Laboratory of Adaptive Lighting Systems and Visual Processing

ALSV

Adaptive Lichttechnische Systeme
und Visuelle Verarbeitung

of

Technical University Darmstadt

TECHNISCHE
UNIVERSITÄT
DARMSTADT

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1. CONTENT

2. EXECUTIVE SUMMARY

The Laboratory of Adaptive Lighting Systems and Visual Processing, known as the Darmstadt Lighting Institute DLI is one of the big contributors for Lighting. The research topics today cover automotive lighting in many subfields like front and rear lighting, interior lighting, autonomous vehicles and VR simulation for all kinds of traffic situations. But it covers much more major lighting issues with research: Smart Lighting, Integrative Lighting Quality, LED Technology and - latest - Photobiology with Plants.

The most important event that is visible from outside is the bi-annual symposium ISAL, the international symposium on automotive lighting. 14 international conferences took place since 1995. ISAL is the worldwide biggest scientific and technical conference. About 1000 participants meet and discuss during the two-day forum and exhibition.

Since 2006 Prof. Khanh is the head of the DLI, with an enormous record of more than 1400 lectures and more than 600 students that now have in their curriculum lighting lectures. His actual research team counts 16 Doctoral Researchers and 6 external Researchers.

The DLI has a quite long history, founded in 1956. Meanwhile 280 Students wrote their Master/Diploma Thesis about lighting topics and 51 Doctors received their academic grade.

3. About the Author

Michael Hamm earned his Physics diploma in 1993, and his Doctor in Electrotechnics in 1997 from the University of Darmstadt, Germany. He joined Bosch's lighting division in 1996. After becoming section manager, he worked twelve years as department manager at Bosch and successor company Automotive Lighting, with the main task to develop front lighting technologies in worldwide headlamp customer projects. In this period, he pushed optical development and simulation as well as lighting innovations. Examples were the development of Mono, Bi- and adaptive HID systems (e.g., curve light; adverse weather light, motorway light…) as well as automotive infrared applications. He contributed to the development of LED systems including the world's first full LED headlamp, and on modules; camera-controlled adaptive partial high beam functions, and light guide and DRL developments. Hamm became Head of Headlamp Development at Audi in 2012. For ten years, his focus was to develop headlamps and to constantly introduce new technology in Audi lamps for market readiness with his team and the suppliers. Examples from this period include the introduction of generations of Matrix Beam headlamps; dynamic turn indicators and DRLs; laser high beams, and lighting digitalization with digital projectors.

He has contributed to 76 technical papers and applied for 85 invention patents.

Since 2022 he has returned, as a lecturer for vehicle lighting and lighting technology, to the Laboratory of Adaptive Lighting Systems and Visual Processing at Technical University Darmstadt. Besides this, one of his main pleasures is to advise and support DVN in their groundbreaking activities as an industry standardization and research community.

4. About Driving Vision News

DVN is the vehicle lighting and ADAS industry's journal of record, dedicated to keeping the community informed and communicating about the latest progress and developments. DVN's three pillars are:

• **Technological watch** on new emerging technologies, with weekly electronic newsletters bringing news, analysis, and crucial information on innovation in lighting, ADAS, and smart car interiors; there are also monthly technical reports with sharp focus on cutting edge technologies, company profiles, regulatory matters, and other relevant content available only from DVN

• **Networking** of high-level decisionmakers, researchers, innovators, practitioners, academics, and regulators to make new business connections with two workshops per year in rotating locations throughout America, Europe, China, Japan, India, and Korea. DVN Workshops gather over 300 participants.

• **Promotion of innovations** from DVN's 150 member companies—we facilitate the promulgation of knowledge of innovation, which in turn paves the way for commercialisation, enabling to build new relationships through DVN Community to forge new business worldwide. The DVN Gold membership roster includes 180 companies including automakers; lighting and ADAS tier-1 and -2 suppliers, and a wide variety of universities; research outfits, and consultants. DVN Gold members receive all publications and attendance privileges at all DVN Workshops.

5. Introduction

The Technical University of Darmstadt is the first fully autonomous university in the Federal Republic of Germany. With around 25,000 students and 5,000 employees, including around 320 professors (as of 2019), it is one of the medium-sized universities in Germany and is part of the TU9 university network. In 2018 and 2019, TU Darmstadt was one of the universities with the most DAX board members among graduates— the DAX is a German blue-chip stock market index which tracks the performance of the 40 largest companies trading on the Frankfurt Stock Exchange. In the 2022 university rankings by Wirtschaftswoche ("Business Week"), TU Darmstadt is the № 2 university in Germany for business informatics; the № 4 in electrical engineering and industrial engineering, the № 5 in computer science, and the № 6 in mechanical engineering. In the 2020 Humboldt Ranking by the Alexander von Humboldt Foundation, TU Darmstadt takes fourth place in engineering.

Part of the Historical University Building and the new University and State Library Darmstadt (2012)

The university was founded in 1869 as a polytechnical school. In 1882, the renamed Technical University of Darmstadt founded the world's first chair for electrical engineering. The world's first faculty for electrical engineering followed in 1883, and with it the introduction of the world's first course in electrical engineering. Graduates and employees of TU Darmstadt played key roles in establishing computer science; business informatics, and artificial intelligence as scientific subjects in Germany.

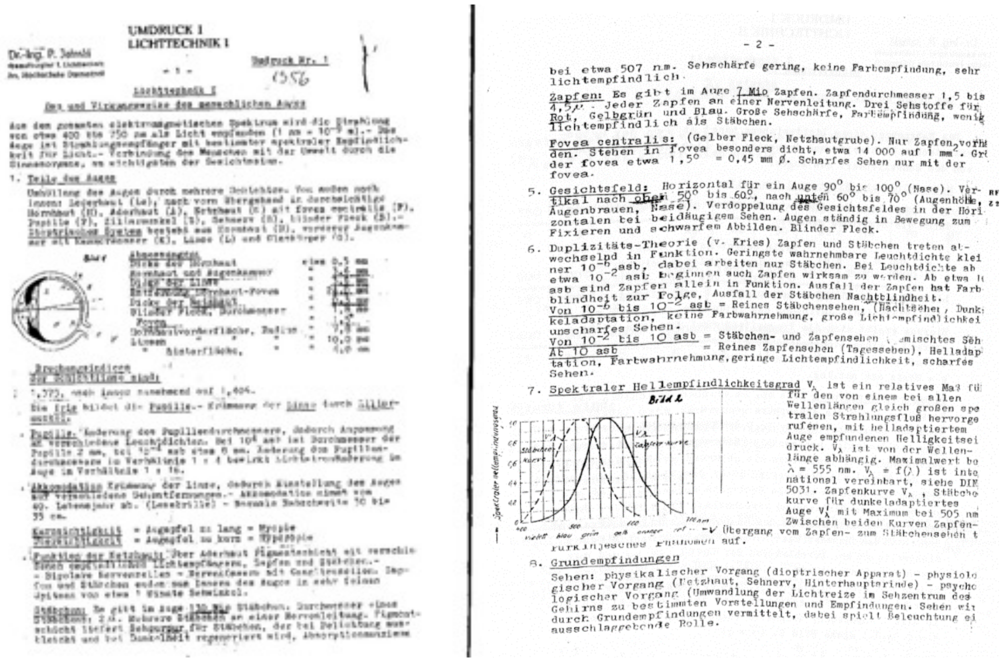
Electrical Engineering is a part of the TUD 'ETIT' engineering research division (ElectroTechnics and Information Technology). And within the Electrical Engineering department is the Laboratory of Adaptive Lighting Systems and Visual Processing, generally known as the Darmstadt Lighting Institute (in this report we say DLI, for short).

The DLI is responsible for research and teaching in the field of lighting technology, in particular automotive lighting technology—interior and exterior lighting; optoelectronics; human visual interfacing, and photobiology. The team work as specialists for interdisciplinary problems wherein lighting technology issues are important, and seek contact with related disciplines.

The special tradition of Darmstadt lighting technology is the combination of theoretical and experimental research. The aim is to develop the skills and knowledge in the lighting world's basic area today that will be required in 3 to 5 years in transfer projects. In this respect, research and application reference are the basic of such work. Above all, the transfer projects help to identify tasks for future basic research, and they provide an additional contribution to the financing of DLI's work. In-depth research in human visual perception; human spectral sensitivity, and the eye and visual optical path is also driven by the research team.

6. LIGHTING HISTORY IN DARMSTADT

In winter semester 1956, the Technical University of Darmstadt started a lecture called Lichttechnik I ("Light Technology I"). This was promoted by electrotechnics professor Karl Küpfmüller. The lecturer at that time was Dr.-Ing. Paul Jainski, a renowned specialist for traffic signalling and colours. He worked on railway and maritime issues, and was later employed at the german ministry of transport in Bonn. In 1962, Jainsky was appointed Honorary Professor for the Institute of Lighting Technology at Darmstadt Technical University. The institute was organized as section of the electrotechnics faculty.



First two pages of the Scriptum to the Lecture "Lighting Technology I" from Prof. Jainsky 1956

The first lectures by Paul Jainsky covered the human eye; photometry, and metrics as well as physiological elements of visual perception. Since basics for photometry and visual perception are still basics, some of the readers will smile to see the first page of the scriptum from that time.

The dominating high-tech light sources at that time were discharge lamps, so the lectures covered mostly sodium and mercury discharge sources and the carbon arc lamps still in use for e.g. cinema projections. In summer semester, the lecture Lichttechik II was added, covering topics like visual perception; colour; vehicle lighting, and exterior and interior lighting.

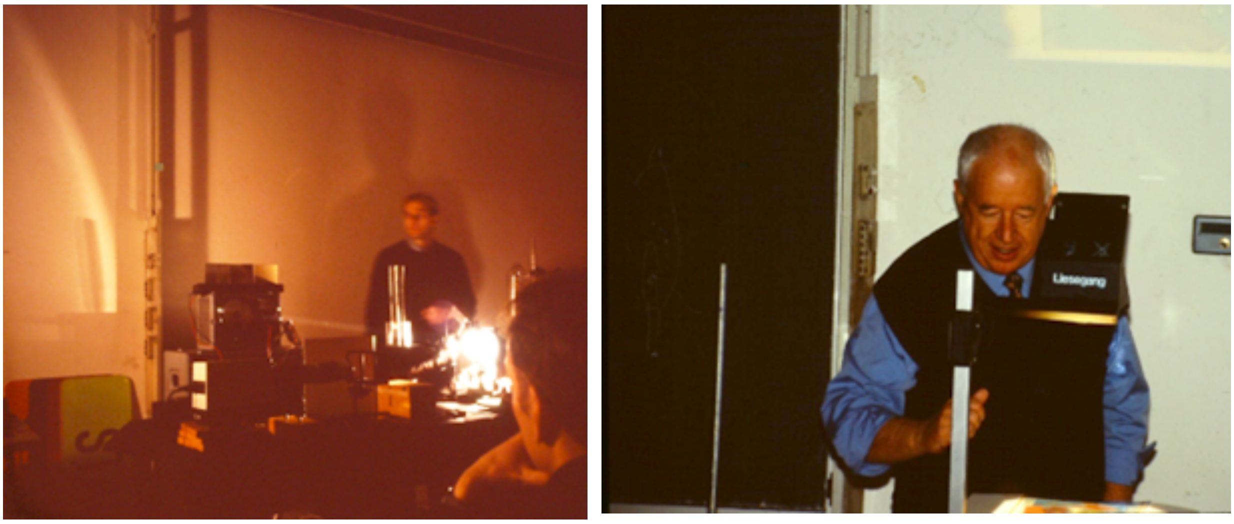
A first generation of PhD students emerged from the pool of interested students.

At that time, the visual process of seeing; perceiving, and then recognizing was not well understood. Additionally, colours and intermittent signals made standard scientific knowledge insufficient. So understanding the optical system of the eye was followed by research on visual processing in the human visual system. Based on this theoretical research, experimental research was started for the transformation into real life. Research topics were signal lights for marine traffic; visibility of pulsed or blinking signals; design and optics for light beacons; colour perception, and the investigation of V(λ), the spectral human sensitivity of the eye.

One of the young Doctoral Students was H.-J. Schmidt-Clausen. After earning his Doctor, he worked at the Botanical Institute of TU Darmstadt with research on radiation interference of photosynthesis. Subsequently he worked on lighting research at Philips Eindhoven and for a long time at Hella, one of the dominant vehicle lighting suppliers based in Lippstadt, Germany. Prof. Schmidt-Clausen was appointed head of the Lighting Laboratory 1981.

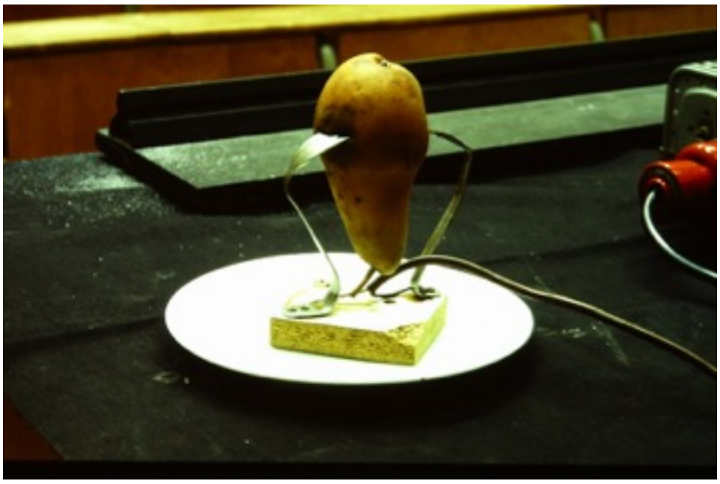
Over time, the course structure changed. Standard presentation became the overhead projector with slides accompanied by explanations on the blackboard (actually greenboards, at TUD) and a revised scriptum. All students had to add practical exercises in the laboratory on lighting themes.

One of the outstanding unique features of the program was that during lectures experiments were always shown. For the author of this report, this factor was the convincing argument to sign on and do this program. Since lighting is mostly visual, many experiments could be done at the front of the auditorium.



Light Sources Demonstration by Ernst-Olaf Rosenhahn during the lecture with Prof. Schmidt-Clausen

Experiments for Lecture "Light Sources" in Session Lighting Technology 1 from 1995.



Remarkable experiment during the special Christmas lectures: a bulb-shaped light source fresh from the grocery, which glows at 380V.

(in German, light bulbs are known as "Glühbirne", literally 'glow-pears')

Research focus for basic human eye properties was kept during the Schmidt-Clausen period, and enhanced by other aspects of vehicle lighting and road lighting infrastructure improvements. Some of the basic research done at that place and time for street geometries; adaptive light distributions, and construction zone delineators are present in our streets to this day. Investigations on surface reflection and retroreflection; glare; fog, and wet roads influenced the ECE Regulations. The DLI was awarded with research orders for spectral sensitivity V(λ) of the human eye by the DFG, the German Research Foundation. Experimental research was carried out for BASt, the German Federal Highway and Street Research Institute. Additional research was carried out for on improvements and practical proposals for visually-impaired persons; precision engineering workplace illumination, proposals for uniform worldwide headlight beam patterns and the European VEDILIS project (VEhicle DIscharge LIghting System) which developed the HID headlighting components and technical definitions eventually adopted in regulations worldwide.

Prof. Schmidt-Clausen was active in the national and international organizations for rulemaking in the field of lighting like GTB; GRE, and VDA.

Helped by these international contacts, he started 1995 a vehicle lighting symposium first known as PAL (for Progress in Automobile Lighting). The International Symposium on Automotive Lighting (ISAL), as it is now known, is the most-visited conference on the subject, with the highest reputation in the field. Up to 1,000 participants meet in Darmstadt every second year to discuss topics on lighting. A large exhibition area offers the experts direct contact with the contributors to the lighting community from automakers, suppliers Tier1,2,3 and research organisations.

Alongside the international activities, the lighting team enlarged their contacts and attractivity for students. During Summer and Winter semesters, the lectures were accompanied by laboratory experiments for the students. Once a year the students; assistants, and the professor went on a 5-day tour to various companies in the lighting field.

Excursion from students to companies in the lighting industry

The level of Research was—and is—strongly dependent on the budget of granted projects. The university supplies only a basic budget for a secretary and one Assistant full employee. After German reunification in 1989, third-party funds became a precious good, because many East German universities and research labs had to be integrated by funding in the research community. So the number of Doctoral Students oscillated from many to few. Max was about 12, including external PhD workers; minimum was one assistant together with a part-time secretary. But the research and lectures were a reliable and stable contributor during all times. And the PAL/ISAL lighting conferences continued to attract even more specialists from all over the world.

7. INDUSTRY CONSORTIUM FOR ENDOWED PROFESSORSHIP

Professor Schmidt-Clausen retired officially at the end of 2002, reaching age limit. There had been no activity on a succession plan. From then on, the Laboratory of Lighting Technology was officially managed by Professor Helmut Schlaak, the Dean of the Engineering Research Division of Electrotechnics and Information Technology and Head of the Institute for Mechatronics (EMK).

Prof. Schlaak, as head of the Laboratory, arranged together with some ex-members of the lighting team very special and unique constellations—these were what guaranteed the continuation of the laboratory and its programmes.

With active support from an industry consortium led by Dr. Wolfgang Huhn (head of Audi's lighting department, at that time), the Dean; research professoral conference, and the university chancellor and president was persuaded in 2003-04 to send out a call for the vacancy of the Laboratory of Lighting Technology in Darmstadt. One unique and in this field unprecedented constellation was that the industry consortium of 12 members guaranteed and financed a budget for the first five years. Every consortium representative had to take care that upper management in their company was convinced that funding money into a university for lighting issues was a win. In total about €1.8m came in as sponsorship money. Accordingly, an endowed professorship was created.

The 12 members of the consortium were:

- **Adam Opel AG**
- **Audi AG**
- **Automotive Lighting Reutlingen GmbH**
- **BMW AG**
- **Daimler Chrysler AG**
- **Genthe X Coatings GmbH**
- **Hella KGaA**
- **Osram AG**
- **Philipps GmbH Business Center Aachen**
- **Schefenacker Vision Systems GmbH**
- **Valeo Vision SAS, France**
- **ZKW Zizala Lichtsysteme GmbH, Austria**

LMT Lichtmesstechnik Berlin, specialists in photometric equipment, contributed measurement devices as physical support.

Without this unprecedented idea and final execution, lighting research in Darmstadt would have gone extinct.

The lighting community and all following students, doctors and researchers owe happy continuous thanks to the consortium members and drivers of the process.

Parallel to these activities, it was clear in 2003 that the best start for a coming professor would be an operational and working system of students and scientific research base. Without constant lectures the visibility of the Laboratory of Lighting Technology was estimated to be zero, making a restart even more difficult.

So the wish was for lectures; practical exercises; research, and seminars to be continued during that transition period. The research department for Electrotechnics and Information Technology appointed a lecturer for doing the lectures; exercises, and final exams: Dr. Michael Hamm, the author of this present report.

A lecture series was created from 2004 on, with contributions by invited lighting specialists from the industry consortium and former Doctoral students. In order to ease the work, double lectures were created with two 1. 5-hour blocks of scientific lectures and practical experiments.

Laboratory practical exercises were supervised by the Assistant at the laboratory, Holger Sprute. Students who participated in the lectures and exercises and positively passed the examination received 4 + 2 credit points. The lecture series was a success. Students participated and so the DLI was visible and created interest for students collaborating and doing their Bachelor thesis in the field of lighting.

An der Technischen Universität Darmstadt ist im Fachbereich Elektrotechnik und Informationstechnik ab 1. Oktober 2005 eine

Universitätsprofessur für Lichttechnik

(Kenn-Nr.: 188) zu besetzen.

Im Rahmen einer neu eingerichteten Stiftungsprofessur soll die Stelleninhaberin/der Stelleninhaber das Gebiet der „Lichttechnik" durch mehrere der nachfolgend genannten Schwerpunkte in Forschung und Lehre neu gestalten und vertreten und damit auch den Forschungsschwerpunkt Mechatronik an der TU Darmstadt verstärken:

- Innovative Licht- und Beleuchtungssysteme
- Adaptive Light
- Optoelektronik
- Optische Systeme und Mikrooptik
- Energieeffiziente Lichterzeugung
- Verkehrslichttechnik
- Visuelle Kommunikationstechnik
- Technisches Sehen
- Human-Machine Interfaces

Geeignete Persönlichkeiten sollen auf mehreren dieser Gebiete im Bereich der Forschung und Entwicklung ausgewiesen sein. Es wird von der Bewerberin/dem Bewerber die Übernahme von Lehrverpflichtungen auf dem Gebiet der Lichttechnik sowie im Bereich der Grundlagenvorlesungen erwartet. Eine moderne und umfangreiche Laborausstattung zur Lichtmesstechnik steht zur Verfügung.

Vorausgesetzt werden eine hervorragende wissenschaftliche Qualifikation sowie eine

Official Search/Advertisement for a Professor 2005

In March 2006, the Technical University of Darmstadt officially appointed Professor Dr.-Ing. Tran Quoc Khanh as professor for the Laboratory of Lighting Technology at the institute for EMK in the research department for Electrotechnics and Information Technology. Prof. Khanh assumed full work with administration; research, and teaching from winter 2006 onwards.

Technische Universität Darmstadt

Grundlagen der Lichttechnik, SS 06
Prof. Dr.-Ing. H. F. Schlaak / Dr. Hamm

Vorlesung mit Praktikum 2+2 SWS oder 4+2 CP, S2 07/109, 11:40 Uhr
für Elektrotechnik, Physik und WI/ET ab dem 5. Semester

Termin	Thema	Dozent
15.05.06	Bau und Wirkungsweise des Auges Physiologie des Sehens	Dr. Enders, BMW Dr. Hamm, AL
22.05.06	Größen der Lichttechnik Stoffkennzahlen	Dr. Diem, Koito
29.05.06	Photometrie I - Grundlagen Photometrie II - Messempfänger	Dr. Hamm, AL
12.06.06	Lichterzeugung I - Grundlagen Lichterzeugung II - Temperaturstrahler	Dr. Rosenhahn, AL
19.06.06	Lichterzeugung III - Entladungslampen Lichterzeugung IV - neue Lichtquellen	Dr. Khanh, ARRI
26.06.06	Lichttechnische Bauelemente Innenraumbeleuchtung	Dr. Wambsganß, Hella
03.07.06	Straßenbeleuchtung Lichtanwendung am Kfz	Dr. Huhn, Audi Dr. Hamm, AL

Fachgebiet Lichttechnik

Lecture Series announcement " Lighting Technology" at Technical University Darmstadt during the vacancy 2004..2006 with contributions of invited specialists.

8. THE NEW LABORATORY OF ADAPTIVE LIGHTING SYSTEMS AND VISUAL PROCESSING

Adaptive Lichttechnische Systeme
und Visuelle Verarbeitung

In 2006 Prof. Tran Quoc Khanh was appointed as Professor at the Technical University of Darmstadt.

Prof. Khanh in an Interior Lighting interview 2018

Prof. Khanh started his scientific career with his PhD thesis in 1989 at the faculty for Physics and Electronic Devices at Technical University Ilmenau, Germany. From 1990 to 1999 he worked in various constellations as project leader for radiometric; colorimetric, and photometric systems in Munich and Berlin

In 2000 he joined the renowned ARRI— Arnold & Richter Cinetechnik, of Munich, Germany—and became the first developing engineer and then project manager for digital cinema cameras; laser recorders and scanners, and LED luminaires. ARRI are the leading company in cinema technology, and in 2002 were awarded an Oscar for their work. In the 100-year history of ARRI, they have won 19 Scientific and Technical Awards.

In 2005 Dr. Khanh habilitated in the field of mesopic vision; colour image processing, and colour appearance.

His research topics that time were and are:

- **Optoelectronic elements and systems (optical systems, lenses, reflectors, LED, OLED, laser, phosphor systems)**
- **Vehicle lighting (LED-OLED-laser technology for adaptive headlamps; rear lamps, and interior lighting for regular and automated vehicles)**
- **Colorimetry, display technology**
- **Digital camera technology (colour image processing and evaluation, CMOS-CCD-sensors)**
- **Human eye physiology (colour appearance, glare, detection)**
- **Interior and exterior lighting, human-centric lighting**

In October 2021 the (old) name of Fachgebiet Lichttechnik (=Laboratory of Lighting Technology) was changed into (current) : Adaptive Lichttechnische Systeme und Visuelle Verarbeitung (=Adaptive Lighting Systems and Visual Processing.

TECHNISCHE UNIVERSITÄT DARMSTADT	FACHGEBIET LICHTTECHNIK	ALSV Adaptive Lichttechnische Systeme und Visuelle Verarbeitung

Excerpts from the Arguments to change the Laboratory's name

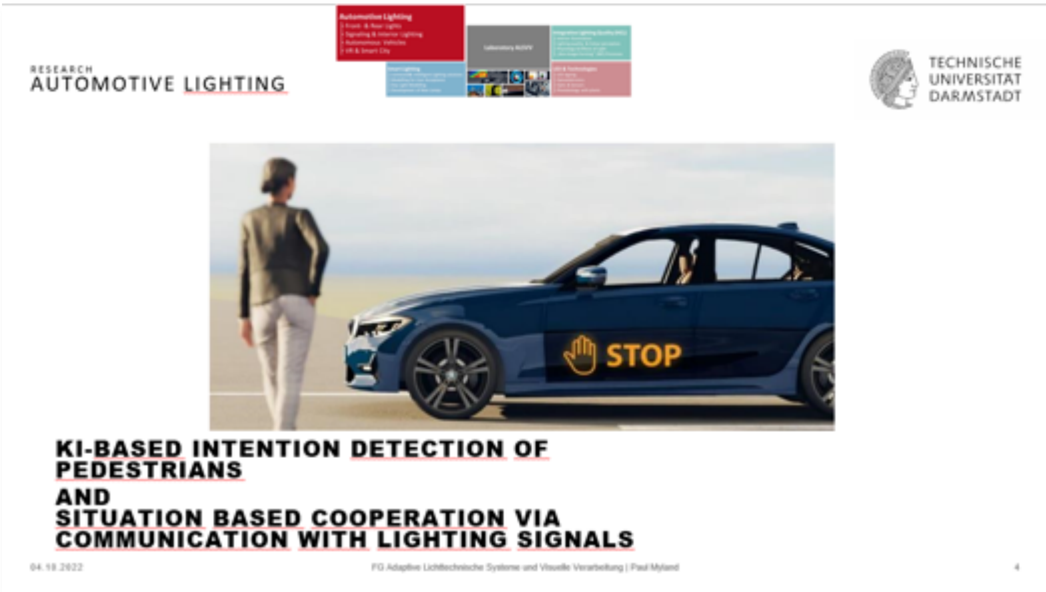
"…Since the beginning of the 21st century, the research focus of modern lighting technology has been less and less on researching light sources as such and more and more on developing a fundamental understanding of the interaction between the illuminated space and the people who use it (Human Centric Lighting). Lighting technology has developed into a highly interdisciplinary field of research. As researchers in this field, we have therefore not only dealt with the neuronal-cognitive processing and evaluation of visual stimuli in a wide variety of application scenarios (e.g. nursing homes, retirement homes, office and industrial hall lighting, vehicle lighting technology, digital cinema and TV image processing, automated vehicles, light in medical surgery), but have also gradually advanced into physiological-ergonomic and psychological-emotional terrain…"

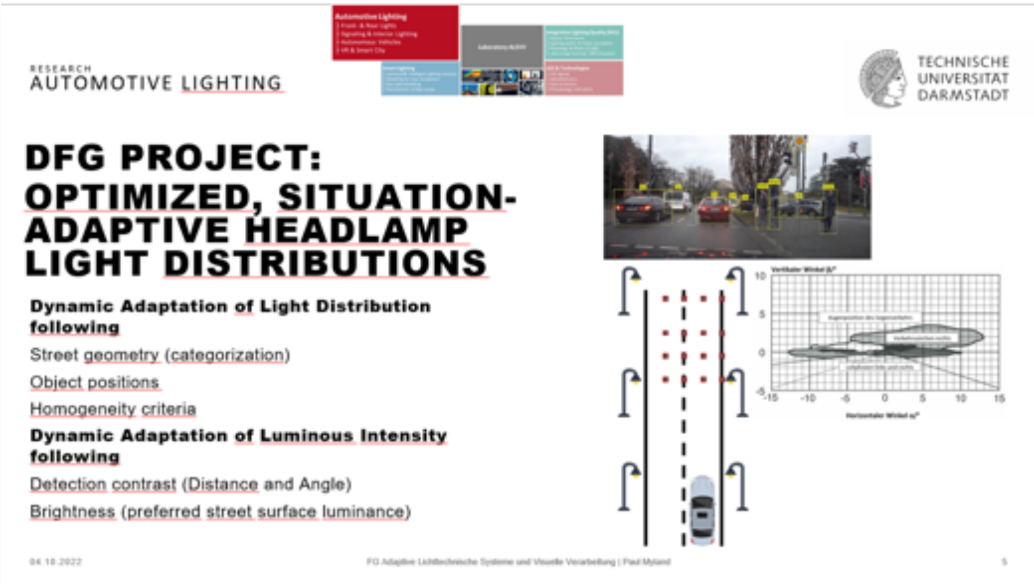
"..In addition, there are newly developed, highly topical research fields, such as adaptive LED plant lighting in digitally controlled greenhouses or research into intelligent, self-learning systems (automated vehicles, adaptive building technology, medical technology, etc.), which make use of the fundamental knowledge gained over the past few years. This will allow the offer of lighting solutions that are optimally tailored to the mental, psychological and human-biological needs and preferences of a wide variety of organisms. Modern lighting systems interact with human visual and non-visual processing and serve to optimally support the visual apparatus in its functionality. Current approaches in automotive and interior lighting technology are therefore primarily concerned with neurovisual modeling tasks in order to be able to automatically adapt networked lighting systems to the human organism in a time- and spectral-dependent manner. Due to the increased presence of people in the interior area and the systematic withdrawal of the daylight effect, a so-called "biological darkness" arises, which from a medical point of view should be compensated by the artificial adaptive lighting technology. The discovery of the effects of light on the internal biological clock in the central and peripheral nervous system of humans by Jeffrey C. Hall, Michael Rosbash and Michael W. Young, for whom the Nobel Prize for Medicine was awarded in 2017, forms the basis for us on which we want to advance our light research…."

"..We would like to continue on the path we have successfully taken in the years and decades to come. We see ourselves as being very well positioned for this in terms of content, especially in an international comparison, but unfortunately this has not yet been reflected in the naming of the department … A renaming would therefore be desirable, also with the chance of increasing the attractiveness for future students and researchers…"

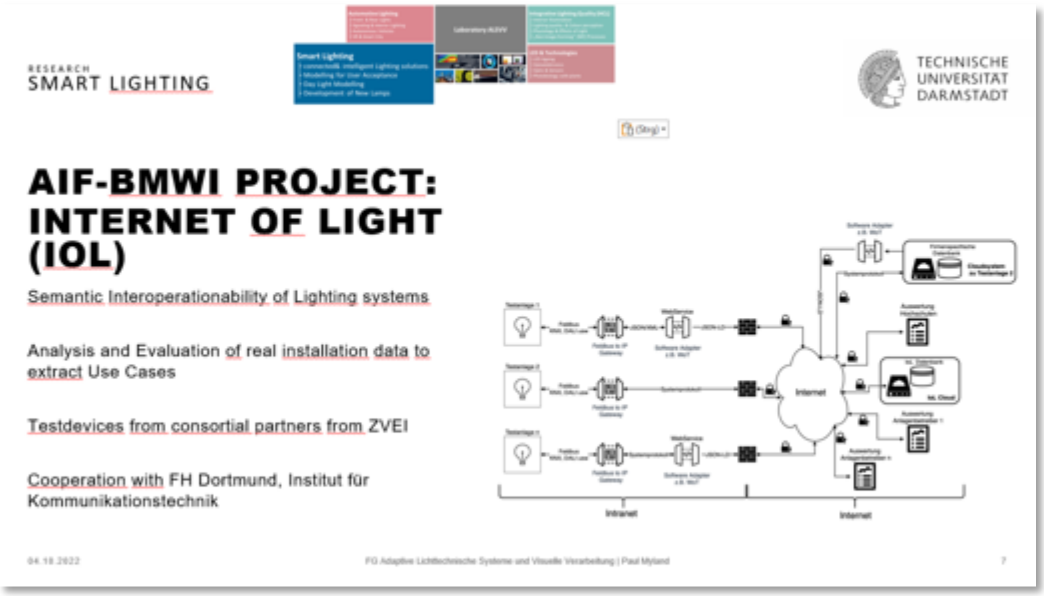
Overview on Research in Darmstadt

The following pages demonstrate the diversity of research that is currently running in the Laboratory for Adaptive Lighting Systems and Visual Processing


RESEARCH
AUTOMOTIVE LIGHTING
TECHNISCHE UNIVERSITAT DARMSTADT
STOP
KI-BASED INTENTION DETECTION OF PEDESTRIANS
AND
SITUATION BASED COOPERATION VIA COMMUNICATION WITH LIGHTING SIGNALS
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland


RESEARCH
AUTOMOTIVE LIGHTING
TECHNISCHE UNIVERSITAT DARMSTADT
DFG PROJECT:
OPTIMIZED, SITUATION-ADAPTIVE HEADLAMP LIGHT DISTRIBUTIONS
Dynamic Adaptation of Light Distribution following
Street geometry (categorization)
Object positions
Homogeneity criteria
Dynamic Adaptation of Luminous Intensity following
Detection contrast (Distance and Angle)
Brightness (preferred street surface luminance)
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland


ISAL
APRIL 2022
ISAL 2023
TECHNISCHE UNIVERSITAT DARMSTADT
INTERNATIONAL SYMPOSIUM FOR AUTOMOBIL LIGHTING
biennal: next Conference September 2023
Darmstadtium: exhibitions & multiple lectures & posters
> 600 experts
automobile lighting today and tomorrow
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland


RESEARCH
SMART LIGHTING
TECHNISCHE UNIVERSITÄT DARMSTADT
AIF-BMWI PROJECT: INTERNET OF LIGHT (IOL)
Semantic Interoperationability of Lighting systems
Analysis and Evaluation of real installation data to extract Use Cases
Testdevices from consortial partners from ZVEI
Cooperation with FH Dortmund, Institut für Kommunikationstechnik
Internet
Intranet
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland
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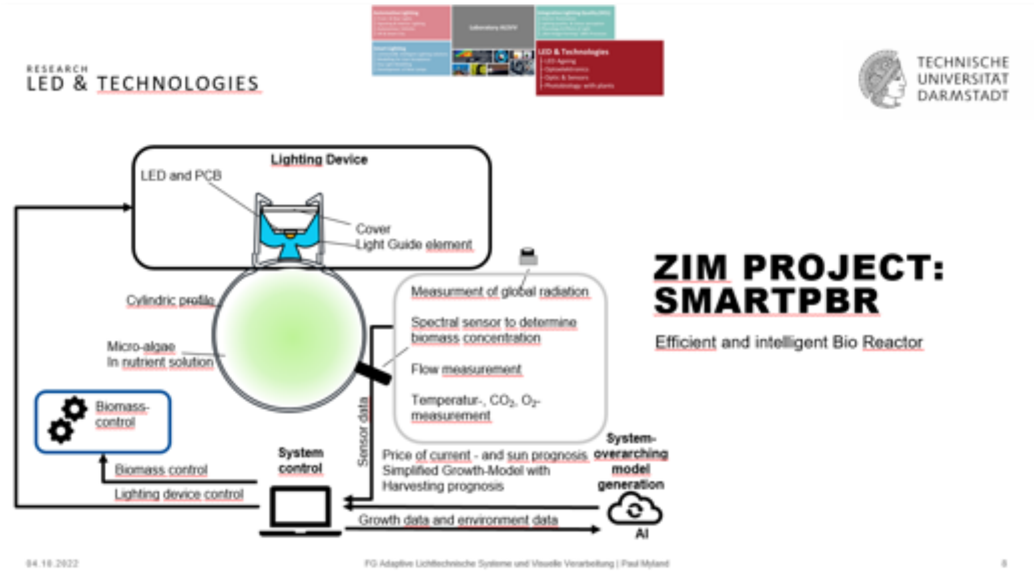
RESEARCH
LED & TECHNOLOGIES
TECHNISCHE UNIVERSITÄT DARMSTADT
Lighting Device
LED and PCB
Cover
Light Guide element
Cylindric profile
Micro-algae In nutrient solution
Measurment of global radiation
Spectral sensor to determine biomass concentration
Flow measurement
Temperatur-, CO2, O2-measurement
Biomass-control
Sensor data
System control
Biomass control
Lighting device control
Price of current - and sun prognosis
Simplified Growth-Model with Harvesting prognosis
System-overarching model generation
Growth data and environment data
AI
ZIM PROJECT: SMARTPBR
Efficient and intelligent Bio Reactor
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland
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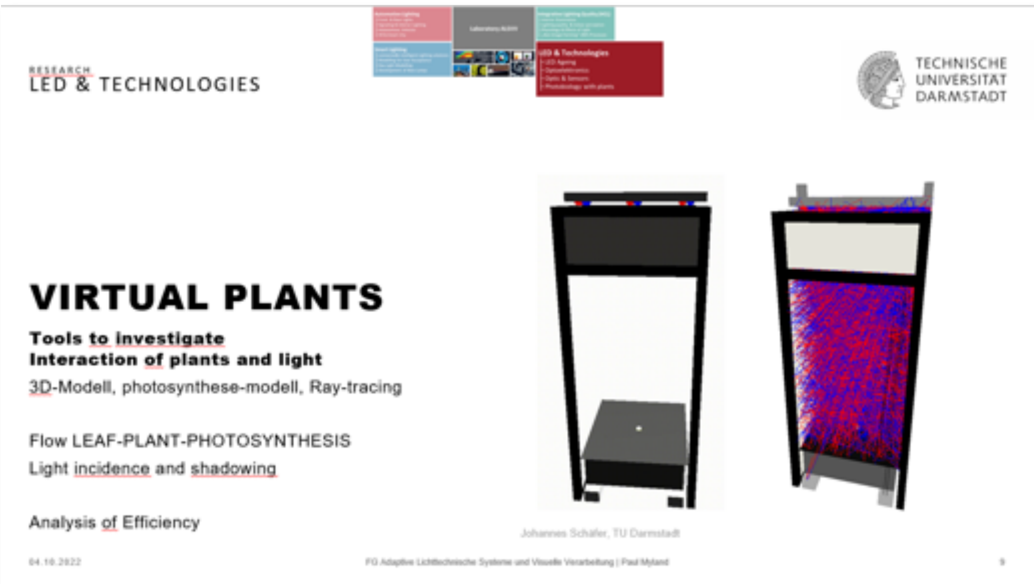
RESEARCH
LED & TECHNOLOGIES
TECHNISCHE UNIVERSITÄT DARMSTADT
VIRTUAL PLANTS
Tools to investigate
Interaction of plants and light
3D-Modell, photosynthese-modell, Ray-tracing
Flow LEAF-PLANT-PHOTOSYNTHESIS
Light incidence and shadowing
Analysis of Efficiency
Johannes Schäfer, TU Darmstadt
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland
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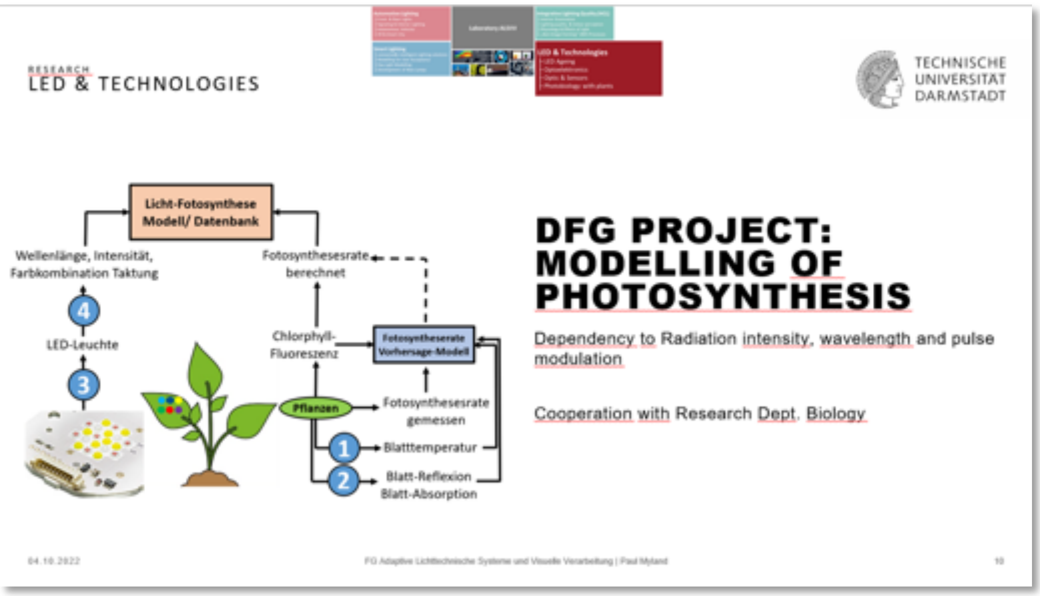
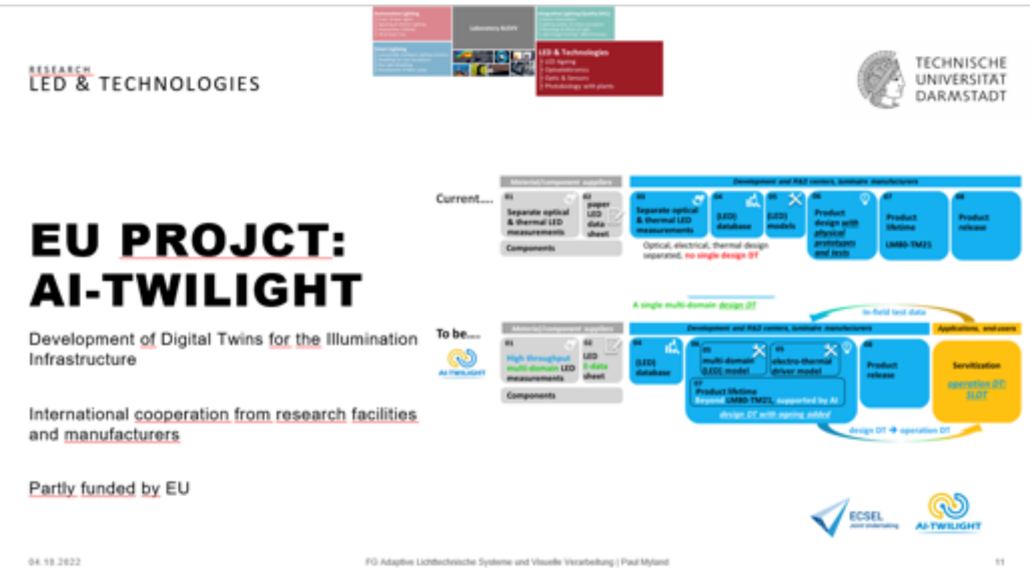
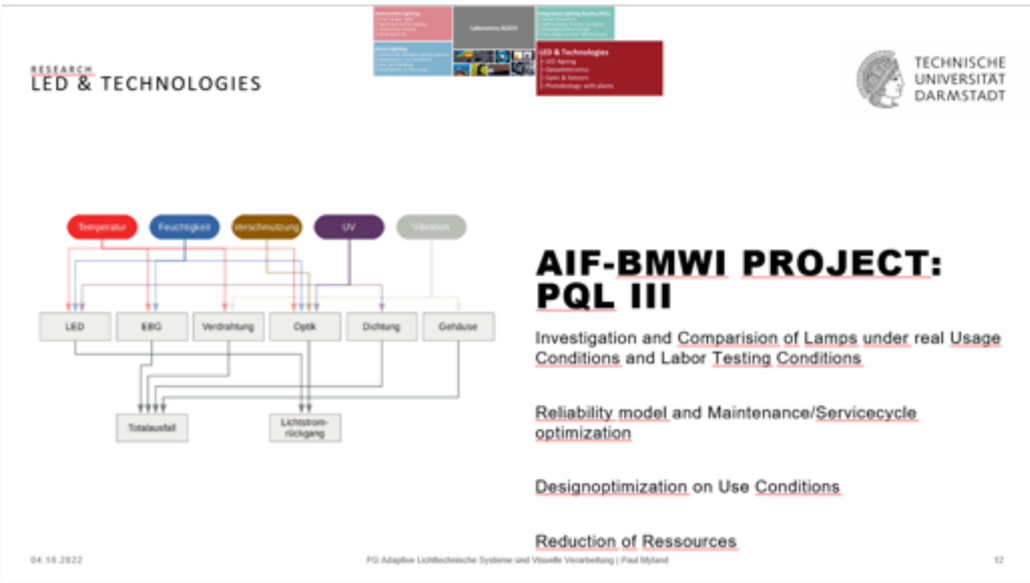
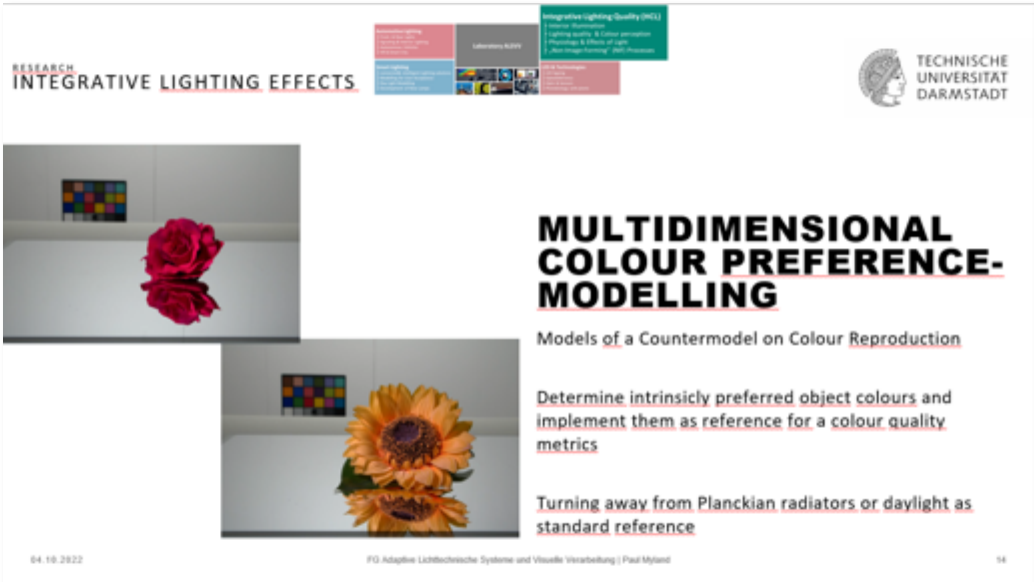
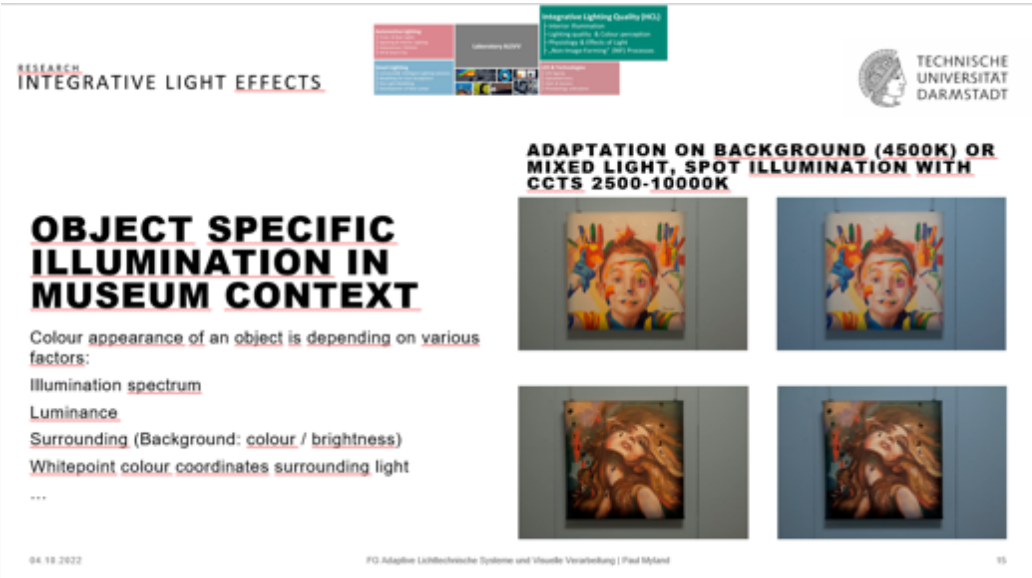

RESEARCH
LED & TECHNOLOGIES
TECHNISCHE UNIVERSITÄT DARMSTADT
Licht-Fotosynthese Modell/ Datenbank
Wellenlänge, Intensität, Farbkombination Taktung
Fotosynthesesrate berechnet
LED-Leuchte
Chlorphyll-Fluoreszenz
Fotosyntheserate Vorhersage-Modell
Pflanzen
Fotosynthesesrate gemessen
Blatttemperatur
Blatt-Reflexion
Blatt-Absorption
DFG PROJECT: MODELLING OF PHOTOSYNTHESIS
Dependency to Radiation intensity, wavelength and pulse modulation
Cooperation with Research Dept. Biology

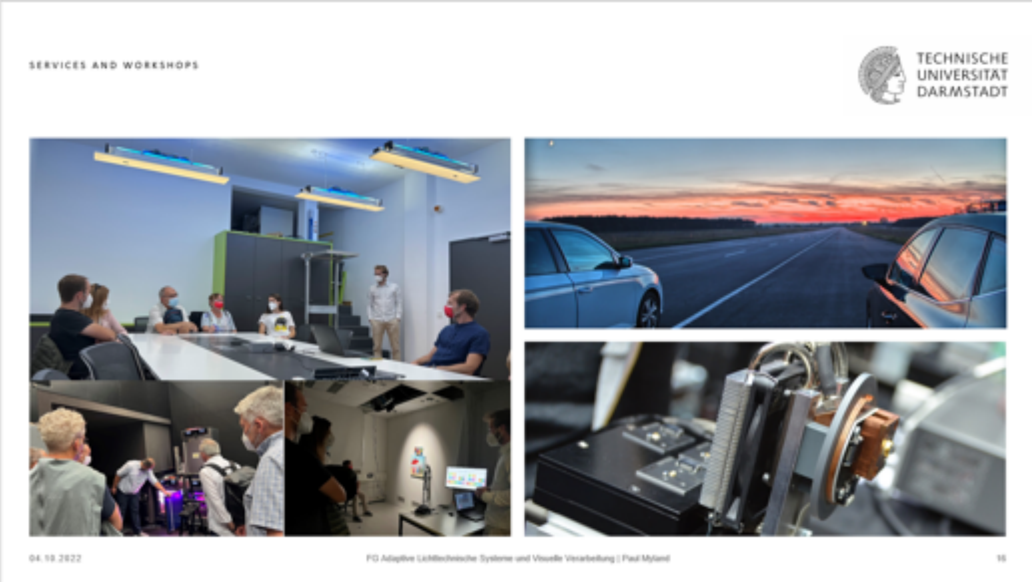

RESEARCH
LED & TECHNOLOGIES
TECHNISCHE UNIVERSITÄT DARMSTADT
EU PROJCT: AI-TWILIGHT
Development of Digital Twins for the Illumination Infrastructure
International cooperation from research facilities and manufacturers
Partly funded by EU
Current....
To be....
ECSEL
AI-TWILIGHT

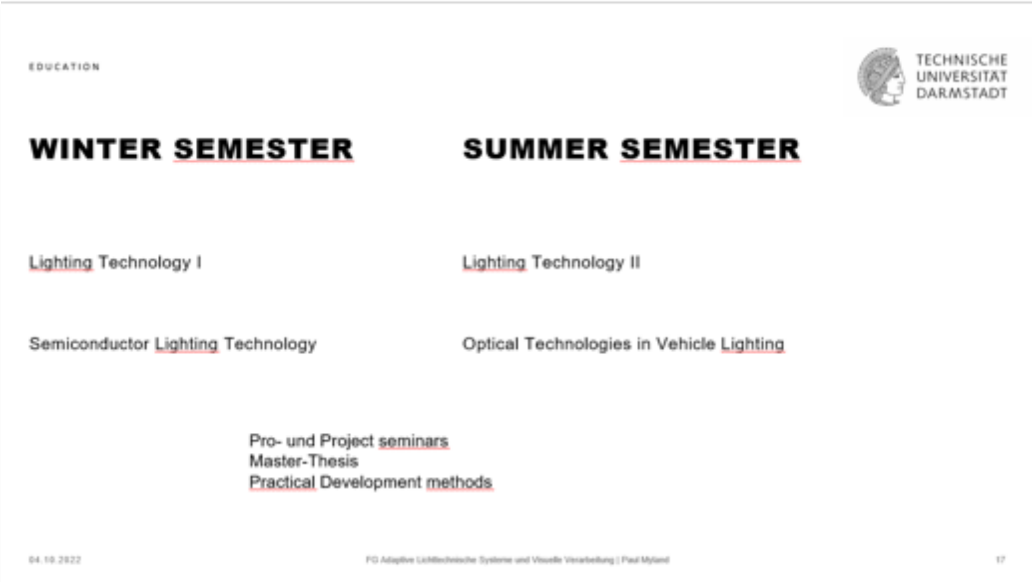

RESEARCH
LED & TECHNOLOGIES
TECHNISCHE UNIVERSITÄT DARMSTADT
Temperatur
Feuchtigkeit
Verschmutzung
UV
Vibration
LED
EBG
Verdrahtung
Optik
Dichtung
Gehäuse
Totalausfall
Lichtstrom-rückgang
AIF-BMWI PROJECT: PQL III
Investigation and Comparision of Lamps under real Usage Conditions and Labor Testing Conditions
Reliability model and Maintenance/Servicecycle optimization
Designoptimization on Use Conditions
Reduction of Ressources


RESEARCH
INTEGRATIVE LIGHTING EFFECTS
TECHNISCHE UNIVERSITÄT DARMSTADT
DFG PROJECT: TIME DEPENDENT MODELLING OF PUPILS
Pupil reflex time-dependant (phasic, tonic) modelling in dependency of spectrum
① Konstriktion
② Re-Adaptation
③ Latenzzeit
Pupillendurchmesser in a.u.
Lichtreiz
0
Zeit in Sekunden
10
① Adaptation
② Re-Adaptation
Pupillendurchmesser in a.u.
Lichtreiz
0
Zeit in Sekunden
10
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland
13


RESEARCH
INTEGRATIVE LIGHTING EFFECTS
TECHNISCHE UNIVERSITÄT DARMSTADT
MULTIDIMENSIONAL COLOUR PREFERENCE-MODELLING
Models of a Countermodel on Colour Reproduction
Determine intrinsicly preferred object colours and implement them as reference for a colour quality metrics
Turning away from Planckian radiators or daylight as standard reference
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland
14


RESEARCH
INTEGRATIVE LIGHT EFFECTS
TECHNISCHE UNIVERSITÄT DARMSTADT
OBJECT SPECIFIC ILLUMINATION IN MUSEUM CONTEXT
Colour appearance of an object is depending on various factors:
Illumination spectrum
Luminance
Surrounding (Background: colour / brightness)
Whitepoint colour coordinates surrounding light
...
ADAPTATION ON BACKGROUND (4500K) OR MIXED LIGHT, SPOT ILLUMINATION WITH CCTS 2500-10000K
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland
15


SERVICES AND WORKSHOPS
TECHNISCHE UNIVERSITÄT DARMSTADT
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland
16


EDUCATION
TECHNISCHE UNIVERSITÄT DARMSTADT
WINTER SEMESTER
SUMMER SEMESTER
Lighting Technology I
Lighting Technology II
Semiconductor Lighting Technology
Optical Technologies in Vehicle Lighting
Pro- und Project seminars
Master-Thesis
Practical Development methods
04.10.2022
FG Adaptive Lichttechnische Systeme und Visuelle Verarbeitung | Paul Myland
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9. INTERVIEW WITH PROF. KHANH

Q.: Professor Khanh, will you tell us about the current academic teaching and research?

Prof. Khanh: Currently we have two lectures per semester plus seminars and practical exercises: Lighting Technology Basics, Lighting Technology 2, Semiconductor Light Sources, and Vehicle Lighting. Each Lecture is visited by about 15-20 students, thereof some still in home-office due to Covid influence on living and working location.

Q.: How do you estimate your academic reach, then?

Prof. Khanh: If I am accumulating all lighting lectures since I was appointed, I see more than 1,400 lectures and about 600 students that passed my classes. That is quite a lot!

Q.: How do you position your laboratory in the greater university science offering?

Prof. Khanh: Lighting lectures are a master's degree specialization in the ETIT (Electrotechnics and Information Technology) research division. We are working on implementing lighting lectures in the bachelor's degree program in future.

Q.: After 15 years, what are your takeaways and knowledge gains?

Prof. Khanh: After so many theories and scientific models known so far in glare and detection show both to be inappropriate. Why did this happen: We made many experiments in the laboratory, the test persons were laboratory-conditioned and did not have real tasks like driving tasks or realistic parameter environment. Threshold as widely used criterion did not give realistic results, because a bare threshold is not leading to sufficient and concise object detection and thus a realistic reaction. For scale-based experiments the [deBoer discomfort scale] answers "too bright", "I am glared" or "just acceptable" deliver too many deviations without exact explanation to the test persons and conditioning. In order to become more precise, the experiments must tend to have more relation to the complex surroundings we human beings [face in the] real world.

Q.: So what is the lessons learned?

Prof. Khanh: Technical Improvements also have influence on scientific research. Static tests were the best experimental basis in former times. Now, we can increase the complexity of sceneries by virtual or real projections, detect online the gaze behavior and the surrounding photometrical parameters. We are living in a dynamic surrounding and thus also the research should use such dynamics in traffic and environment. And our measurement devices have become smaller, digital and more precise. And for example, drivers do not only focus on the street 55 m away, between -3° and +3° horizontal and -2° vertical all night driving time. So even this difference needs to be addressed and investigated.

Q.: What does 'detection' mean, then?

Prof. Khanh: We see that dynamic environments are giving more complex formulas. Our predecessors had an easy life with one fixation and one formula—unfortunately not good for life. Detection remains an object of probability and statistics. Reflection coefficients vary, and thus the detection and probability changes. And our task must be to find simple and understandable answers.

Q.: What is the future core challenge of lighting and research?

Prof. Khanh: The buzzword is adaptive. Every system, independent of whether visual or even botanical processing, is adapting to the changing environmental parameters. Adaptivity influences all thresholds of criteria, for example glare; detection; colour perception; shadows; inhomogeneities, and more. Our job is practical [yet] nevertheless academic lighting research on these adaptive parameters. Another example: We look to a colour rendering index (CRI) with three results; CRI 70; 80, and 90. Now the question whether 80 is good or bad remains open. It has to do with adaptivity.

Q.: What is your feeling on where lighting and lighting research are positioned today?

Prof. Khanh: The most important knowledge gain: lighting today is interdisciplinary. We are even the bridge between other disciplines. Lighting can be therapy; lighting controls the inner human biological clock (sleep-wake-period, sleep quality in the nighttime, alertness in the daytime…), lighting is part of psychology to have impact on emotion, wellbeing, room architecture. Our brain does not understand lux and candelas, it wants wellbeing. And this is valid in the car, in an office workspace, in a nursing home, in a hospital, in an art gallery and on many other places.

Q.: A personal question: How does it feel to be professor for lighting technology?

Prof. Khanh: I have a tight schedule, very very tight. Only after 10 years I leave the industry habit of only outlook-dominated time slots, telecons etc. After that, science is the dominating rule; I want to create new knowledge. As professor, when I am thinking to the expectations for a professor, most people only see the lectures. But first, a professor works for the university. Dean, Vice Dean, in research conferences, in public, always in social context—I am a representative of the university. Second: I am responsible for my PhDs. Not only for their pure business, but for the entire human being. Third: the researcher from today has to take care for budget, funding, acquiring research projects, employing the right people and look that the budget fits. You see, the professor of today is researcher, social worker, manager, PR specialist and business administrator in one person.

Q.: You mentioned the university. How do you see the Laboratory for Adaptive Lighting and Visual Processing in the university environment?

Prof. Khanh: Lighting today is adaptive and deals with unexpected fields like biology; agriculture; energy saving, and efficiency. We interface with sport science; sleep research; neuroscience; cognitive science; medicine, and bio-engineering. This is placing our field of competence and interest in the middle of many new business and research fields. This makes us a valuable contributor to scientific research. We are based on physics; technology; mechanical engineering, and electrical engineering. The future adds biological and psychological aspects. We can deliver know-how and realistic explanations and solutions. So I feel pretty good.

Prof. Khanh, thank you for your time and open words!

10. ISAL - International Symposium on Automotive Lighting

In 1995, Prof. Schmidt-Clausen initiated the symposium "PAL—Progress in Automobile Lighting". The beginnings were smaller than today, about 200 or 250 participants. The conference room was a lecture hall for Inorganic Chemistry at the university campus "Lichtwiese", a little outside of central Darmstadt.

After Prof. Schmidt-Clausen's retirement, since 2005 the symposium was organized under the name ISAL: International Symposium on Automotive Lighting.

In 2007 all plans were ready to be the first conference held in the new Darmstadtium conference center, but, like it is sometimes, the facility was not ready. So the conference took place in the ancient Darmstadt electric power building with an extra tent in front.

Since 2009, the symposium takes place at the Darmstadtium, the great big Darmstadt conference centre.

Looking at the bare numbers, this scientific conference is more than outstanding. In 2019 alone, 1,000 visitors came to Darmstadt just for ISAL. Over these 27 years, a total of 1,246 lectures and papers from 25 nations have been presented.

Looking a little into the story of those more than 1,000 papers, it was—and is—a precise mirror of what the lighting community has been covering in that timeframe. We saw in those 27 years technologies come and go. It all started with HID; design improvements, and performance papers. Today we talk much more about digitalization; communication, and energy saving. L

Looking a little into the story of those more than 1,000 papers, it was—and is—a precise mirror of what the lighting community has been covering in that time window. We saw in those 27 years technologies come and go. It all started with Xenon; design improvements, and performance papers and today we talk much more about Digitalization, Communication and Energy Saving.

The "Darmstadtium", the location for ISAL conferences since 2009

From the small beginnings, ISAL became a synonym for a globally reputable technical and scientific conference on up-to-date topics in the field.

14 conferences have been held on a biennial schedule, every odd-numbered year (2021's event was delayed to 2022 on account of Covid). The records are impressive

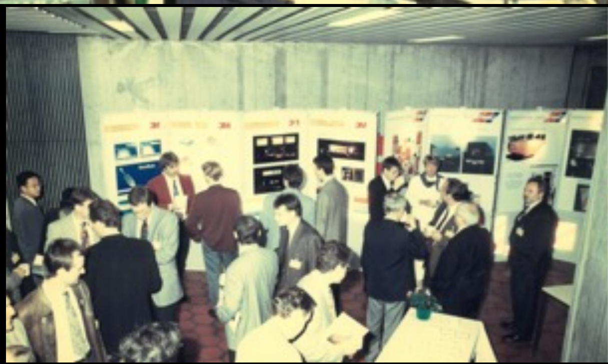
- **14 Conferences**
- **1551 abstracts submitted**
- **1246 lectures, papers and posters**
- **7500 participants and exhibitors**
- **25 Nations Contributing**

The ISAL conference was and is the melting pot of scientific and engineering progress and serial application

The following pages want to give insight in 27 years of expert meetings, presentations, exhibitions and discussions.

Fotostory: 27 years ISAL Impressions 1995..2022

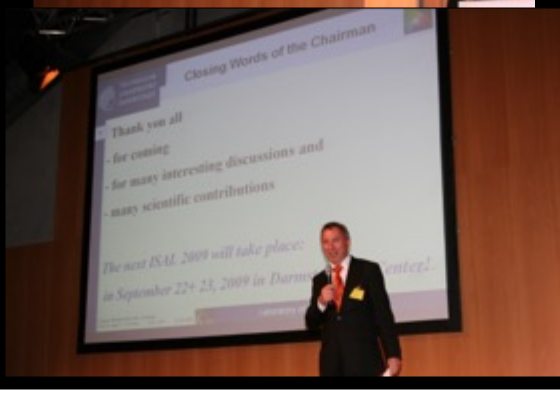
1995…2005



2007	


HABEL & SCHLAPP

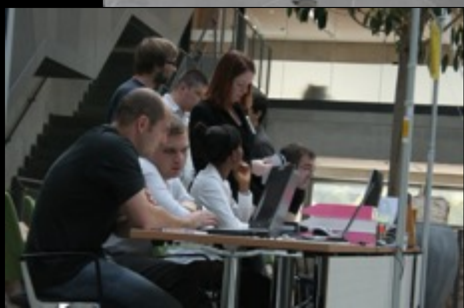

IN R 806


Closing Words of the Chairman
Thank you all
- for coming
- for many interesting discussions and
- many scientific contributions

2009	


ISAL2009


Prof. Dr. habil. T. Q. Khanh

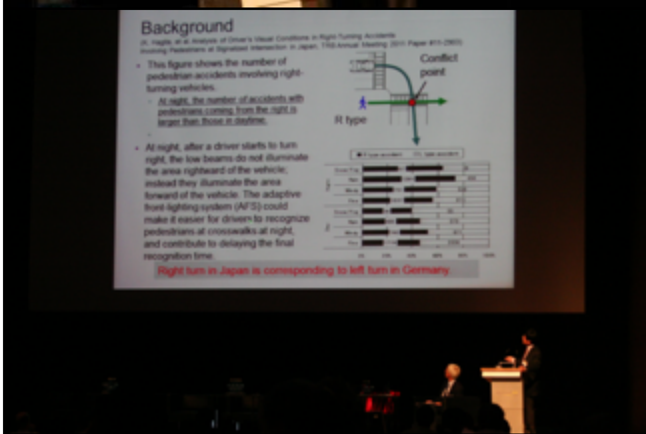


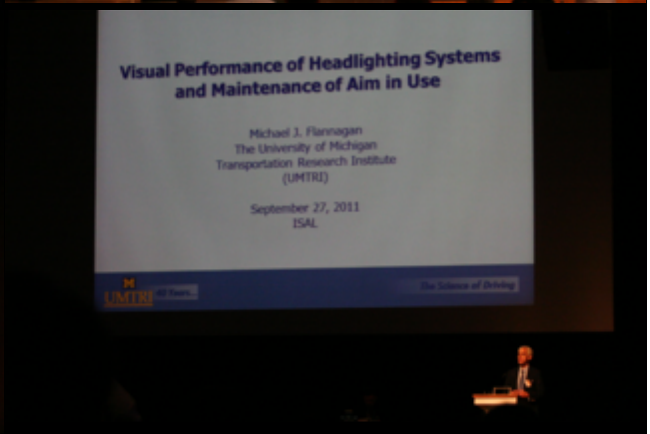

• safety/security
• ecology/climate
• economy


2009 | Prof. Dr. Helmut F. Schlaak

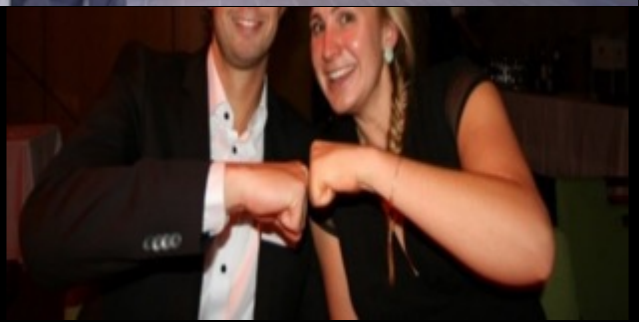
2011

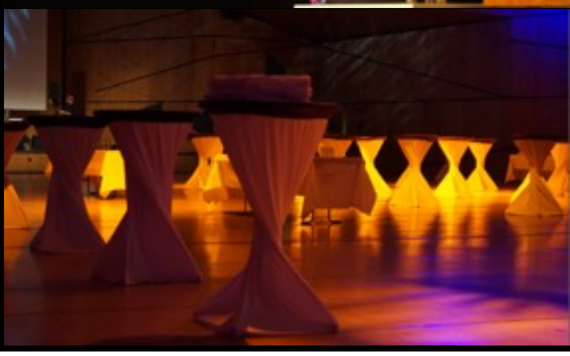

9th International Symposium on Automotive Lighting


Background
Right turn in Japan is corresponding to left turn in Germany

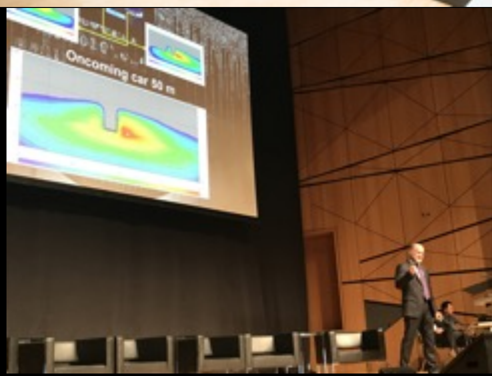

Visual Performance of Headlighting Systems and Maintenance of Aim in Use
Michael J. Flannagan
The University of Michigan
Transportation Research Institute
(UMTRI)
September 27, 2011
ISAL

2013

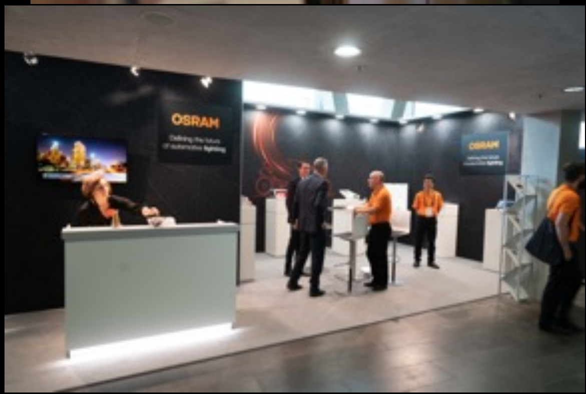


2015	
	
	
	
	
	

2017



2019



2021/22	








It could be an idea to look to the technical highlights and lowlights of these events. As there is no exact figure of merit, the ranking of a "top" or a "flop" is just personal ranking by the author, and the readers may follow that also with a friendly twinkle in your eyes. And the author apologizes to all who are forgotten.

Every conference is opened with a greeting statement from TUD administration, and the professor gives some statistical overview. Traditionally, a keynote invited lecture follows. A very good keynote was the contribution of Prof. Johann-Dietrich Wörner from the DLR, the German center for Air and Space Research. Besides the world of stars and space stations, he captivated the audience with the research activities of DLR for energy and traffic, safety and digitalization. This was a 30-minute excursion to another fascinating world.

And the ISAL conference can be proud to have a Nobel laureate keynote in its records; Prof. Shuji Nakamura explained the moments of his inventing the blue III/V LED.

Together with Isamu Akasaki and Hiroshi Amano, Prof. Nakamura is one of three recipients of the 2014 Nobel Prize for Physics for the invention of efficient blue light-emitting diodes, which enable bright and energy-saving white-light sources. Our modern lighting in all fields of application is influenced by Prof. Nakamura's invention. The use of blue InGaN LEDs in combination with a phosphor converter allowed the development of white LED with extremely high efficacy at affordable production costs.

Prof. Nakamura's LEDs are everywhere. On christmas trees; in refrigerators; in interior office lighting. In street lighting; architectural lighting and, for sure, also in automotive low beams, high beams, matrix beams, and DRLs.

Shuji Nakamura, Physics Nobel Prize Laureate of 2014 was giving a key note on ISAL 2015. Prof. Khanh welcomed him on the conference.

Pretty much every conference had contributions and sessions on Optics; Technology; Regulation; Photometry; Simulation; Rear Lighting and Front Lighting; Physiology, and (especially) Glare. Participant numbers grew over the years from about 200 to nearly 1000.

Car Accident and Safety Research played an important role at the conferences. It started in 1995 with the characteristics of nighttime accidents. 1999 the mortality in Rieti and Frascati counties was analyzed. Later, safety and visibility improvements from HID projectors; dynamic bending light, and adaptive cutoffs were investigated. Especially safety aspects became more and more important from about 2013 onwards. New technologies created also conservative reactions—what the real benefits of such new technologies could be and what the drawbacks were. So, a bunch of studies and investigations covered ADB; digital construction zone light; lanekeeping; reaction times to dynamic signal functions, as well as conspicuity; eye mark investigations; distraction potential, and glare on wet roads.

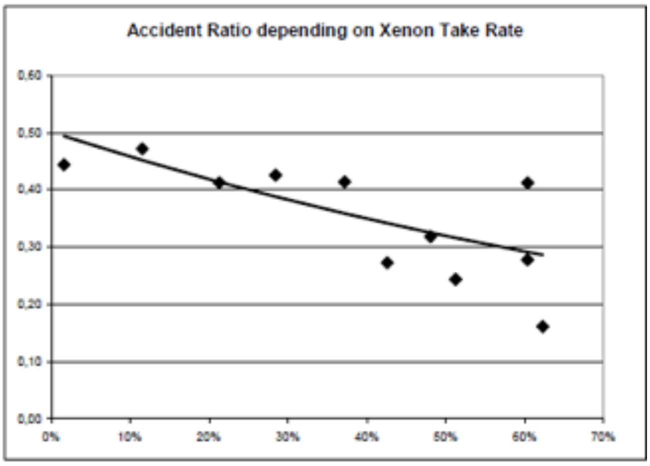


Figure 2 Correlation between Xenon take rate and accident ratio

Schäbe,H.; Schierge, F.: Investigation on the influence of car lighting on nighttime accidents in Germany. In: ISAL 2007, pp. 1-5

One of the most cited accident and safety research highlights is an analysis published in 2007. In a TÜV study, the first big proof came forth that good lighting—at that time it was Xenon—avoids accidents. The study was based on the German DESTATIS accident data base. Different road types and ambient illumination could be addressed. Two datasets were created: one with high Xenon equipment and one with low or zero Xenon equipment. As expected, on city roads there was no significant difference in reported accidents. On rural roads and highways however, the night:day ratio of reported accidents was significant lower for the group of cars with high Xenon take rate.

For the group of cars with high Xenon take rate, the risk of having a nighttime accident was fully 25 per cent lower on rural roads, and 17 per cent lower on highways. In ISAL we need more of such good news…!

11. Tech Stories and Innovation Cycles in ISAL History

Some In-depth analysis:

In 1995, about six contributions covered high-intensity discharge systems (i.e. Xenon). Only one single lecture in 1995 covered LED, and this was in rear lamps. After 1995, Xenon was always at the conferences, but the interest decreased after 2011 with the (at that time named) last chapter of Xenon, the 25-watt 2,000-lm D5S bulb. Finally after this invention, for the developers the story was over. There was a single, more or less historic reminder in 2015 with one D9S paper.

This shows pretty well the innovation cycle. New technology rises first slowly and then suddenly, and the old technology at the end fades away and disappears from public interest.

From rise to fall, the conference lifespan of Xenon was about 20 years.

ISAL: What were the 'tops' and anticipatory ideas, the most successful topics introduced at ISAL over 27 years?

Obviously LEDs, but this would be too easy. Looking to the history, it is interesting to see when the first paper with an innovative idea was offered and how many years later this idea became series reality. One of the champions of innovative lead was the paper of BMW's Martin Enders in 2001. His paper on pixel light based on the DLP chips was at that time met with not more than a smile.

Ahead of time:

Enders M.: Pixel Light. In: PAL 2001, pp. 234-239

This idea just needed about 18 years before the first digital projections in Audi and Mercedes cars arrived on the market. The ISAL community should congratulate him for that nearly 2-decade prediction!

Another prediction was shown in 2007 by Mojrzisch and Strauss from Hella's L-Lab, where they described a segmented Xenon shutter—most likely the beginning of ADB and Matrix systems, at that time a dream. But eventually the first Matrix headlamp reached the market with the Audi A8 in 2013.

Rear lamp technology also needed a long ramp-up. In 2007, OLED was first mentioned by Kraus, Benter, and Börner from Philips Lighting.

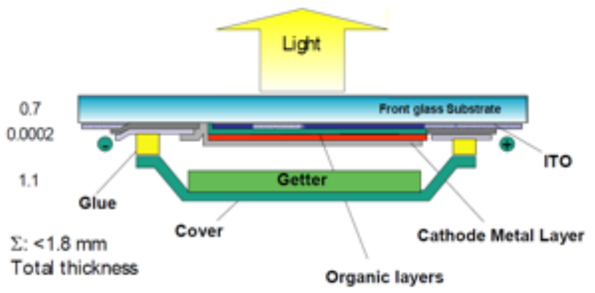


Figure 1: Basic structure of an OLED

Ahead of time:

Kraus,A.; Benter, N.; Börner, H.: OLED Technology in Automotive Applications. In: ISAL 2007, pp. 558-556

Nine years later in 2016, the OLED story came true. But unlike others, this technology changed into the digital world and still makes increasing part of the lighting story today…!

ISAL: What were the 'flops' that popped up, excited the community for a while, and disappeared again?

First to mind is infrared night vision. First mentioned in 2001, the peak of papers was about seven, in 2005. In 2009 the last paper investigated some IR diode improvements. Then the story was over. Eight years' lifetime for that technology, from invention to oblivion.

Next, Spot marking light, mentioned in 2009, was overrun by Matrix. After the Matrix stripes came to exist, there was just no need for a separate module to make a striped light that was activated to highlight a pedestrian at night perhaps once or twice a year.

Or LCDs as a headlamp projection device: a nice idea announced in 2015, unfortunately with many drawbacks like temperature-sensitivity and big bulk. So Pixel Light; microLEDs, and DMD made the story after 2019. This was extinction before production for LCD.

Other technology innovations (all named "NEW…") that didn't meet with commercial success: NEO (new extra-efficient optics for halogen lamps); new vertical-shape elliptics; new crystal lenses, new Opti-LED, new Omni-Blade, new 1,024 LED pixels…good ideas, but no breakthrough.

And some other announced coming great technologies were just too strange (at least for now): water cooling in headlamps, heat pipes, diffractive optics, and many more.

ISAL: What's still to improve?

At more or less every conference, new simulation and evaluation systems have been presented. Each paper followed the idea to make a light distribution easier to evaluate and explain. In 2022, another rating was presented by six lectures and a podium discussion: the HSPR (Headlamp Safety Performance Rating). After 20 years of trials this is the first time a rating system is objective, understandable, and covers current technology in a meaningful way, and thus has a chance to be accepted. HSPR became one of the first Recommended Practice publications of GTB. It can be expected that also in ISAL 2023 new reports will be presented about correlation to reality and practical database applications.

ISAL and future: What are the unknown stars?

As of today, nobody knows know which ones will evolve as flop or top: V2V, V2H, V2X communication, digital driver assistance, symbol projections, animations, FOD function-on-demand, MEMS, LCOS, laser scanners, illuminated front grilleboards, 360° light around the car, and many more. So we should be keen to be part of the ongoing development. Next chance is next ISAL, 25-27 September, 2023.

12. Prof Khanh: Three Questions on ISAL 2023:

#1: What is your expectation to ISAL 2023, after having successfully carried out ISAL 2022?

Prof Khanh*:*

In 2022 we had about 600 participants due to the pandemic situation in April 2022 (the lock-down period was opened just 1 week ago so that the most companies could not be able to react). I hope that much more lighting experts from the USA, Japan and Korea will come this time. If the pandemic situation in China will be normal or better than now, we can also welcome more Chinese lighting and vehicle experts from China.

#2 : What do you expect as trends, innovations and research results @ISAL ?

Prof. Khanh:

a) To the research result: we all had a wave of technology developments in the last 22 years with light sources based systems, with intelligent systems with little software efforts (AFS, marking light, dynamic leveling, segmented and matrix beam until 84 pixels). But the research and validation on the lighting distribution on the road (low beam, city light, bending light, high beam etc.) has not been performed so far so that we have to think on the optimization of lighting distribution curves and on an internationally accepted method on how we can evaluate these distribution regarding visibility, brightness on the road, driving comfort and homogeneity. These topics shall be a focus on the ISAL 2023 with a long session on the method HSPR.

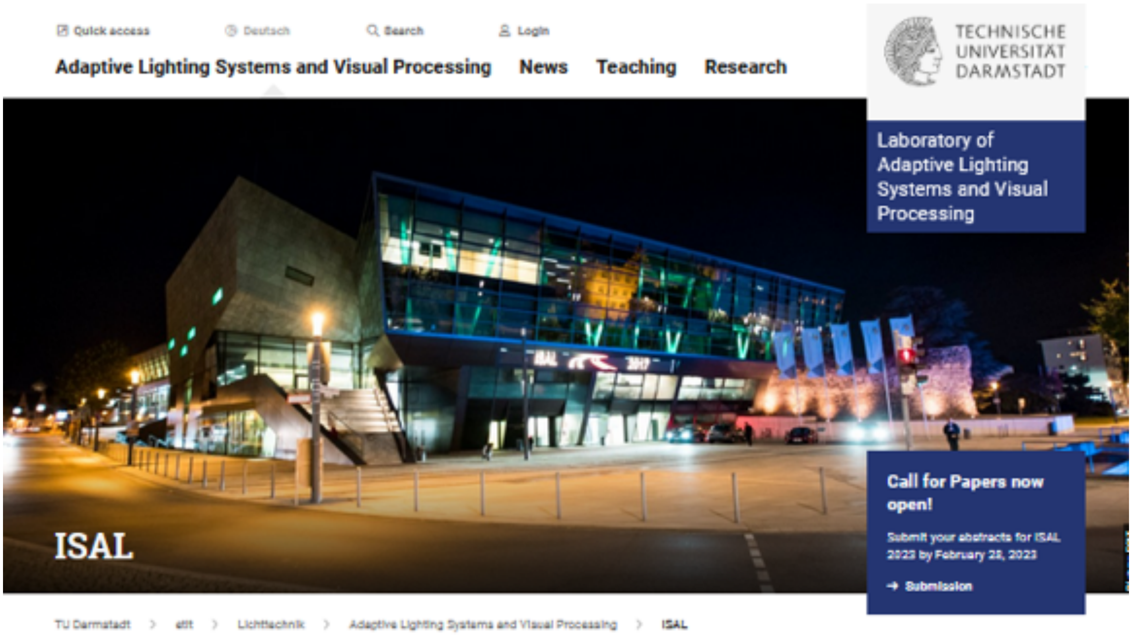
b) As trends: with the forced production of e-vehicles and discussion on the climate change (CO2-emission) and on the consumption of energy generally, a discussion on potentials and solutions of energy saving will be moderated on the ISAL 2023 and in this context, intelligent and adaptive lighting systems with environment sensors (camera, navigation, GPS, laser sensor…) and software will help to detect the traffic situations for reducing the energy without reducing the traffic safety and well-being of the drivers.

c) To innovations: as mentioned above, light-source based lighting systems and lighting systems with only little integration of software and sensors have been dominating the activities in the last 22 years. From the technological point of view, it is also difficult to have a fast progress from 25,000 pixels to about 100,000 pixels so I think that a purely hardware-based progress of lighting systems shall be slower in the speed of realizations. The innovation shall be, and here I am very sure, that a combination between high qualitative digital cameras with low noise and dark current, a matrix beam headlamp system and an AI-based software will be the innovation on the next ISAL 2023.

DVN: How important is Automotive Lighting and the ISAL Symposium for the Technical University of Darmstadt?

Prof Khanh*:*

The Technical University Darmstadt and its new Management Board have developed in the recent time a transfer strategy and are searching for cooperation with academic, industrial, social and political partners. We think that the future of Germany and Europe is closely related with the Automotive Industry generally and the Automotive Lighting specifically. ISAL Symposium is one of the most important conferences organized by a research institute of the TU Darmstadt since many years and stays a highlight in the process of science and innovations of the TU Darmstadt.



13. Selected Research Reports and Publications

The following section displays some research publications from the DLI, the Laboratory for Adaptive Lighting Systems and Visual Processing.

1. Automated Vehicle Research

The following article was published in the IEEE Transaction on Intelligent Transportation Systems. *"Displaying the Driving State of Automated Vehicles to Other Road Users: An International, Virtual Reality-Based Study as a First Step for the Harmonized Regulations of Novel Signaling Devices".* Authors: Timo Singer , Jonas Kobbert, Babak Zandi and Tran Quoc Khanh. Laboratory for Adaptive Lighting Systems and Visual Processing, TU Darmstadt, Germany.

Due to the article length, only a selection of pages is displayed. The full article is available on DOI link below.

DOI: 10.1109/TITS.2020.3032777, license agreement: https://creativecommons.org/licenses/by/4.0/

2904 IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, VOL. 23, NO. 4, APRIL 2022

Displaying the Driving State of Automated Vehicles to Other Road Users: An International, Virtual Reality-Based Study as a First Step for the Harmonized Regulations of Novel Signaling Devices

Timo Singer, Jonas Kobbert, Babak Zandi, and Tran Quoc Khanh

***Abstract*—Additional signaling devices for highly automated vehicles (AVs) that can communicate their driving state to other road users can simplify the integration process in existing road traffic. This paper presents the results of an international, virtual reality-based study conducted in China, South Korea and the USA in which subjects assume the role of a pedestrian and are placed in direct encounter situations with an AV in a parking lot. A novel communication interface consisting of three displays is attached to the AV's front and used to show additional information about its driving state. In total, three encounter scenarios are investigated: the AV approaches from the left, front and right outside of the pedestrian's line of sight. The influence of different symbol types on the subject's moving behavior, recognition of intention and perceived safety is investigated. The results show that additional signals ensure a better perception of the AV's intention and increase the perceived safety. The moving behavior of subjects is significantly changed when additional signals are used during driving tasks compared to the same tasks without such signals. The change of moving behaviour is similar in encounter situations where the AV approaches from the left and front but differs in encounter situations from the right. These results could equally be proven for all nationalities, which shows that a uniform, international solution for additional signaling devices of highly automated vehicles is possible.**

***Index Terms*—Automated vehicles, encounter situation, pedestrian, international test, light signals, external human–machine interface.**

I. Introduction

THE integration of highly automated vehicles (AVs) into existing road traffic is likely to cause many difficulties. This integration requires acceptance by other road users, such as pedestrians. With increasing levels of automation, human drivers will no longer monitor the surroundings of vehicles [1].

Manuscript received February 12, 2020; revised July 9, 2020 and October 13, 2020; accepted October 17, 2020. Date of publication October 29, 2020; date of current version March 29, 2022. This work was supported by Groupe de Travail (GTB) "Bruxelles 1952". The Associate Editor for this article was S. A. Birrell. *(Corresponding author: Timo Singer.)*

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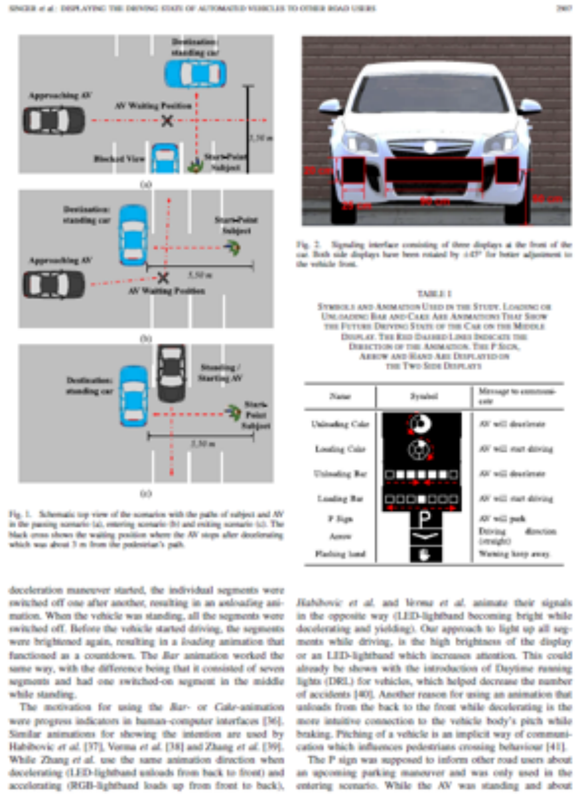
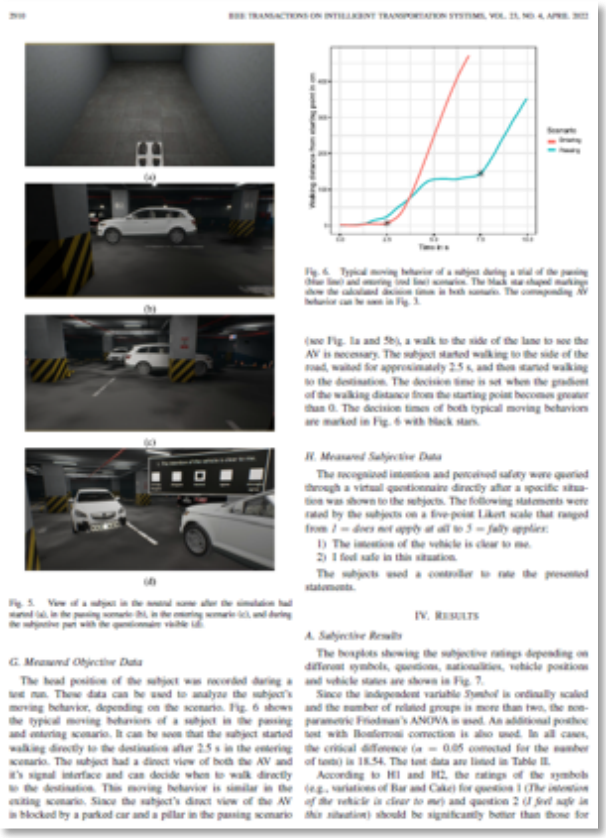
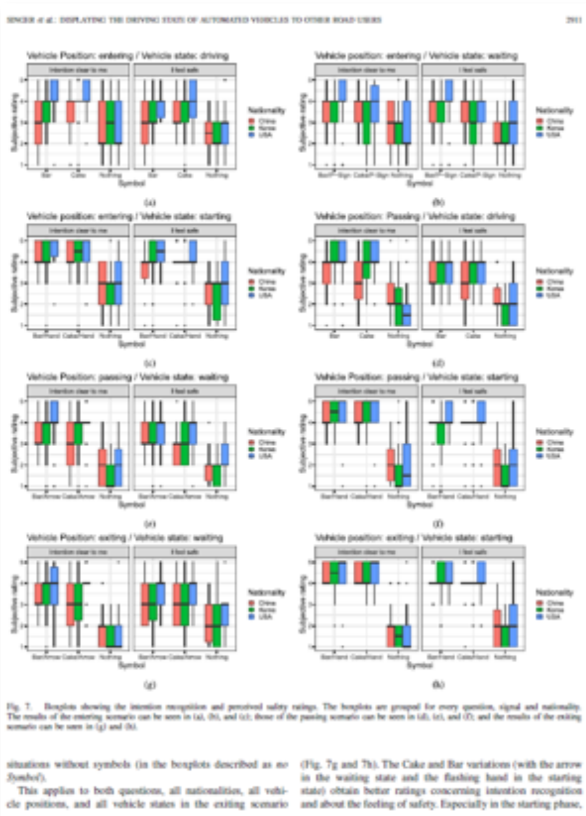
It can also be assumed that the driving behavior of an AV will differ from that of a human driver. This difference can lead to a reduction of safety and traffic flow and therefore to a lower acceptance and trust towards AVs. A survey by the American Automotive Association from April 2018 shows that 63 % of 1014 U.S. drivers say they would feel less safe by sharing the road with a self-driving car while walking or riding a bike (26 % say they would feel no difference, 9 % would feel safer, 2 % are unsure) [2]. A rather extreme consequence of this can be seen in Google Waymo's test area in Chandler, Arizona, where residents are destroying test vehicles or threatening emergency drivers [3]. While such aggressive behavior cannot be generalized worldwide, it shows the possible uncertainty and anxiety of people regarding the introduction of this new technology. To allow the fluent implementation of AV, it is essential to increase trust and acceptance.

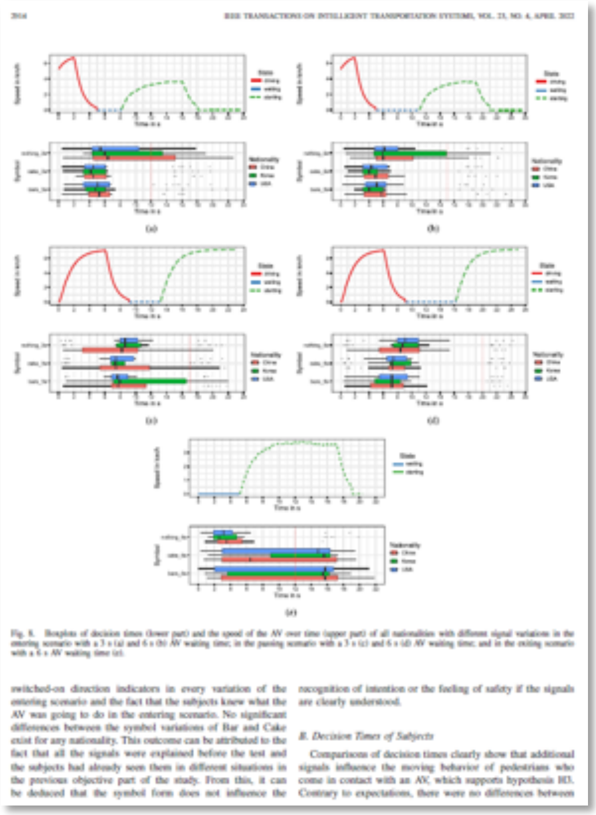
Car manufacturers and suppliers of lighting components see potential in novel light signals for AVs which could increase trust in this new technology. The information of multiple sensors used to plan future driving maneuvers can be displayed to other road users, e.g., through lighting signals attached to the vehicle. For that, car manufacturers or suppliers develop concepts for novel light signaling devices that usually consist of displays [4], additional lamps [5] or projections on the road [6]. On the one hand, it can be argued that a special light signal makes an automated vehicle even easier to detect, thus increasing road users' hostility towards AV's even further (especially with regard to the Waymo example in Chandler). On the other hand, a signal showing future driving states of the AV has potential to increase situational awareness of a pedestrian encountering an AV. Petersen *et al.* [7] show in a driving simulator study that trust in automated driving systems can be increased by enhancing situational awareness with more information about the driving state. This additional information can also provide more transparency in encounter situations with AVs. System transparency is one of three crucial constructs that positively influence trust in automated vehicles [8].

Many scientists are currently investigating the question of how external human–machine interfaces (eHMI) for AV can









2. Energy Saving in Automotive Applications:

"Efficiency enhancement opportunities for automotive lighting systems by traffic situation analysis"
Authors: Anil Erkan, Lily Antoinette Engelbrecht-Schnür, David Hoffmann, Markus Peier, Korbinian Kunst, Timo Singer, Tran Quoc Khanh.

Laboratory for Adaptive Lighting Systems and Visual Processing, TU Darmstadt, Germany.

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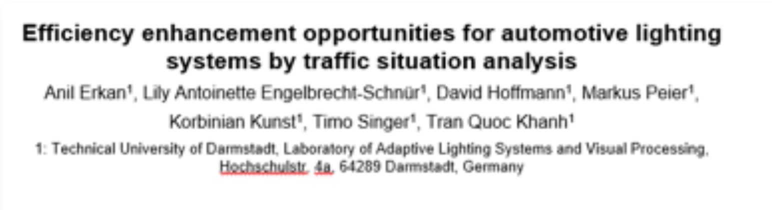

Efficiency enhancement opportunities for automotive lighting systems by traffic situation analysis

Anil Erkan[1], Lily Antoinette Engelbrecht-Schnür[1], David Hoffmann[1], Markus Peier[1], Korbinian Kunst[1], Timo Singer[1], Tran Quoc Khanh[1]

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Abstract: In all socially relevant areas, the demand for more energy efficient solutions is increasing steadily. Thus, also driven by the switch to electric vehicles, the demand for energy efficient concepts for the realization of each component is also increasing in the automotive industry. This naturally includes the vehicle's lighting systems. The aim is to develop lighting concepts that are more energy efficient than current systems. In this context, it should be noted that the lighting systems are of great importance in terms of safety and perception in road traffic at night. For this reason, the question arises when and how the efficiency of automotive lighting systems can be increased without compromising safety and perception.

The aim of this work is to identify night time traffic situations that have potential to increase efficiency to a large extent by analysing traffic statistics. These can include traffic jams, rush hour traffic, or night time traffic in illuminated areas. Then, these situations will be sorted based on their potential and the adaptation possibilities of the corresponding lighting functions to increase efficiency will be analysed. For example, switching from low beam to daytime running lights in congestion situations could be such an adaptation option.

Keywords: Sustainability, automotive lighting, efficiency enhancement, traffic statistics

1. Introduction

Talking about the sustainability of lighting components on the vehicle, the entire product life cycle from development to product disposal has to be considered [1-4]. In terms of the sustainability of automotive lighting components in the various phases, there are already some considerations and approaches for improvement.

For Schmidt et al. the motto for sustainability improvement is "Reduce Reuse Recycle" [3].

There are two approaches to the topic of Reduce. On the one hand, the energy demand of the luminaires during the operating time should be reduced. On the other hand, material reduction in the sense of material savings and simultaneous weight reduction represents an important aspect. In addition, the production of components and semi-finished products and the transport of individual components between facilities are possible reduction parameters that can be optimized, since in some cases components are installed in the vehicles that have already covered greater distances at the time of vehicle sale than the vehicle will later cover in the entire operating cycle. [3]
Compared to the Reduce aspect, the Reuse idea is more difficult to implement, since here many parts cannot be installed in the next vehicle directly after the operating time of another vehicle has expired due to the high integrity (e.g. soldered LED on a circuit board) or high quality standards. Here, however, there are already components, such as the heat sink, which could be reused when using a universal concept. Work is also already being done on LEDs that are separated from the PCB. [3]
If recycling is considered, it is more likely that the material will be reused. According to Schmidt et al., this can be done by reusing the material for an equivalent successor product or for a substandard product. Another possibility would be thermal recycling for energy generation. [3]
According to Hartmann et al. the sustainability of headlamps should be understood as a new property of a complex system product. In addition to the product level, this should also be continuously evaluated at the component level and thus include all actors in the supply chain. Thus, the headlight would also be an opportunity to gain understanding of the redesign of complex components and to apply the findings to other components of the vehicle and to be able to meet the requirements of balancing carbon footprint, functionality and circular economy. [4]
Boehm and Hartmann predict that the headlight trend will move towards function-optimized headlights but also design-oriented headlights and very energy-efficient headlights. Thus, compromise solutions are conceivable. A µLED system with a resolution of e.g. about 100,000 pixels would represent such a compromise between cost, energy efficiency and resolution since light is only activated where it is needed. [5]
The considerations and approaches outlined above represent important steps in increasing sustainability. Nevertheless, the operating time of the headlight is the most relevant phase for increasing efficiency. For this reason, approaches that consider the increase in efficiency during the operating time are discussed below.
The strategy of a car manufacturer outlined by Feid focuses on the operating time and aims to reduce the energy demand of the lighting function by replacing halogen tungsten lamps with LED technology. In addition to replacing halogen tungsten lamps, vehicles with high performance headlights (Matrix, Pixel, etc.) should also comply with the limit of 0.5 g CO_2 per km. Through this strategy, exterior lighting on vehicles has already contributed to a reduction in the CO_2 footprint of 0.6 to 1.1 g per vehicle and km. [6]
Furthermore, the low beam function can be identified as the lighting function with the highest potential for efficiency enhancement. [6]
A study conducted by the Technical University of Darmstadt also identified the low beam as the most relevant lighting function for efficiency enhancement. This study also looked at the reduction in CO_2 emissions by replacing halogen lamps with LEDs in the low beam, daytime running lights, rear lamps and brake lights, which would lead to a reduction in emissions up to 250,000 tons of CO_2 per year when considering all vehicles equipped with halogen tungsten lamps in Germany. [7]
These considerations are very important and valuable and should be followed up and expanded. Nevertheless, it is also important here to first consider relevant and promising use cases in terms of traffic situations in order to achieve a large-scale efficiency enhancement with minimal adjustments to the lighting components.
This is exactly where this work comes in. To determine such relevant use cases in road traffic, several traffic situations are considered and analysed. From this consideration, a relevance analysis is then made for the highest efficiency enhancement potential that does not compromise road safety.

2. Traffic situations

In this section, the analysis of traffic situations is performed using traffic statistics. The basis for the analysis is mainly derived from traffic statistics in Germany.
The starting point for all the following considerations is the total annual mileage of passenger cars in Germany, which reached 644.8 billion km in 2019 [8]. Furthermore, a night time mileage share of 20 % is assumed [9-11].

2.1 Congestion

Congestion (see Figure 1) is probably the most annoying traffic situation for most road users. Nevertheless, it is one of the traffic situations that could have a high potential for efficiency enhancement due to the number of vehicles involved.
Thus, in 2019, there were a total of 708,500 congestions in Germany with a total length of about 1.4 million km and about 521,000 congestion hours [12].

Figure 1: Congestions offer high potential for efficiency enhancement. [13,14]

Taking into account the average length of passenger cars in Germany of 4.60 m [15] and maintaining a safety distance of 2 m, equation 1 results in approximately 215.6 million vehicles stuck in congestion in 2019. [12,15]

$$n_{\text{Vehicles}} = \frac{d_{\text{Congestion}}}{d_{\text{Vehicle}} + d_{\text{Safety}}} \quad [1]$$

In order to consider the total time spent by these vehicles in congestion, the average duration of a congestion is first calculated. For this purpose, the ratio between congestion hours (521,000 hours) and the number of congestions (708,500) is calculated. This results in an average congestion time of about 0.74 hours per vehicle.

If this average congestion duration is multiplied by the number of vehicles in congestions, the total duration is about 159.5 million hours, which is divided into 127.6 million hours during the day (80 %) and 31.9 million hours during darkness (20 %).

To address the issue of which lighting functions should be considered to increase efficiency during congestion, daytime and night time congestion situations are considered separately.

While driving in daylight, only the daytime running lights are activated in the headlights for better visibility of the vehicle. In a congestion situation, this information is not urgently needed because the relevant road users are also in the immediate vicinity in a stationary state. It would therefore be conceivable here to switch off or at least dim the daytime running light function. In the rear area, the brake light is active in congestion situations, which should not be changed in daylight, since the brake light function, in addition to the flashing warning lights, signals the end of the congestion to the following traffic.

If the congestion situation is considered at night, both the low beam, which is responsible for the driver's visibility, and the position light of the headlight are switched on. At the same time, the low beam can no longer fulfil its actual function in a congestion situation, as it only illuminates the rear of the vehicle in front. Thus, the low beam function is obsolete in night time congestion situations and could be replaced by the daytime running light or position light.

In contrast to the daytime congestion situation, the brake light function could be dimmed in night time congestion situations, since lower contrasts would already be sufficient for the signal function to be fulfilled. Another positive effect of dimming the brake light function would be the reduction of the glare potential for the following traffic.

For the adjustment of the daytime running light during the day and the low beam during night time congestions, existing sensors such as speed and GPS sensors could be used, while for adjusting brake lights, parking sensors could be used to detect the presence of any following traffic.

2.2 Rush hour at dusk

Another traffic situation that could have a high potential for efficiency enhancement is commuter traffic during dusk and dawn (see Figure 2). In Germany, 68 % of the workforce commutes to work by car, and most commuters take between 10 and 60 minutes (72.1 % of the workforce) to get to work [15]. Consequently, the rush hours in Germany are approximately between 06:30 and 08:30 in the morning and between 15:30 and 17:30 in the afternoon [16].

Figure 2: Rush hour at dusk [18,19]

Thus, with 45.4 million in the workforce [20], there are approximately 30.9 million commuters. In order to estimate the commuting time at dusk, the sunrise and sunset in Darmstadt are taken as an example (see Figure 3) [21].

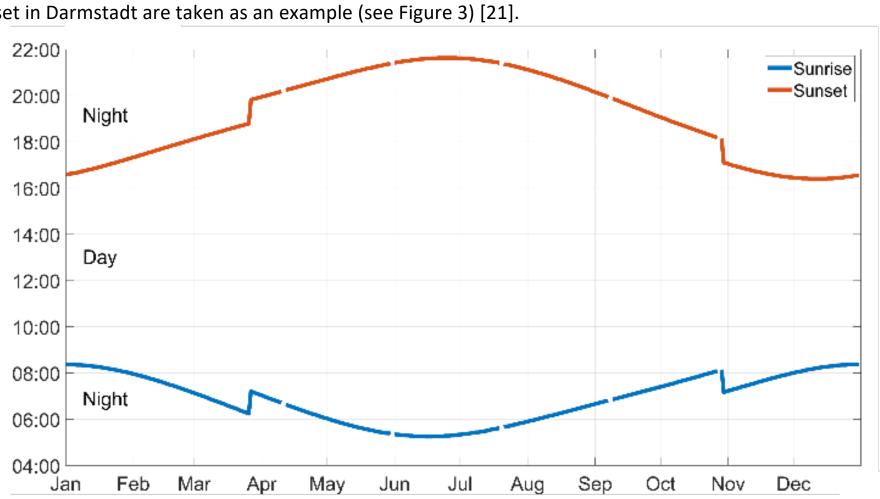


Figure 3: Course of sunrise (blue) and sunset (red) over the year in Darmstadt, Germany [21]

Looking at sunrise and sunset, it is clear that rush hour traffic occurs primarily during the winter months from November to February at dusk, which is about one-third of the year.
For the purpose of considering the total duration of rush hour traffic at dusk, the following assumptions are made based on the data shown. A commute duration of one hour in the morning and one hour in the afternoon is assumed, one third of which takes place at dusk. This results in a commute duration of 0.67 hours at dusk per day. With approximately 250 workdays per year, the dusk commute time adds up to approximately 166.67 hours per commuter. Thus, for all 30.9 million commuters, the dusk commute time is 5.15 billion hours if each worker commutes alone in his or her vehicle.
A possible modification in dusk can be made by adjusting the threshold values defined in UNECE Regulation 48 for switching between low beam and daytime running lights. Currently, the low beam must be switched on at illuminance levels below 1000 lx and switched off above 7000 lx. [22]
By identifying new suitable thresholds, daytime running lights could be used for a longer period of time and energy consumption could be reduced by switching off the low beam. The actual adjustment of the light functions can be done directly via the already existing light sensor behind the windshield.
2.3 Urban night time traffic
As mentioned at the beginning of this section, the total mileage of passenger cars in Germany was about 644.8 billion km, of which about 20 % is completed during the dark hours. If it is also taken into account that about 26 % of the mileage of passenger cars is driven in urban areas [23], the total mileage for urban traffic at night is about 33.53 billion km. With the maximum average driving speed of 27.6 km h^{-1} for major German cities (determined in Leipzig) [24], this results in a total driving time of 1.2 billion hours in urban traffic at night. This directly demonstrates the enormous potential for efficiency enhancement in this traffic situation.
Possible adjustments would again concern the low beam. For example, the intensity of the low beam could be significantly reduced due to the street lighting that already exists in urban areas (see Figure 4). At the same time, the safety when driving a vehicle must not be compromised. For example, the low beam could be reduced to a forefield lighting in order to maintain the visibility of the vehicle and the subjective safety feeling of the vehicle occupants.

Figure 4: The urban traffic area offers great potential for increasing efficiency due to existing street lighting

The adaptation of the low beam could be realized via various already existing sensors, such as GPS, the light sensor or even cameras, which are used to control ADB systems.
2.4 Traffic lights
Standstill during traffic light red phases also offers potential for increasing efficiency. Assuming a daily operating time of passenger cars in Germany of about 0.75 hours [25] and a time loss of 10 % [26] at intersections, this results in a total stationary time of about 1.3 billion hours for the 48.5 million passenger cars [27] in Germany, which is divided into 1.1 billion hours (80 %) during the day and 265.5 million hours (20 %) during the night.
Here, as in the case of congestion at night, the brake light could be dimmed, since on the one hand the traffic light itself already signals that the traffic has to stop and on the other hand the glare potential for following traffic could be reduced. During the day, the brake light function should not be modified, as the signal function must remain clearly visible here.
3. Relevance analysis of traffic situations
In the next step, the relevance of the considered traffic situations for the efficiency enhancement is analysed, based on the following comparison parameters. This includes the total annual duration in the respective traffic situation and also the adaptable lighting functions. In addition, the power consumption of the respective lighting functions for both headlights and rear lamps is taken into account. For better comparability of the traffic situations, the maximum power consumption of standard halogen tungsten lamps for the respective lighting function is considered according to UNECE Regulation 37 [28]. In addition, the effort for the realization of the adaptation is considered [28]. Table 1 shows an overview of the traffic situation with the considered parameters.

It is directly evident from Table 1 that rush hour traffic at dusk has the highest efficiency enhancement potential due to the very high total usage duration, followed by urban night time traffic. On the other hand, congestion situations and traffic light red phases are less relevant. In the case of traffic lights, the reason for this is that during the long total duration of about 1.1 billion hours during the day, it is not possible to make any meaningful adjustments to the lighting function, so that no direct increase in efficiency can be achieved here.
Thus, in the near future, studies should be conducted on the switching thresholds between low beam and daytime running lights at dusk and the necessary intensities in urban traffic areas at night in order to exploit the efficiency enhancement potential.
The fact that the effort required in all traffic situations is low allows all traffic situations to make their contribution to increasing efficiency through simple adjustments.

Table 1: Traffic situations and parameters for relevance analysis in terms of efficiency enhancement

Traffic Situation	Total Duration per Year	Adaptable Light Function	P_{HAL} of Light Function	Effort for Realization
Congestion day	127.6 million hours	Daytime running light (DRL)	53 W	Sensors: already present Activation: dimming electronics
Congestion night	31.9 million hours	Low beam (LB), brake lights (BL)	116 W (LB), 53 W (BL)	Sensors: already present Activation: dimming electronics
Rush hour at dusk	5.15 billion hours	Low beam (LB)	116 W	Sensors: already present Activation: on/off switching
Urban night time traffic	1.2 billion hours	Low beam (LB)	116 W	Sensors: already present Activation: dimming electronics
Traffic lights day	1.1 billion hours	None	0 W	None
Traffic lights night	265.5 million hours	Brake lights (BL)	53 W	Sensors: already present Activation: dimming electronics

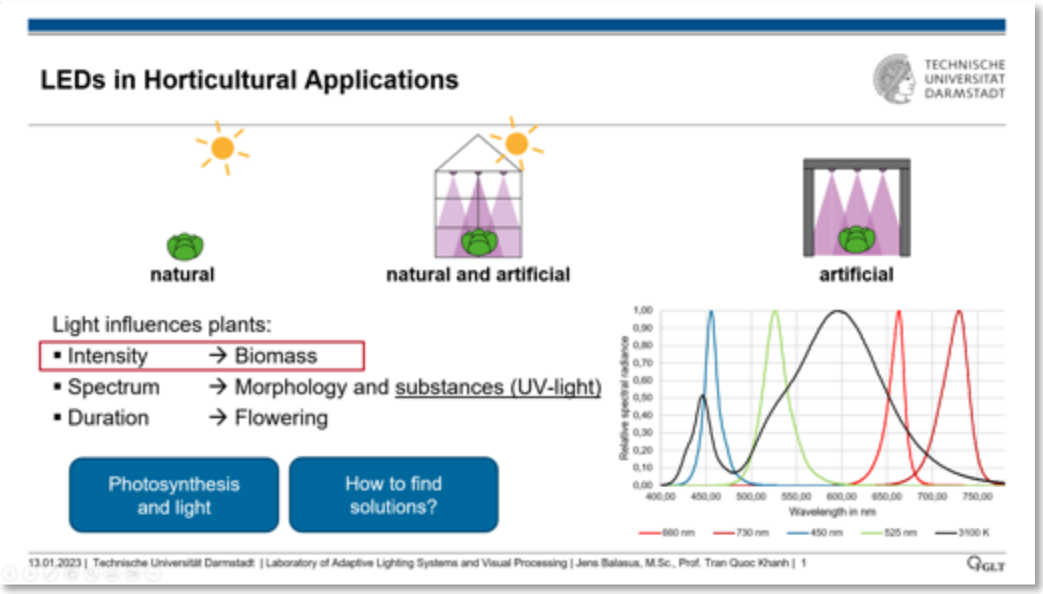
Finally, if the maximum possible energy savings by switching off the respective light functions in the traffic situations are considered, this results in an energy savings potential of about 6.76 GWh during the day and about 5.39 GWh at night for the congestion situation. For rush hour traffic at dusk, the potential energy savings are about 597.4 GWh. For urban night time traffic, energy savings of about 139.2 GWh would be possible. Since it was not possible to identify any useful light function for efficiency enhancement in the case of traffic light red phases during the day, only the energy savings potential at night of around 14 GWh is of interest here.

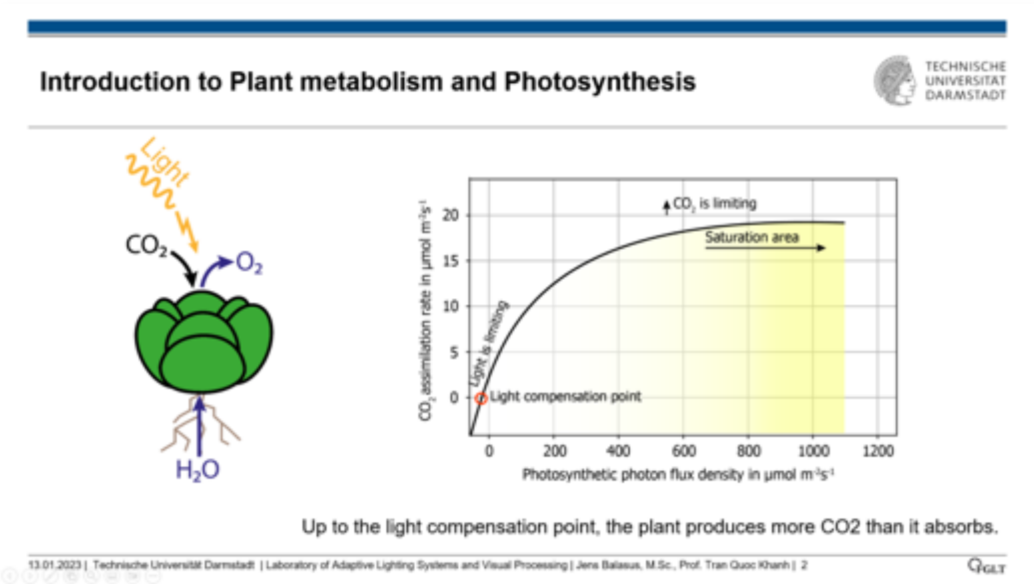
4. Conclusion

Within the scope of this work, various traffic situations were selected and analysed for their efficiency enhancement potential on the basis of traffic statistics. The selection was made for congestion situations, rush hour traffic at dusk, urban night time traffic and traffic light red phases. The analysis shows that primarily rush hour traffic at dusk and urban night time traffic should be considered for further investigation. However, since all lighting function adjustments are easy to implement in the respective traffic situations, energy savings potentials of several GWh can already be realized through small adjustments.

3. LED and Photobiology

Photobiology is a new field of research and has a high transformation chance


LEDs in Horticultural Applications
TECHNISCHE UNIVERSITÄT DARMSTADT
natural
natural and artificial
artificial
Light influences plants:
▪ Intensity → Biomass
▪ Spectrum → Morphology and substances (UV-light)
▪ Duration → Flowering
Photosynthesis and light
How to find solutions?
Relative spectral radiance
Wavelength in nm
660 nm
730 nm
450 nm
525 nm
3100 K
13.01.2023 | Technische Universität Darmstadt | Laboratory of Adaptive Lighting Systems and Visual Processing | Jens Balasus, M.Sc., Prof. Tran Quoc Khanh | 1


Introduction to Plant metabolism and Photosynthesis
TECHNISCHE UNIVERSITÄT DARMSTADT
Light
CO_2
O_2
H_2O
CO_2 is limiting
Saturation area
Light is limiting
Light compensation point
CO_2 assimilation rate in µmol m⁻²s⁻¹
Photosynthetic photon flux density in µmol m⁻²s⁻¹
Up to the light compensation point, the plant produces more CO2 than it absorbs.
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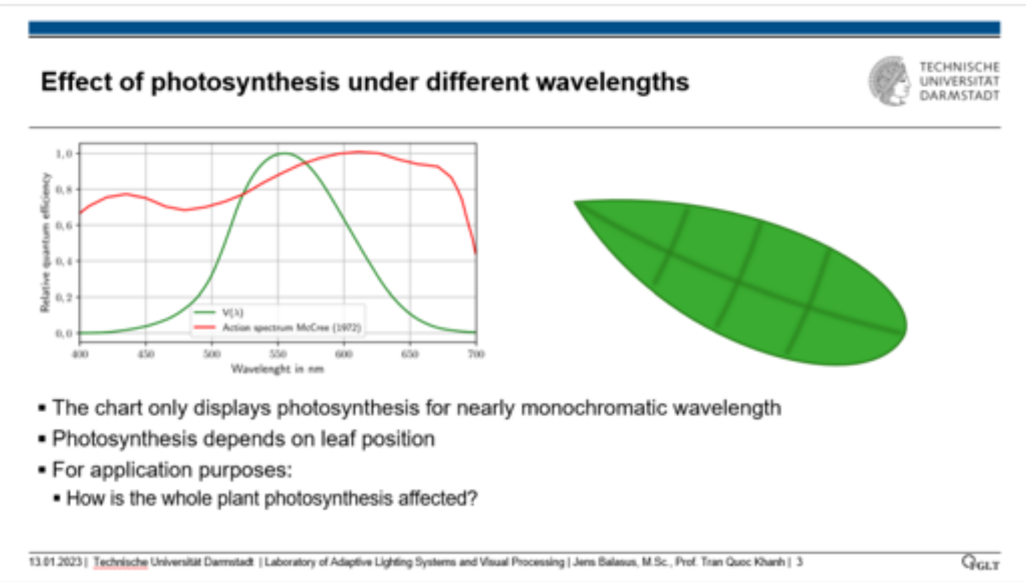
Effect of photosynthesis under different wavelengths
TECHNISCHE UNIVERSITÄT DARMSTADT
Relative quantum efficiency
V(λ)
Action spectrum McCree (1972)
Wavelenght in nm
▪ The chart only displays photosynthesis for nearly monochromatic wavelength
▪ Photosynthesis depends on leaf position
▪ For application purposes:
▪ How is the whole plant photosynthesis affected?
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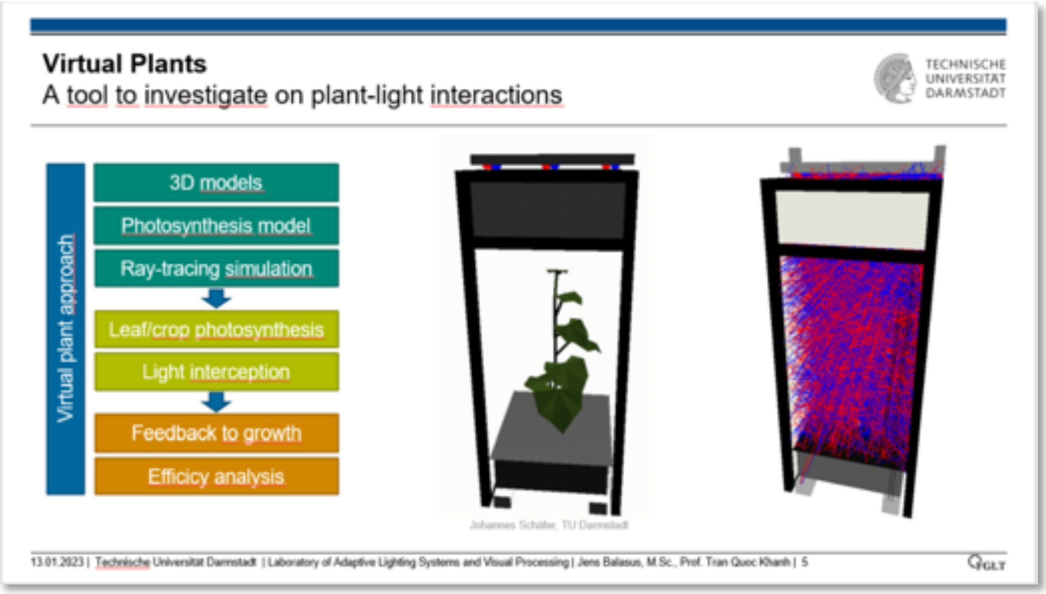
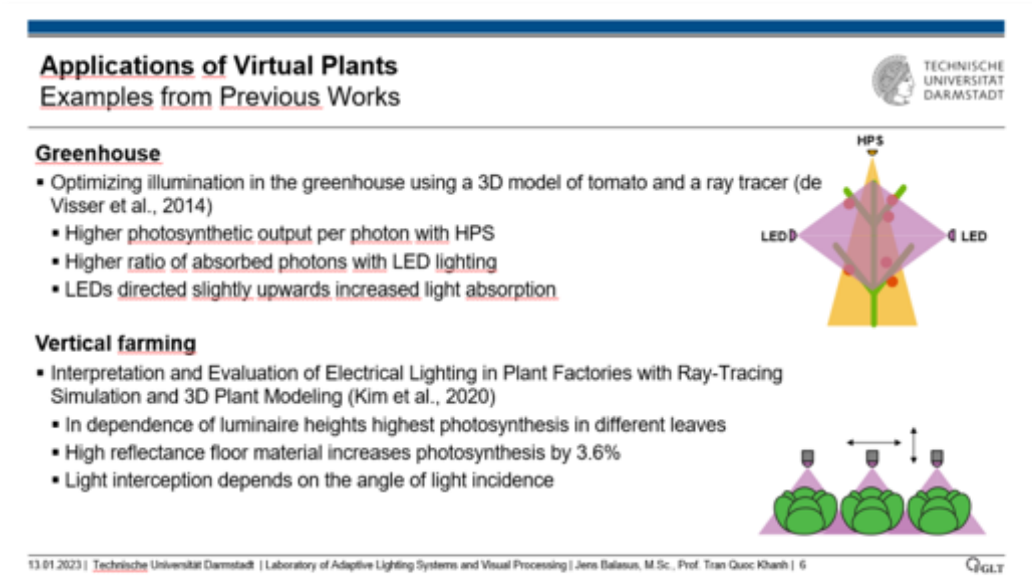
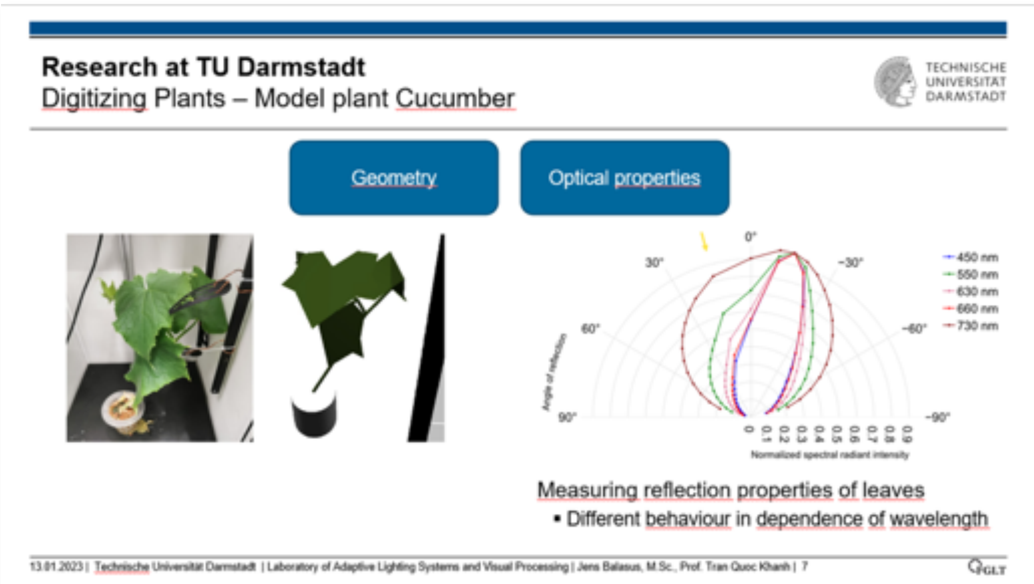

Virtual Plants
A tool to investigate on plant-light interactions
TECHNISCHE UNIVERSITÄT DARMSTADT
Virtual plant approach
3D models
Photosynthesis model
Ray-tracing simulation
Leaf/crop photosynthesis
Light interception
Feedback to growth
Efficicy analysis
Johannes Schäfer, TU Darmstadt
13.01.2023 | Technische Universität Darmstadt | Laboratory of Adaptive Lighting Systems and Visual Processing | Jens Balasus, M.Sc., Prof. Tran Quoc Khanh | 5

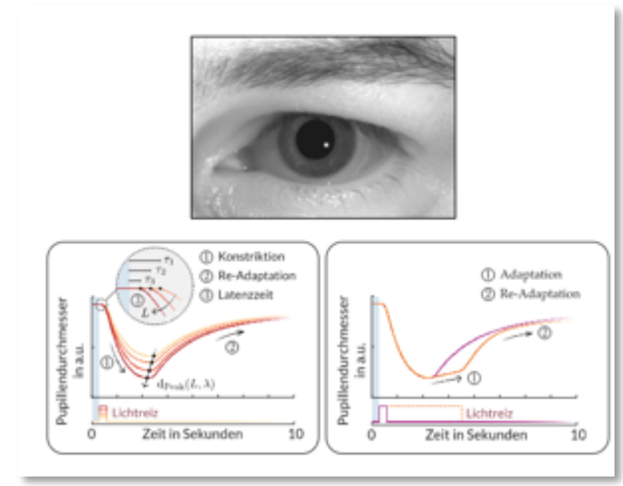

Applications of Virtual Plants
Examples from Previous Works
TECHNISCHE UNIVERSITÄT DARMSTADT
Greenhouse
▪ Optimizing illumination in the greenhouse using a 3D model of tomato and a ray tracer (de Visser et al., 2014)
▪ Higher photosynthetic output per photon with HPS
▪ Higher ratio of absorbed photons with LED lighting
▪ LEDs directed slightly upwards increased light absorption
HPS
LED
LED
Vertical farming
▪ Interpretation and Evaluation of Electrical Lighting in Plant Factories with Ray-Tracing Simulation and 3D Plant Modeling (Kim et al., 2020)
▪ In dependence of luminaire heights highest photosynthesis in different leaves
▪ High reflectance floor material increases photosynthesis by 3.6%
▪ Light interception depends on the angle of light incidence
13.01.2023 | Technische Universität Darmstadt | Laboratory of Adaptive Lighting Systems and Visual Processing | Jens Balasus, M.Sc., Prof. Tran Quoc Khanh | 6


Research at TU Darmstadt
Digitizing Plants – Model plant Cucumber
TECHNISCHE UNIVERSITÄT DARMSTADT
Geometry
Optical properties
0°
30°
-30°
60°
-60°
90°
-90°
450 nm
550 nm
630 nm
660 nm
730 nm
Measuring reflection properties of leaves
▪ Different behaviour in dependence of wavelength
13.01.2023 | Technische Universität Darmstadt | Laboratory of Adaptive Lighting Systems and Visual Processing | Jens Balasus, M.Sc., Prof. Tran Quoc Khanh | 7

4 . Special Report for DVN: Basic Research on Human Eye

Pupil model by predicting time and spectral dependent light responses

by Dr. Babak Zandi, Laboratory for Adaptive Lighting Systems and Visual Processing, TU Darmstadt, Germany. Published 31.01.2023.



The ocular components of the eye and the stimulus processing in the retina play a key role in human perception of indoor or vehicle lighting. For processing light quanta, the human retina contains rods, which are responsible for night vision, and cones, which drive colour perception and sharp vision during daytime lighting conditions. Photometric quantities or their derivatives used in automotive lighting such as (il)luminance, luminous intensity or contrast values, are based on the luminous efficacy function V(λ). Since the turn of the millennium, it is known that a third class of photoreceptors, the so-called intrinsically photosensitive ganglion cells (ipRGCs), exists in the retina. None of the conventional photometric lighting metrics, including the luminous efficacy function V(λ) consider this third class of photoreceptors. The ipRGCs are highly sensitive in the short-wavelength range and were initially linked with non-visual aspects of light, such as nocturnal melatonin suppression or synching the human's circadian rhythm via light. Latest research in the field of lighting, however, surprisingly showed that the ipRGCs also affect human contrast sensitivity or brightness perception. Further, the ipRGCs are also the main driver of the human's pupil size, which affects depth of field or visual acuity.

Therefore, the laboratory of Adaptive Lighting Systems and Visual Processing at the Technical University of Darmstadt is conducting fundamental research for developing new metrics that integrate the ipRGCs, rods and cones for evaluating the visual performance of humans in response to light distributions in the environment. Where in previous research projects related to lighting, mostly subjective assessment criteria were used, objectively retrieved metrics become more important for developing new lighting metrics.

One key biomarker for objective assessments is the temporal behaviour of the human's pupil size. Via the pupil size, arousal, sexual interest, sleepiness or the cognitive performance can be reliably tracked. Research groups also apply the pupil size in early recognition of neurodegenerative diseases, pain monitoring during surgeries or in lie detectors. However, for the practical use of pupil size in modern human-machine interfaces, a model is required that predicts the influence of light on the human pupil diameter, allowing to extract the influence of other non-lighting induced modalities. In fact, over 100 years of international research activities were put into the attempt to develop a pupil light response model. Due to the pupil's complex behaviour, developing a valid model that predicts the human's temporal pupil size is considered a holy grail type of problem.

At the Laboratory of Adaptive Lighting Systems in Darmstadt, a modern experimental laboratory setup was developed (see Fig. 1) to collect empirical data on the pupil light response and study how light can affect non-visual responses. The setup consists of a temperature-controlled 15-channel LED luminaire (see Fig. 1a) with which arbitrary polychromatic spectra can be additively mixed to trigger the retinal photoreceptors, including the ipRGCs in a different manner. When using a multi-channel LED luminaire, spectral optimisation is a crucial step in engineering light stimuli that features specific lighting metrics. In such systems, each LED channel's dimming level can be controlled via the duty cycle (see Fig. 2a). However, the combination of the dimming levels across the LED channels needs to be computed.

In a spectral optimisation pipeline, the lighting objectives need to be defined, which could be chromaticity coordinate and the (il)luminance in simple cases. Then with heuristic or gradient-based optimisation methods, the duty cycle combinations are computed, which produce a light stimulus that matches the previously defined lighting objectives (see Fig. 2a). Early research in pupil modelling, for instance, mostly considered thermal light sources with CIExy chromaticity points placed along the Planckian Locus, limiting the prediction space of the proposed models. Therefore, the multi-channel LED system developed by the TU Darmstadt provides a new degree of freedom in engineering light.

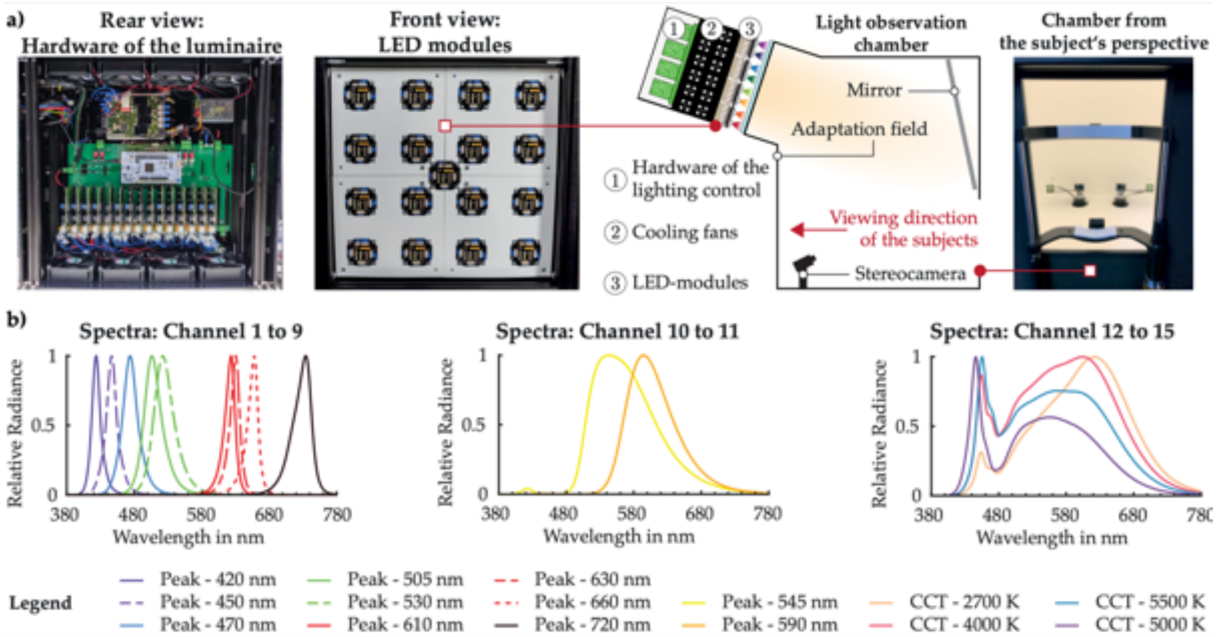


Figure 5 a) The front and rear view of the temperature-controlled multi-channel LED luminaire that is used at the Technical University of Darmstadt to study and collect data on the human's pupil light reflex. b) Spectra of the individual 15-channels that were integrated in the luminaire, with which polychromatic light stimuli can be additively mixed. The Figure is reprinted with modifications from Zandi, B., Klabes, J. & Khanh, T.Q. Prediction accuracy of L- and M-cone based human pupil light models. Sci Rep 10, 10988 (2020). https://doi.org/10.1038/s41598-020-67593-3 under CC BY 4.0 license.

The developed multi-channel LED luminaire also allows to engineer so-called metameric light spectra, i.e., light stimuli that share the same (il)luminance and chromaticity coordinate but affect the ipRGCs differently. With metameric spectra, non-visual responses or contrast sensitivity could be tuned without altering the visual appearance of the light. In Fig. 2b), the possibilities of metameric spectra are shown when using a 6-channel LED luminaire consisting of four chromatic LEDs and two phosphor-converted white LEDs. For example, at a correlated colour temperature (CCT) of 6702 K (Duv: 0.003) and a colour fidelity index Rf of at least 85, thousands of spectra can be optimised that meet these requirements.

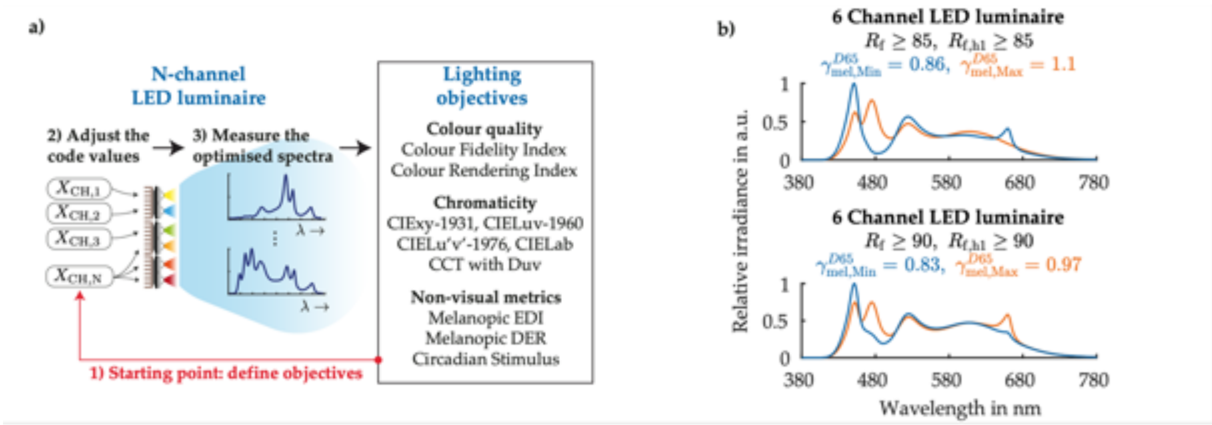


Figure 6 a) Pipeline of a spectral optimisation task. b) A set of metameric spectra that have a CCT of 6702 K (Duv: 0.003) but differ in their melanopic illuminance, used to trigger the non-visual human responses without affecting visual parameters. The Figure is reprinted from Zandi, B., Khanh, T.Q. Towards intelligent illumination systems: from the basics of light science to its application. Z. Arb. Wiss. (2022). https://doi.org/10.1007/s41449-022-00341-7 under CC BY 4.0 license.

From the set of optimised spectra, however, two pairs of spectra can be extracted (see Fig 2b) that match the above defined objectives but differ in their melanopic illuminance. The higher the melanopic illuminance is, the more the ipRGCs can be triggered; thus, non-visual responses or contrast sensitivity could be tuned. Metameric spectra can be applied in future intelligent indoor lighting systems to solve the potential conflict between visual preference (CCT, (il)luminance) and non-visual needs to synch the circadian rhythm or adjust melatonin suppression. In automotive lighting, metameric spectra could be used to design headlamps that enhance the human's contrast perception without affecting the CCT or the luminance of the light source. At the laboratory of Adaptive Lighting Systems in Darmstadt, one of the world's most extensive simulations on multi-channel LED luminaires was carried out to analyse the melanopic limits of metameric spectra.

To measure the human's pupil size in the above-mentioned setup (see Fig. 1), the team at the laboratory of Adaptive Lighting Systems developed an open-source platform called PupilEXT (Link: https://github.com/openPupil/Open-PupilEXT). The software PupilEXT (Fig. 3) can record eye images using a stereo camera system or a single camera to measure the pupil diameter in real-time. Additionally, it is possible to analyse externally recorded images without connected cameras via the PupilEXT interface. The team in Darmstadt aimed to provide a professional open source pupillometry measurement platform, making an easy and inexpensive entry into pupil research for interdisciplinary research groups possible. PupilEXT integrates high-resolution industrial cameras. The pupil detection itself can be performed with one of the state-of-the-art open-source algorithms, Starburst, Swirski2D, ExCuSe, ElSe, PuRe, and PuReST. The published paper of PupilEXT has today more that 10 000 views and the video tutorials were watched more that 2000 times, making the platform to a major contribution to the open source research community.

Figure 7 The graphical user interface of the programmed software PupilEXT during a pupil recording in stereo camera mode. The figure was reprinted from Babak Zandi, Moritz Lode, Alexander Herzog, Georgios Sakas & Tran Quoc Khanh. PupilEXT: Flexible Open-Source Platform for High-Resolution Pupillometry in Vision Research. Frontiers in Neuroscience. 15, (2021). Frontiers Research Foundation. DOI: 10.3389/fnins.2021.676220 under CC BY 4.0 license.

Summary:
In the field of pupil light response modelling, the team in Darmstadt developed the first pupil model that can predict the human's temporal pupil size in response to distinct light spectra with a mean absolute error of below 0.1 mm. Compared to previously proposed luminance-based pupil models, the model from Darmstadt can reconstruct the temporal pupil size up to 300 seconds and considers the adaptive receptor weighting in the afferent pupil control pathway for the first time. The research results on the pupil light reflex were published by the team in Darmstadt in the renowned journal Scientific Reports (Nature Publishing Group) and were recognised two times (2020 and 2021) in the top 100 most read papers of the journal.

Literature from the lab for the interested reader

[1] Babak Zandi, Julian Klabes & Tran Quoc Khanh. Prediction accuracy of L- and M-cone based human pupil light models. Scientific Reports. 10, 10988 (2020). Nature Research. DOI: https://doi.org/10.1038/s41598-020-67593-3

[2] Babak Zandi & Tran Quoc Khanh. Deep learning-based pupil model predicts time and spectral dependent light responses. Scientific Reports. 11, 841 (2021). Nature Research. DOI: https://doi.org/10.1038/s41598-020-79908-5

[3] Babak Zandi, Adrian Eissfeldt, Alexander Herzog & Tran Quoc Khanh. Melanopic Limits of Metamer Spectral Optimisation in Multi-Channel Smart Lighting Systems. Energies. 14, 572 (2021). MDPI. DOI: https://doi.org/10.3390/en14030527

[4] Babak Zandi, Moritz Lode, Alexander Herzog, Georgios Sakas & Tran Quoc Khanh. PupilEXT: Flexible Open-Source Platform for High-Resolution Pupillometry in Vision Research. Frontiers in Neuroscience. 15, (2021). Frontiers Research Foundation. DOI: https://doi.org/10.3389/fnins.2021.676220

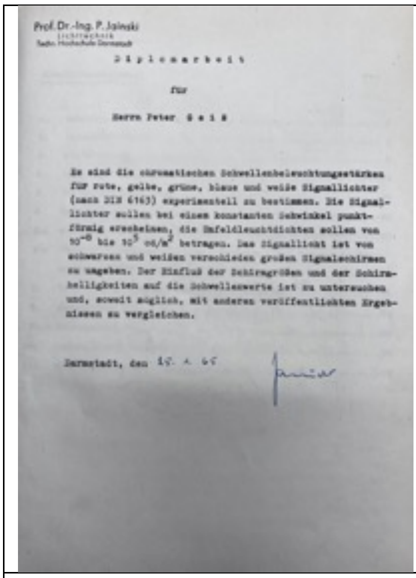
[5] Babak Zandi, Oliver Stefani, Alexander Herzog, Luc Schlangen, Quang Vinh Trinh & Tran Quoc Khanh. Optimising metameric spectra for integrative lighting to modulate the circadian system without affecting visual appearance. Scientific Reports. 11, 23188 (2021). Nature Research. DOI: https://doi.org/10.1038/s41598-021-02136-y

14. STUDENTS AT THE UNIVERSITY AND WHAT IS NECESSARY TO BECOME A DOCTOR.

The mission of a university is a triple approach to lectures, research and publications.

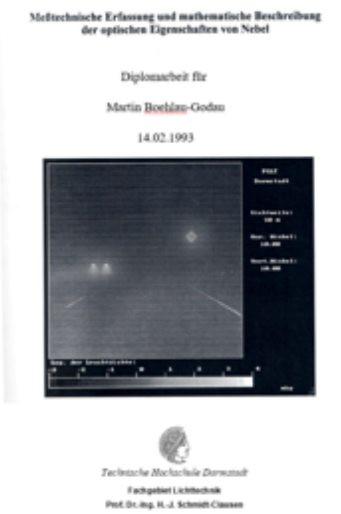
Lectures and practical exams in DLI are attracting students. According to the study regulations for their curriculum in the Electrical Engineering Department they have to proof scientific knowledge by writing a Master- or Bachelorthesis, before 1999 a study thesis or diploma thesis.

Over the years 280 students finished their thesis on various aspects in Lighting.



Diploma Thesis 1965
(Threshold Signal Luminances)

Diploma Thesis 1969
(Glare in Jet Cockpits)



Diploma Thesis 1993
(Mathematical Model of Fog)

Diploma Thesis 1998
(Face Recognition)

Master Thesis 2021
(Luminance Measurement)

Master Thesis 2022
(Eye Mark Investigations)

Examples for Theses from Darmstadt Lighting: 6 out of 280.

Publications are the basic output of scientific work. Followed by presentations at relevant conferences in all parts of the world: China, U.S., Korea and all over Europe.

And – this is the specialty of a university:

It produces doctors. Two small letters “Dr.” for the academic title that can be added to the name for the rest of life. But - before becoming a doctor each candidate has to do year long research, write a scientific report known as dissertation and surviving an exam with 5 testing professors. Not a single candidate has exclusively this as job, as an assistant at the university he has all the duties of lecture, administration, student supervision and third-party research and experiments. And externals are working in industry. Each candidate’s own research is running usually in parallel. Scientific research means sometimes success, sometimes lost days and weeks because the experimental setup did not produce reliable results and/or the measurement devices or process had failures. Or just the weather did not work, the boss has urgent other jobs, the test persons did not show up or the self-written computer program crashed etc., etc…. Research means new. And new means not known yet. So all work is a journey into unknown areas with the hope of success.

The most important thing a candidate needs: perseverance, self-motivation and belief in the goal.

Right after the exam – years of burden fall off the candidate’s shoulders - there is party. And mostly a doctor car prepared by the colleagues with insignia from the now-doctor’s work and some characteristic and individual elements during his or her PhD period.

And then the brand-new doctor sits in that car, is happy and pulled through the Darmstadt streets. And sometimes the people around spend applause for the fresh-baken doctor with that special hat in his funny car.

15. Alumni: Friends of Darmstadt Lighting

Like many universities and institutes, the DLI also receives support from a separate association. Most of the members are former students who have either attended or graduated in some fashion from the institution and as well supporters from the industry.

FREUNDE·DES·FACHGEBIETS

LICHTTECHNIK·DER·TU·DARMSTADT·E.V.

The Alumni Association for the Darmstadt Lighting organizes seminars and trainings in order to sponsor the scientific work.

The Association of Friends of the Laboratory of Lighting Technology of the TU Darmstadt e.V. was founded in 1988. The association aims to support the Laboratory of Lighting Technology in its work:

- Support in the training and qualifications of the students of the Laboratory of Lighting Technology
- Conducting advanced training and science events in the fields of lighting technology
- Organizing Alumni meetings, and fundraising.
- Sponsoring for students work, excursions and laboratory equipment

16. List of 52 PhD Dissertations in Lighting since the Beginning

1	1961	Werner Adrian	Influence of Interfering Light on Detection capability of the Human Eye
2	1967	Reiner Pusch	Colour of Signal Lights
3	1967	Hans-Joachim Schmidt-Clausen	Light Pulses at varying surrounding Luminance
4	1975	Harald Hofmann	Metrics of Luminance, Colour and Presentation Time on Signal Lights
5	1979	Hans-Rüdiger Gerdes	Signal Lights at Chromatic and Achromatic Threshold
6	1984	Klaus Petry	Minimum Illumination at Daylight Work Areas
7	1991	Jörg Ed. Hartge	Spectral Sensitivity with small Lightsources
8	1994	Horst Finsterer	Pattern Conspicuity and perception in mesopic status
9	1994	Helmut Frank	Traffic Sign Requirements at Night
10	1995	Martin Enders	Comparison of Methods to determine Human Eye spectral sensitivity
11	1995	Joachim Damasky	Lighting Requirements on Headlights
12	1996	Herbert Wambsganss	Visibility and Requirements on Road Markings
13	1997	Michael Hamm	Spectral Sensitivity and Visual Response Time
14	1997	Hans-Hubert Meseberg	Lighting Reqirements on Vertical Traffic Control Systems
15	1998	Christian Boehlau	Expert System for Layout of Vehicle Lights
16	1998	Johannes Aulbach	Reqirements on Visual Information of Guidance Signs
17	1999	Wolfgang Huhn	Requirements on Adaptive Light Distribution
18	1999	Ernst-Olaf Rosenhahn	Lighting Requirements in Adverse Weather
19	2001	Joachim Ripperger	Lighting Requirements on Rear and Stop Lamps
20	2001	Thomas Dahlem	Methods to Evaluate Vehicle Headlights
21	2001	Stefan Milch	Video based Detecting on-board a vehicle
22	2001	Peter Lehnert	Vehicle Dynamics effects on Light Distribution
23	2001	Daniel Armbruster	Adaptive Vehicle Signal Lights
24	2003	Martin Grimm	Ambient Interior Lighting
25	2004	Carsten Diem	Viewing Behaviour in Dynamic Traffic
26	2010	Achim Freiding	Human Spectral Sensitivity in Mesopic Adaptation
27	2011	Dominik Schneider	Marking Light
28	2012	Jan-Holger Sprute	Glare Minimization on Adaptive High Beams
29	2013	Quang Vinh Trinh	Lighting quality aspects of high qualitative hybrid LED-lamps
30	2013	Alexander Totzauer	Glare Free High Beam
31	2014	Stefan Brückner	Color rendering and color difference perception
32	2014	Charlotte Bois	Influence of phosphor particle phosphor-converted LEDs
33	2014	Bastian Zydek	Disability Glare- Dynamic Leveling
34	2015	Christioph Schiller	Spectral sensitivity of contrast in the mesopic range
35	2015	Dmitrij Polin	Stroboscopic effects in indoor and automotive applications
36	2016	Felix Kimme	Colourimetric Aspects of Digital Imaging and Reproduction with LED
37	2016	Marvin Böll	Metameric aspect of color perception
38	2017	Nina Müller	Distraction potentials in the night time road lighting
39	2017	Daniel Englisch	Spectral sensitivity of glare in the mesopic range
40	2017	Watschislav Pepler	Brightness perception in the photopic range
41	2018	Max Wagner	Degradation of high power LEDs
42	2018	Katharina Schneider	Contrast visibility of low and high beam
43	2018	Sebastian Babilon	Memory Color and color preference
44	2019	Jonas Kobbert	Lighting distributions on the road and ADB
45	2019	Kiriakos Kosmas	Glare for wet road, headlamp cleaning systems and dynamic levelling
46	2020	Philipp Rabenau	Perception of automotive rear lamp
47	2021	Alexander Herzog	Degradation of UVA and green LEDs
48	2022	Sebastian Schüler	Lighting systems for improving the circadian activity of truck drivers
49	2021	William Truong	Lighting systems in the industrial halls
50	2022	Babak Zandi	Pupil diameter and it's influencing parameters
51	2022	Timo Singer	AV-communication
52	2023	Adrian Eissfeldt	Metameric aspects of daylight perception

17. ANNEX 1 - OFFICES AND RESEARCH LABORATORIES

The first part of the laboratory rooms is much older than the lighting institute. These brick buildings were erected in 1908 and thus belong to the oldest and core buildings of Technical University Darmstadt. Deep in the second basement, the complete area of the university was and is connected. Groundwater pumps and heating and electrical infrastructure are underground connected from the lighting laboratories to various other locations. In 1937, laboratory room 17 was added. in 1964 all buildings adopted their present exterior design, and are now officially preserved as an "ensemble of historic interest". Unfortunately, this nomination also means no significant architectural changes are possible. The windows have to remain as they are, and the raw brick structure, no matter what ecologic needs appear for insulation and modern office design.

Since 1962 lighting research is based in these buildings.

Lighting Technology Research Buildings in 1964

In 1995, small renovations took place, mostly because of the outdated electrical infrastructure. A new power network; digital infrastructure, and modern fuse systems were installed.

First electrical wiring and power renovation 1995

After Prof. Khanh assumed his position in 2006, intensive discussions began within the university administration, as to where and how the new Laboratory of Lighting would be installed.

In 2008 the University agreed to spend significant money for massive updates to the laboratory. While respecting the ensemble-of-interest building status, a complete renovation was made to the offices and research laboratories. All activities on research; administration, and teaching continued in parallel.

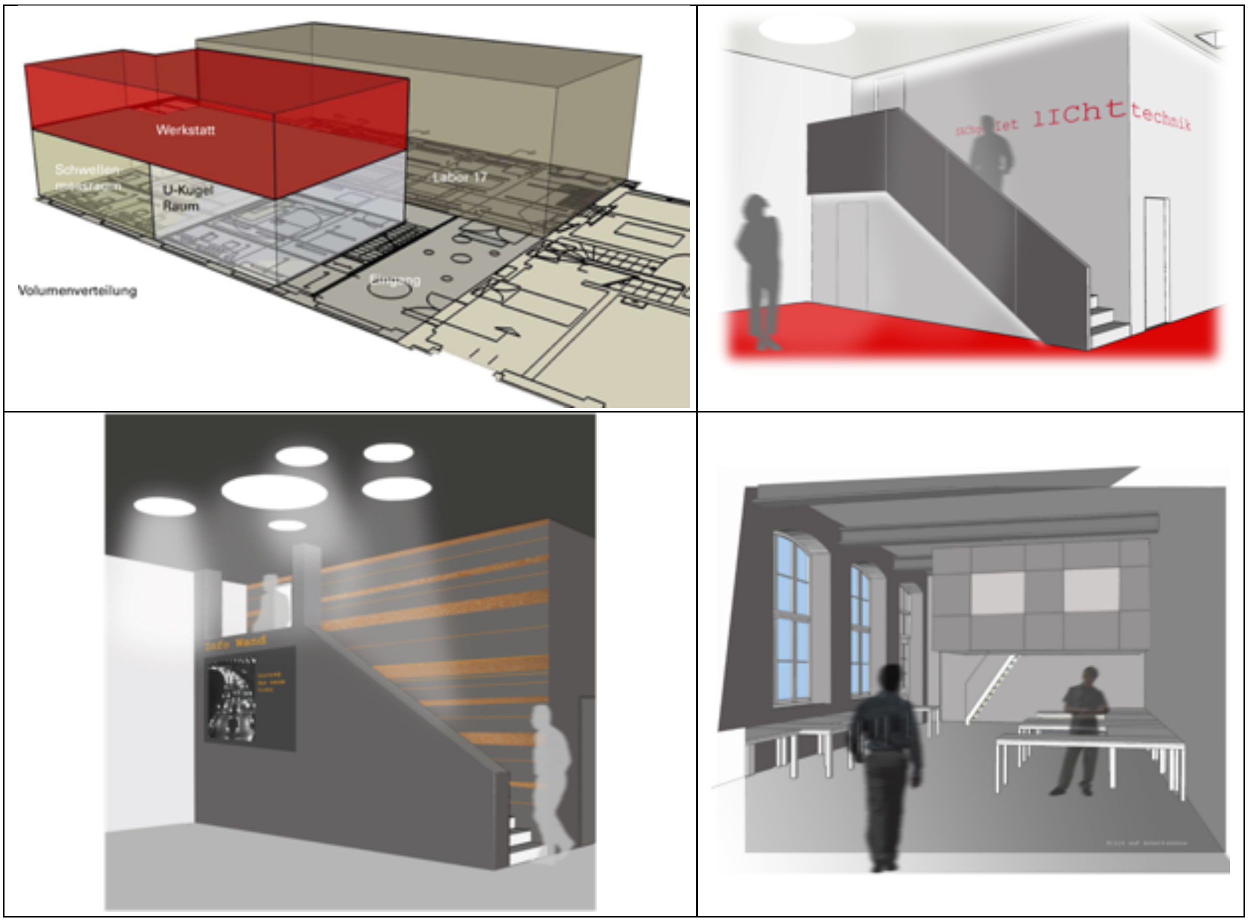
Laboratory (Building 17) and Student's room in Office Building 6, before full renovation.

Until 2008, only the upper floor of the office building (6) was available for the lighting researchers.

That compressed all activity into one miniature secretary, one professor office, one students' room, and two office rooms for the assistants. Up to eight assistants plus several external PhD workers had to find a place to administer, supervise the students and diploma works, organize the optical engineering services and do their own research work. And some eight students had to find a place to work in one room together.

During Renovation Outside and Inside Building 17

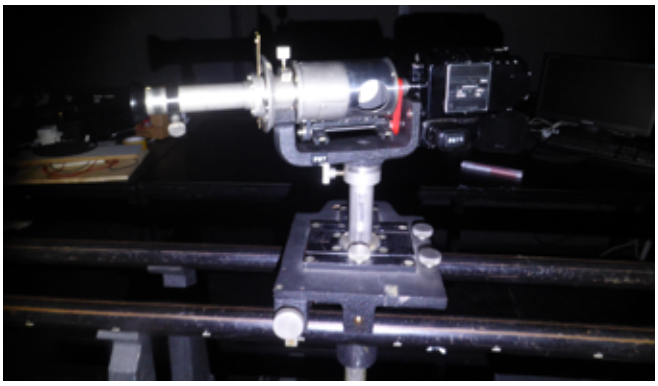
From 2008 on, the full rooms in the office building 6 were granted to the Lighting Laboratory. That enabled a much better organization and space for the workers. A small library was integrated as well as a meeting room; storage rooms, and washrooms. Additionally, a small workshop area could be integrated. A special students' office enabled better and more efficient work.


Werkstatt
U-Kugel
Raum
Labor 17
Volumenverteilung
lICht technik

Plans 2008

And new laboratories and renovated building 2010..22

There are still some devices in the laboratory which have survived even since 1962. One is the flicker photometer which is an instrument to determine the individual eye spectral sensitivity. The largest quasi historic device is the optical bench in the middle of the laboratory room. Initially a loan from Fraunhofer Gesellschaft, it is still in use today with moveable elements for laboratory experiments with varying distances and still high precision.

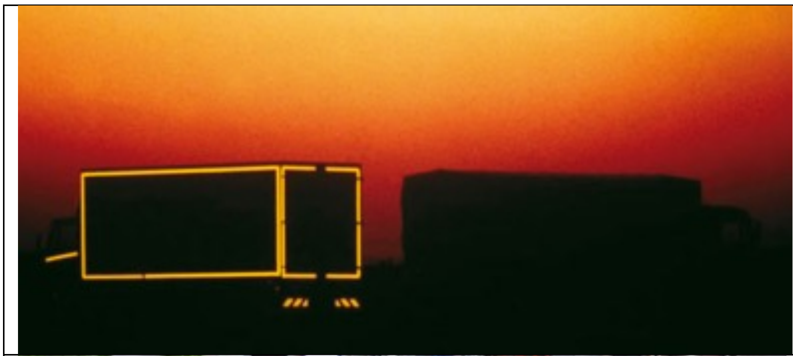
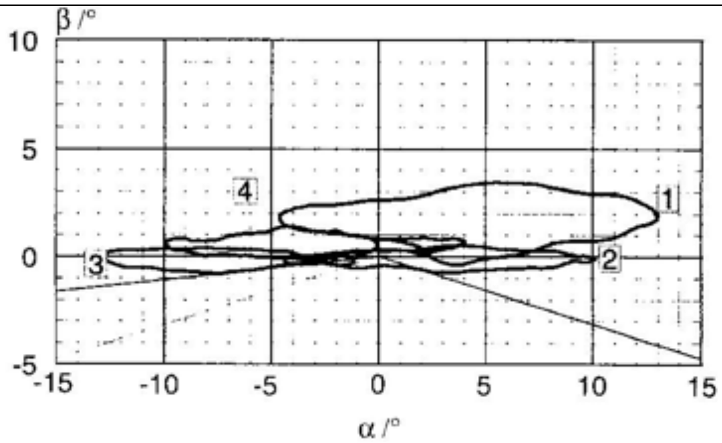


Vintage but still in use: Flicker photometer on the optical bench

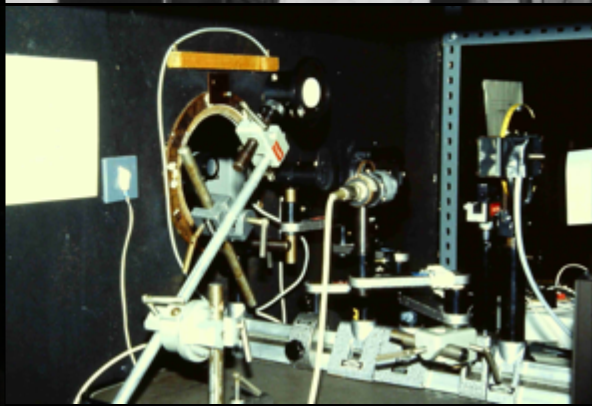
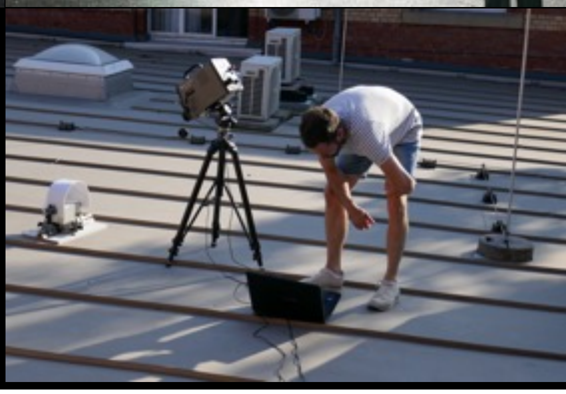
The bench has served for many experiments by generations of students and Doctor candidates. In the early 1990s, many additional parts for it were transformed to Darmstadt when the manufacturer Schmidt & Haensch closed their facilities in Berlin. This acquisition was sponsored by the Alumni Association "Friends of Darmstadt Lighting".

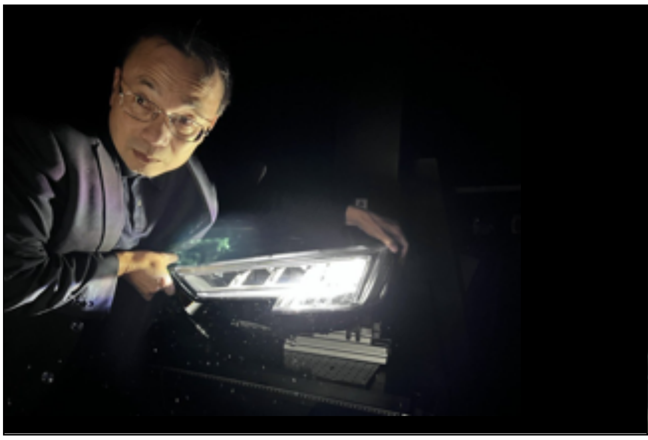
18. ANNEX 2 - VISIBLE RESULTS OF RESEARCH IN REALITY

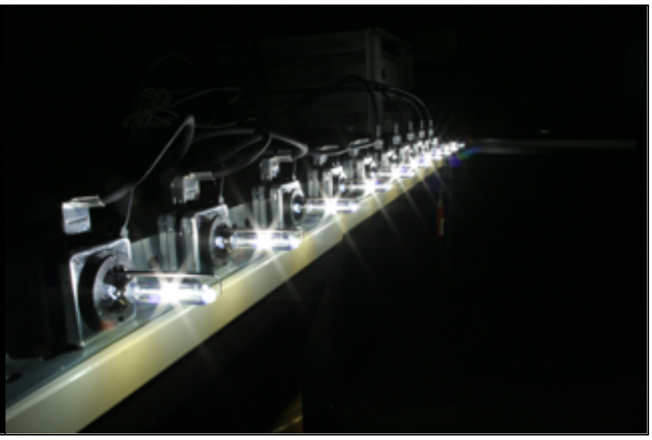
Some research was leading to new database for rulemaking, new products or processes. Some excerpts are listed below.

	*Investigations in Darmstadt published various specifications that ended in Regulation "Retroreflective markings for vehicles of category M, N, O"* *ECE Regulation 104, inforce 2014*
	*Research on improvements for visually impaired persons (e.g. Retinitis pigmentosa) contributed to improved visual guidance in public areas.*
	*If you drive on german motorways, the results of visual research in traffic zones are visible.* *Delineators with chevrons improve visual guidance. New types of road markings are applied.* *Based on research from Darmstadt.*
	*Statistical Data on roads, road inclination and positions of traffic signs and driver's eyes as well as investigations on glare, detection thresholds, rain and fog contributed to new light distributions in* *ECE Regulation 123 "Adaptive Front Lighting System" Inforce 2006.*

19. ANNEX 3 - FOTOSTORY: UNIVERSITY LIFE OVER THE YEARS

Research and Experiments	
	
	
	
	





Parties for the students, Summer party for alumni and supporter association

Doctoral celebration, day of examination and relief


ONLY
Thomas Burg
Ralf Steinmetz
Edgar Dörsam
Tran Quoc Khanh, FB 18
Christian Graeff
Babak Zandi