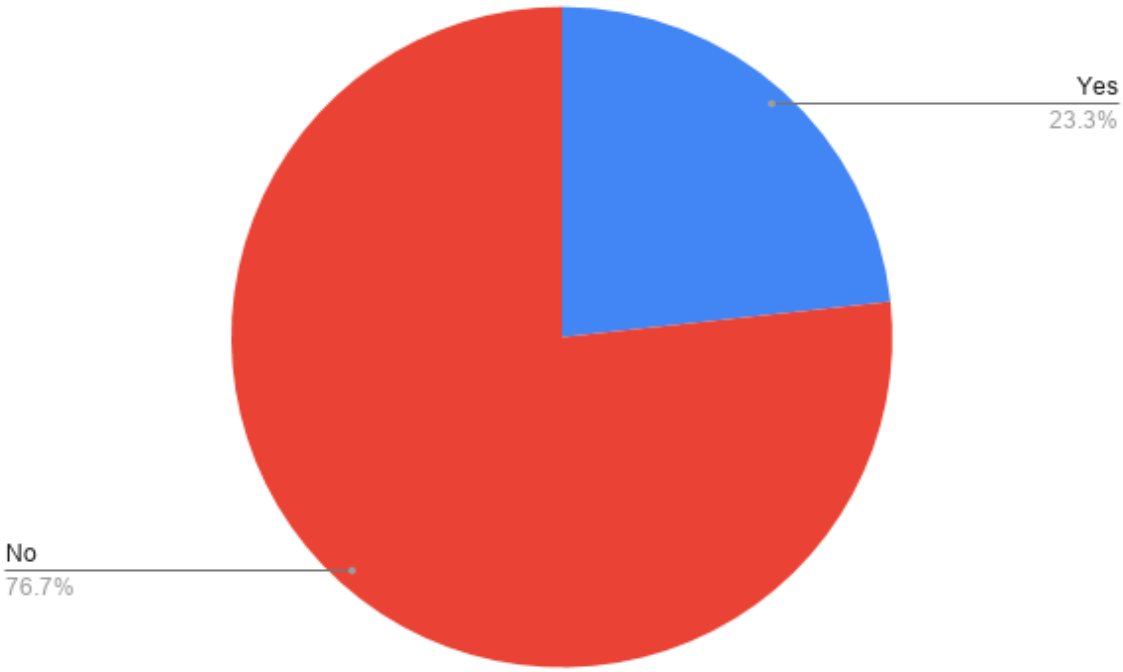
Appendix 13.23. Question 14 data collection.

Do you feel the British Standards covers all the content needed in terms of road lighting and future factors?



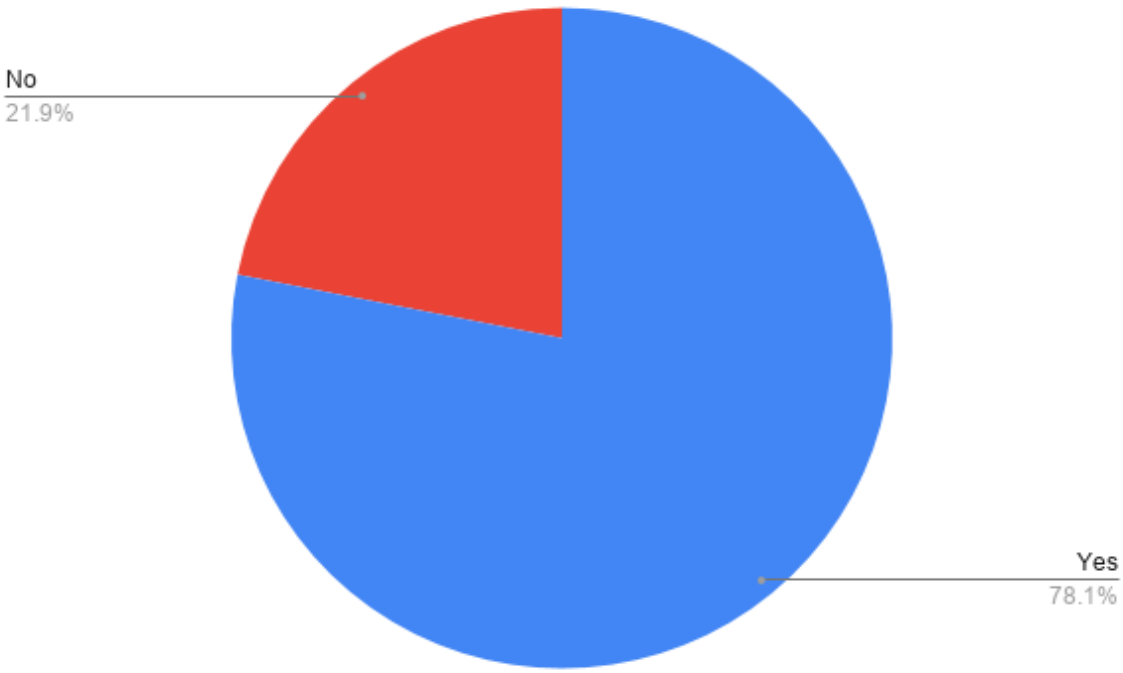
Appendix 13.24. Question 15 data collection.

In the standards you use or are familiar with, do you believe the correct units of measurement have been used?



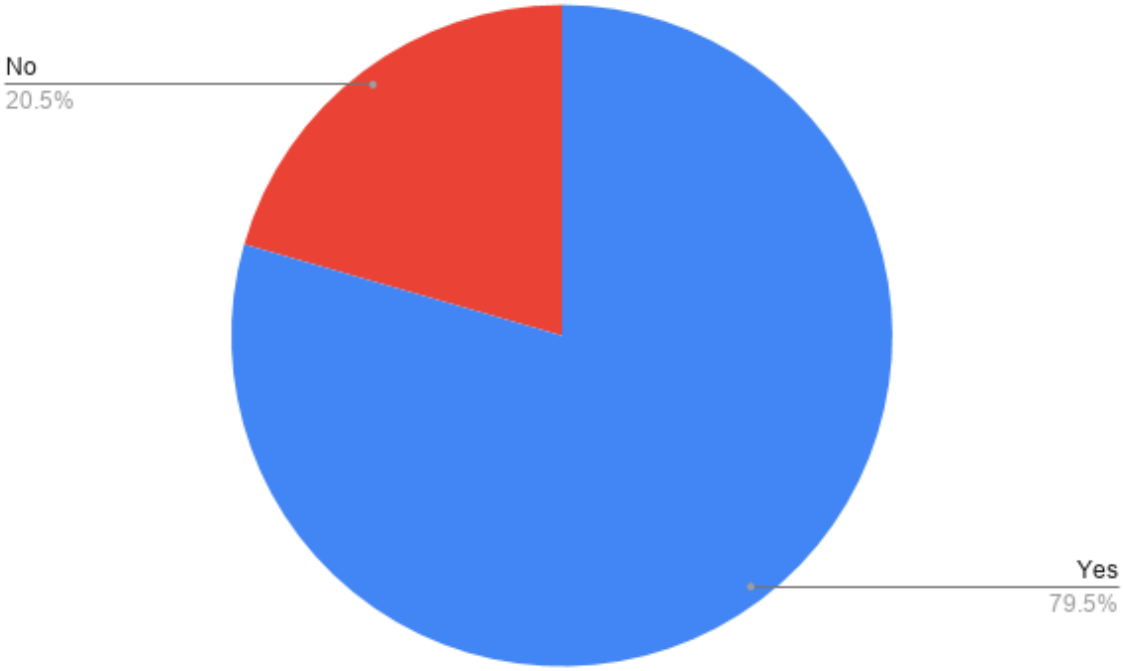
Appendix 13.25. Question 16 data collection.

Do you feel concerns of LED lighting of health and glare are covered adequately in lighting standards?



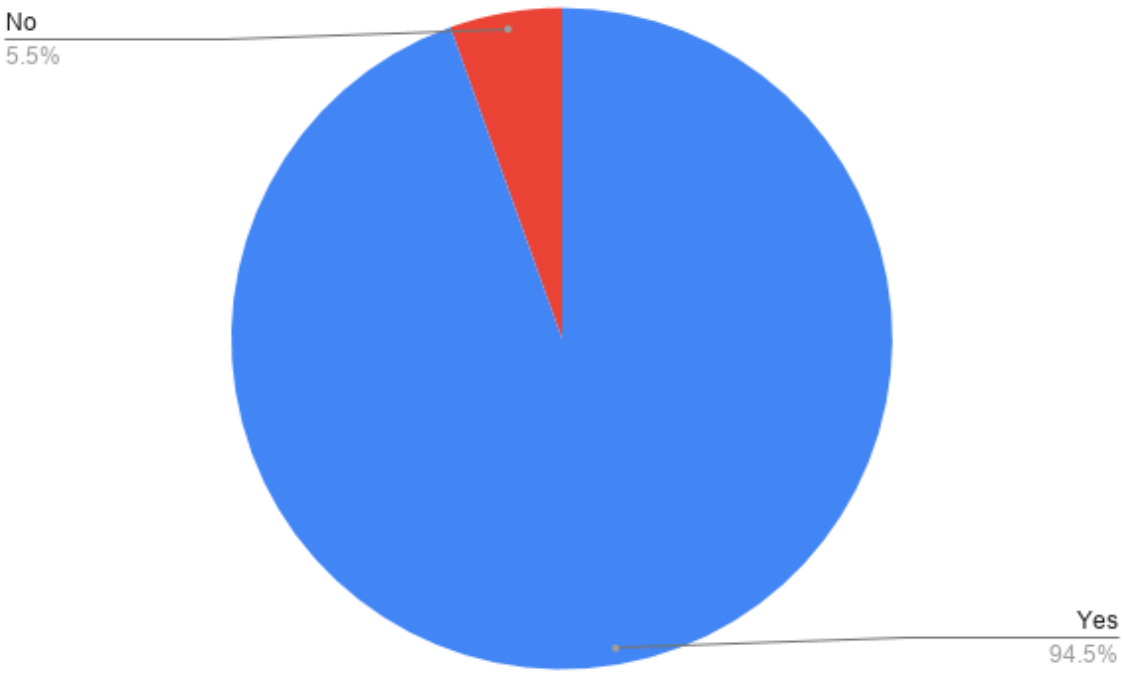
Appendix 13.26. Question 17 data collection.

Do you think developing technologies such as 5G, IOT and street light dimming should be mentioned in the standards?



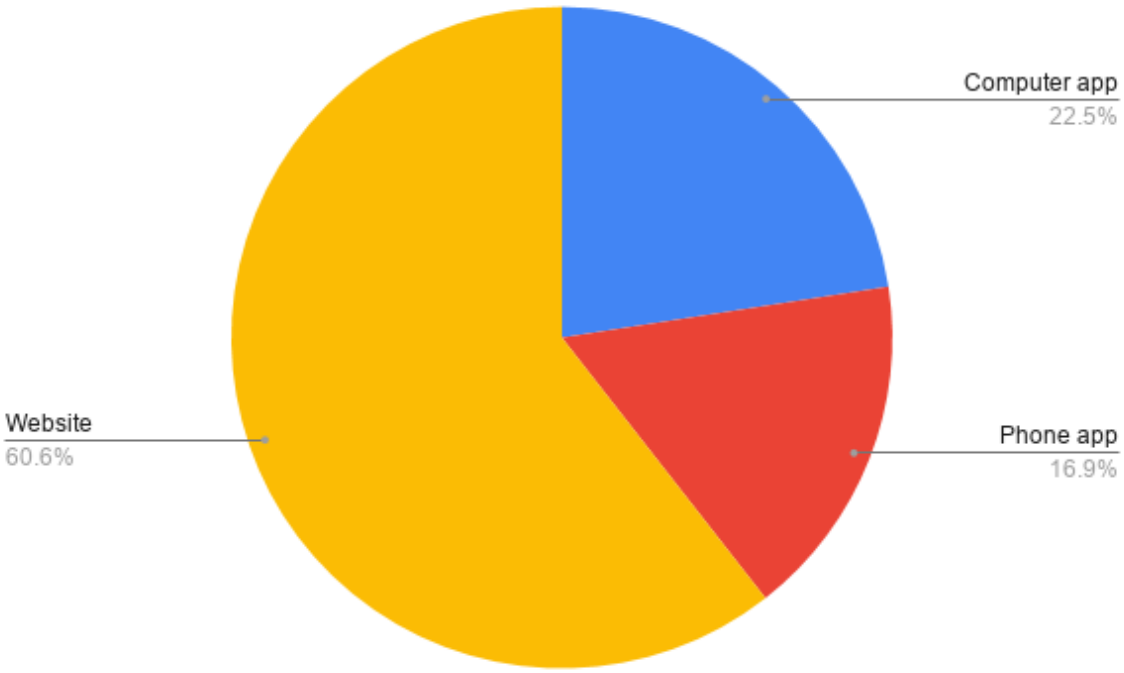
Appendix 13.27. Question 18 data collection.

How about more established topics such as blue light emission?



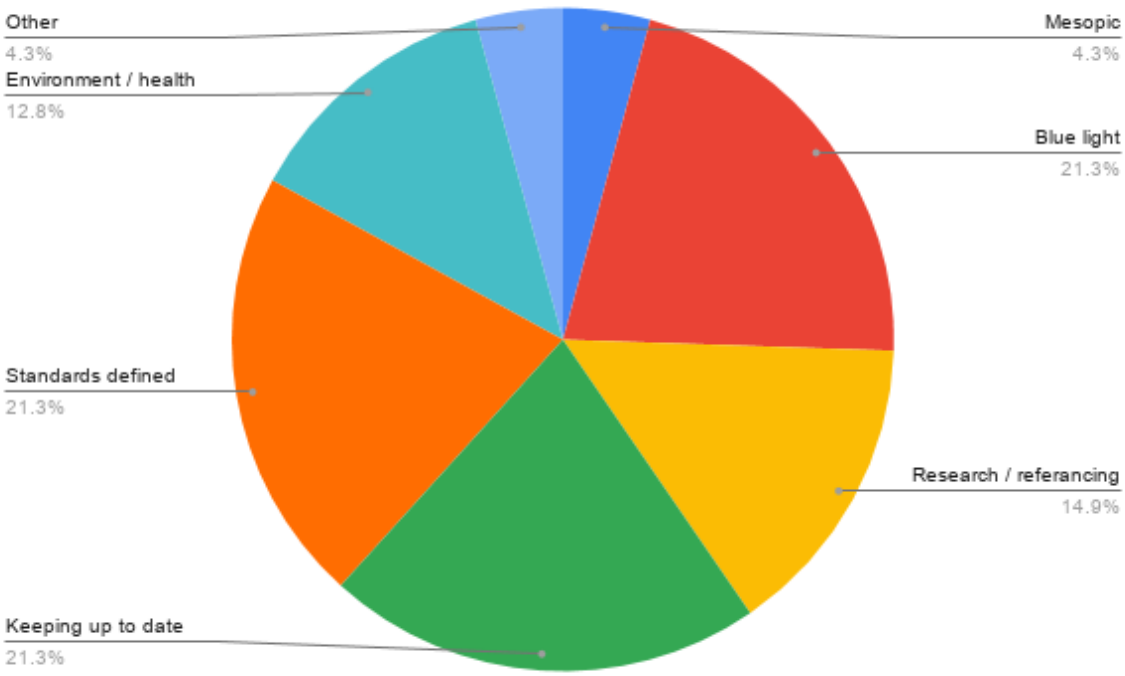
Appendix 13.28. Question 19 data collection.

Do you think an interactive tool, guiding users based on their profession to the location of standards, further information and additional guidance would be useful?



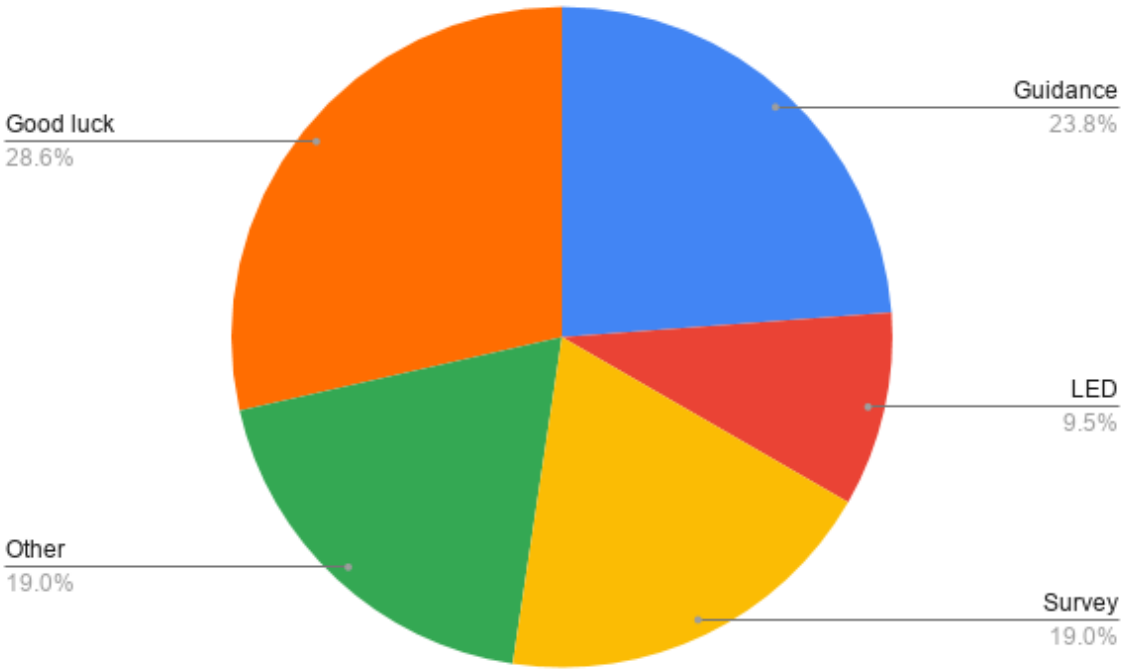
Appendix 13.29. Question 20 data collection.

What would suit you best?



Appendix 13.30. Question 21 data collection.

What do you think should be stated in regards to these topics?



Appendix 13.31. Question 22 data collection.

Thanks for participating in this questionnaire. Your time is much appreciated.

If you feel there is anything you wish to add, please do so below.

Peter Harrison via theilp.onmicrosoft.com

2 Sep 2019, 10:12

to ajayparmardesign@gmail.com, Jess

Hi Ajay,

Looking at your model, I have the following comments:

I would place smart cities under the technology thread, though it may be facilitated by Government, it will be technology that will drive this

Perhaps recycling could be added to Government?

With regard design, we see luminance, so that should be added

Under regulations, you need to add CIE, as they are the international lighting standards organisation

Motorists is interesting, there are other road users that aren't mentioned such as cyclists, horses

Perhaps under Government you could add, sustainable transport and nodes to transport

Under technology, have you thought about Central Management Systems (CMS), they are a sort of IoT, but a closed network

Though advertising will be a part of design, I think it is more a Regulations things, to do with Planning and permission from the Highway Authority

I hope this helps. I have attached a Guidance Note we put together a couple of years ago of the lighting organisations in UK and what they do, which may help

Peter Harrison
Technical Director
peter@theilp.org.uk

Institution of Lighting Professionals
Regent House, Regent Place,
Rugby, CV21 2PN
T: 01788 576492
M: 07505 085792
info@theilp.org.uk
www.theilp.org.uk
Registered in England No. 227499 Registered Charity No. 268547
Delivering #betterlightingforall

Appendix 13.32. Peter Harrison's comments on Figure 49

Middlesex University London

Computer Science REC

The Burroughs
Hendon
London NW4 4BT

Main Switchboard: 0208 411 5000

26/07/2019

APPLICATION NUMBER: 7989

Dear Ajay Parmar and all collaborators/co-investigators

Re your application title: Road lighting and future factors

Supervisor: MICHAEL HEENEY

Co-investigators/collaborators:

Thank you for submitting your application. I can confirm that your application has been given APPROVAL from the date of this letter by the Computer Science REC

The following documents have been reviewed and approved as part of this research ethics application:

Document Type	File Name	Date	Version
Aims, objectives and hypotheses	Road Lighting and Future Factors	22/06/2019	1
Data Protection Act checklist	Data Protection Form V2	17/07/2019	V2

Although your application has been approved, the reviewers of your application may have made some useful comments on your application. Please look at your online application again to check whether the reviewers have added any comments for you to look at.

In particular we recommend that together with your consent statement, you include a statement informing participants that they have the right to withdraw from the study at any time. Also inform them of the process for withdrawing.

Also, please note the following:

1. Please ensure that you contact your supervisor/research ethics committee (REC) if any changes are made to the research project which could affect your ethics approval. There is an Amendment sub-form on MORE that can be completed and submitted to your REC for further review.

2. You must notify your supervisor/REC if there is a breach in data protection management or any issues that arise that may lead to a health and safety concern or conflict of interests.

3. If you require more time to complete your research, i.e., beyond the date specified in your application, please complete the Extension sub-form on MORE and submit it your REC for review.

4. Please quote the application number in any correspondence.

5. It is important that you retain this document as evidence of research ethics approval, as it may be required for submission to external bodies (e.g., NHS, grant awarding bodies) or as part of your research report, dissemination (e.g., journal articles) and data management plan.

6. Also, please forward any other information that would be helpful in enhancing our application form and procedures - please contact MOREsupport@mdx.ac.uk to provide feedback.

Good luck with your research.

Yours sincerely

Appendices 13.33. Ethics approval 1

Chair Dr. Carlisle George

Computer Science REC

Appendices 13.34. Ethics approval 2

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