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Introduction and Motivations

1.1 Introduction: A Historical Review. Current Issues

The International Commission on Illumination (CIE) defined the 2° standard colour matching functions in September 1931, more than 90 years before the publication of this book: the so-called $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ functions for visual colour matching with a visual field of view of 1–4°. This made it possible to calculate the tristimulus values and chromaticity coordinates for any colour stimulus of any spectral composition in the visible wavelength range, to characterise *perceived colours* and communicate them in scientific and industrial processes. In addition, from the end of the nineteenth century until today, the following steps of development have taken place in lighting technology:

(a) *In lighting technology and photometry*: from the end of the nineteenth century until around the 1980s, some parts of the world experienced a steadily growing development of the industrialisation process (e.g. mechanical engineering, shipbuilding, electrical engineering, and construction), so that research in lighting technology concentrated on formulating the requirements for workplaces in offices and manufacturing on the basis of physiological visual performance such as contrast perception ability, visual acuity, reading speed, or error rate of the work performed, using the parameters *illuminance* (in lux) or *luminance* (in $cd\,m^{-2}$) as a basis. The results of research in this field up to the end of the twentieth century formed the basis for today's international and national lighting standards [1–3].

(b) *In light source technology*: from 1879 to 1999, there were several important developmental steps from incandescent lamps to high-pressure discharge lamps, halogen incandescent lamps, three-band fluorescent lamps, and compact fluorescent lamps (see Table 1.1). From 1994 to the present day, light source technology has undergone enormous progress with the new development of high-power LEDs. The luminous efficacy of white LEDs exceeds the values of commonly used discharge lamps (e.g. T5 lamps, Cosmopolis lamps, and HMI lamps). The high luminous efficacy of the LEDs, rated according to the $V(\lambda)$-function for daytime vision, contributes positively to the worldwide effort to save energy and protect the environment.

Human Centric Integrative Lighting: Technology, Perception, Non-Visual Effects, First Edition.
Tran Quoc Khanh, Peter Bodrogi, and Trinh Quang Vinh.

Table 1.1 Major milestones in the development of light source technology.

Year	Contents
1854	Goebel: Light bulb with bamboo fibre
1879	Edison: Incandescent lamp with carbon filament
1900	Cooper, Hewitt: Patent on mercury vapour lamp
1906	Introduction of the tungsten metal filament lamp with nitrogen filling
1934	Introduction of the low-pressure discharge lamp with phosphors
1959–1960	Introduction of the tungsten halogen lamp
1971	Fluorescent lamps with a three-band concept
1980	Introduction of the CFL-i (energy-saving) lamp
1994	White LED based on InGaN material

Source: TU Darmstadt.

(c) *In CIE – colorimetry*: the history of CIE – colorimetry is characterised by the constant efforts to define perceptual colour attributes (brightness, lightness, hue, chroma, and saturation) and to arrange them in a perceptually equidistant colour space. If these perceptually equidistant colour spaces are created, the colour differences between different colours can be calculated there and used for industrial quality control. One benefit of accurate colour difference calculation is the colour rendering index. This task was carried out at several levels of knowledge over the last decades (see Table 1.2 as well as [6, 7]). The research results of colour science have been used in the colour industry (display technology, film technology, printing technology, and textile industry), and more intensively since about 2010 in lighting technology and light source technology (LED, OLED).

Since the beginning of the twenty-first century, some development trends relevant to lighting technology have intensified as follows:

- Societies in large parts of the world (North America, Europe, China, Japan, and South-East Asia) have been oriented towards information technology. The way of working, the work processes (day and night rhythms), as well as the work equipment (monitors, data, and display devices), have reached a new quality. In addition to quality features such as illuminance or uniformity and glare, other discussions about light and health, well-being during office work, stress reduction, and increased concentration through lighting have been added.
- The previous light source technologies had the decisive disadvantage that the spectrum and colour of the lamps could only be varied to a small extent. Today's high-power and mid-power LEDs with their high luminous efficacies and with a few advantages such as dimmability, controllability, and integrability also have the great advantage that they can be formed from coloured and white LEDs into a *lighting system* of variable spectral composition (chromaticity, colour temperature). The *dynamic light* formed in this way enhances the colour

Table 1.2 Major milestones in the development of CIE colorimetry.

Year	Contents
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1931	Definition of the 2° – standard colour matching functions $\overline{x}(\lambda)$, $\overline{y}(\lambda)$, and $\overline{z}(\lambda)$
1960	Definition of the UCS diagram (*Uniform Colour Scale*)
1964	Definition of the CIE 1964 ($U^*V^*W^*$) colour space
1964	Definition of the colour matching functions $\overline{x_{10}}(\lambda)$, $\overline{y_{10}}(\lambda)$, and $\overline{z_{10}}(\lambda)$ for 10° field of view
1976	Definition of the 2 colour spaces CIE $L^*a^*b^*$ (or CIELAB) and CIE $L^*u^*v^*$ (or CIELUV)
2004	CIE Publication: a colour appearance model for colour management systems: CIECAM02, Publication No. 159 (Vienna: Central Bureau of the CIE, 2004) [4]
2006	Definition of the CAM02-UCS colour space based on the colour appearance model CIECAM02 [5]

Source: TU Darmstadt.

and light quality of *interior lighting*, for the evaluation of which non-visual, colour-technological, and photometric approaches are now increasingly expected to come into play.

This makes it clear that the three important components of lighting technology (photometry, colorimetry, and light source technology) should be used much more intensively and closely together in current and future research for the evaluation of the colour and light quality of workplaces and in the lighting industry for the development of new lighting products. In addition – in the period between 2000 and today – the *non-visual effects of light* have been investigated by various international research groups. Despite numerous efforts in the experimental field, these findings are only partially implemented in the practice of lighting product development and lighting design in a comprehensible and interpretable way.

According to the above considerations, the authors elaborated on the present book to answer the following questions:

1. How do the visual and non-visual mechanisms in the brain and in other physiological areas function during night-time hours and during the day?
2. Which influencing parameters and which initial parameters with which metrics in the physiological and psychological – emotional area are decisive for the description of the subjective and objective characteristics of health, well-being, and work performance of human beings? To what extent can scientists and product developers control these parameters – according to the findings to date? Where is there still a need for research?
3. What findings are known so far about the effects of light at night? The focus will be on the relationship between irradiation and its effects on humans.
4. What findings have been made so far for the time during the day? Can some of them be scientifically established to the extent that the long-awaited

recommendation values for lighting designs as well as for the development of intelligent lighting products can be put up for discussion?

5. How to record, measure, and interpret the visual and non-visual parameters of lighting with daylight and electric light? Such measurements should be carried out not only with laboratory measuring devices but also with portable, inexpensive, and accurate measuring units to plausibly record the effects of light in alternating and dynamically changing workplaces and places where people stay.

Derived from these important questions, this book (except for this chapter) is divided into the thematic blocks summarised in Figure 1.1.

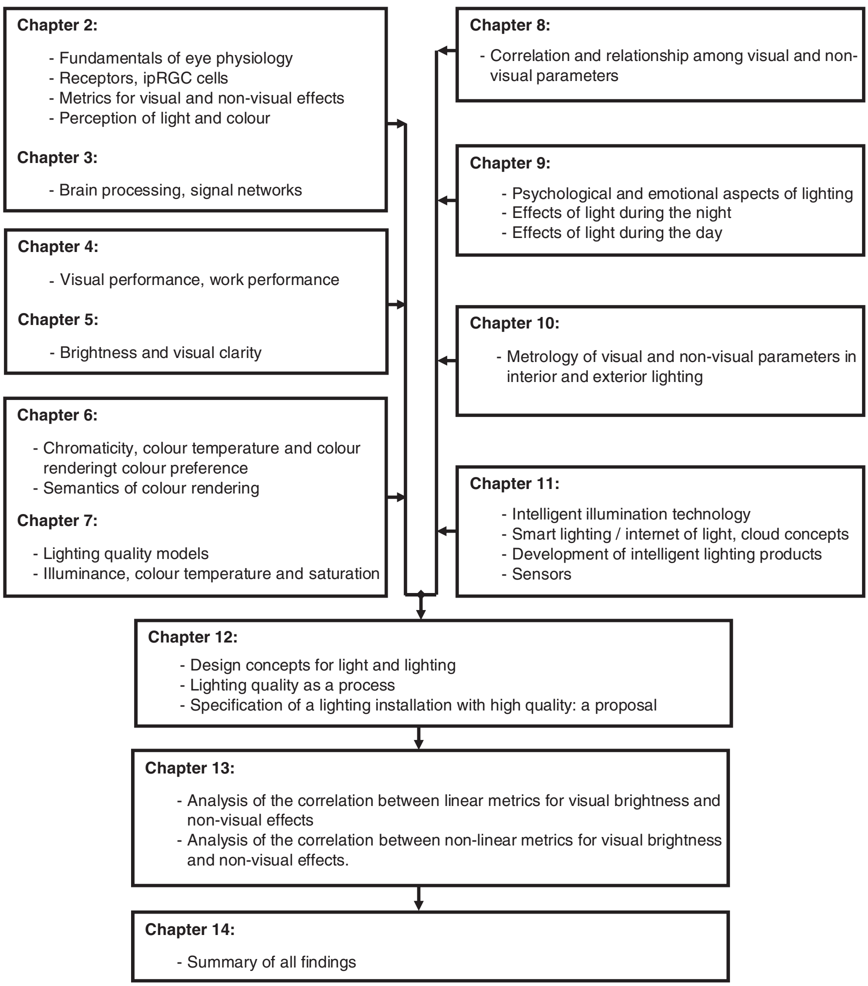

Figure 1.1 Contents of the present book. Source: TU Darmstadt.

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