Intelligent Lighting Institute | Edition 14, May 2021

ILIMAGAZINE

> **DAAN ROOSEGAARDE** DREAMSCAPE GROW

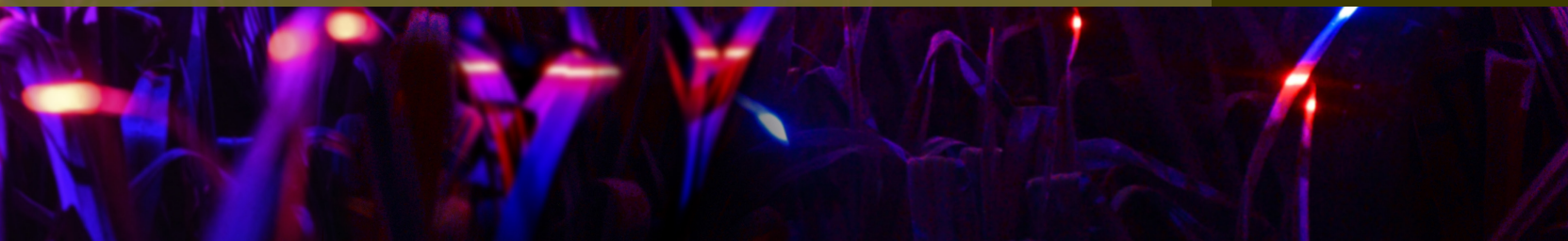
> **AI TWILIGHT PROJECT**

> **MAJOR GRANT FOR BIOCLOCK**

> **OPENING WORKPLACE VITALITY HUB**

TU/e

EINDHOVEN UNIVERSITY OF TECHNOLOGY



Content

ILI Magazine is a biannual edition of ILI for ILI members, colleagues, collaboration partners, policy makers and related companies - ILI Magazine 2021 is published in May

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Enjoy our new ILI magazine!
Harold Weffers
Operational manager

ILI
INTELLIGENT LIGHTING INSTITUTE

TU/e

HAROLD WEFFERS | OPERATIONAL MANAGER

Welcome

I am very pleased to once again be able to present to you a new edition of our ILI Magazine. As you will see, despite the challenges of these times, we have been able to start a number of new R&D and (technological) innovation projects (PDEng/PhD), hire a number of talented researchers, and we are still very active on various levels of education programs (B.Sc., M.Sc.) as well as in TU/e innovation Space.

In this edition, we also have a number of relevant interviews shining a light on related work on light & lighting to the benefit of society at large and we also share with you some of the ambitions of TU/e with respect to R&D and (technological) innovation in the context of the 2021 edition of the GLOW Light Art Festival.

Pleasant reading!

MAY 2021-NOVEMBER 2021

Calendar

3 June 10:00-11:30 h WEBINAR CREATING A SMART LIGHT SYSTEM: SOME LESSON LEARNED FROM THE SMART-SPACE PROJECT. Learn more about the potential of Smart Public Lighting. ILI member Swagata Chakraborthy will be one of the speakers. More information on page 21.

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27 June – 01 July 2021 OSA OPTICAL DESIGN AND FABRICATION CONGRESS, Freeform Optics.
Location: Providence, Rhode island, USA

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6 -13 July 2021 LCIE S 026:2018 TUTORIAL: Understanding and application of CIE S 026/E:2018 CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light (online) https://cie.co.at/news/cie-s-0262018-tutorial

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27-29 September CONFERENCE CIE 2021 (ONLINE) Theme "Light for Life – Living with Light". Conference topics (i) Light in Culture and Heritage, (ii) Urban Lighting Light and Ecology, (iii) Integrative Lighting, (iv) Colour and Lighting in Virtual Reality; and (v) Horticultural Lighting. https://malaysia2021.cie.co.at/

16-24 October DUTCH DESIGN WEEK
Location: Eindhoven

6-13 November GLOW LIGHT FESTIVAL
Location: on 5 sites in Eindhoven, one is TU/e campus

"We seek partnerships with other academic centers of knowledge in its vicinity."
Ingrid Heynderickx
Scientific Director

INGRID HEYNDERICKX | SCIENTIFIC DIRECTOR

Light is not only a necessity for humans to explore the world around them, it also facilitates plants, animals and humans to flourish. The right amount and type of light at the right time of the day improves people's circadian rhythm, their sleep behavior and their cognitive performance during daytime.

ILI grows

Light modulations can also be used to get people's attention, or to change their behavior. The effect of light on animals is very diverse, ranging from facilitating growth, migration and reproduction to declining populations through light pollution. Through a process called photosynthesis, light gives plants their energy, and enables their growth and flowering. Photobiology inspired light scenes can therefore improve crop harvesting and reduce the use of pesticides. Multiple of these topics are described in the current ILI Magazine with, amongst others, a contribution related to the newest scientific insights on the effect of light on the circadian rhythm, a publication on the use of light to stimulate vitality in buildings, research on the effect of light to improve life in public spaces, and a reflection on GROW. The latter is the latest artwork of Daan Roosegaarde, in which he illuminates 20.000 m2 of farmland with waves of blue, red and ultraviolet light, not only to illustrate the beauty of agriculture, but also to improve plant growth with a scientifically designed light recipe.

Together with Daan Roosegaarde and Anja Dieleman, scientist at Wageningen University and expert in plant physiology, we reflect on this artistic and scientific project of light affecting plant growth.

Apart from enabling growth of life through light, ILI has the ambition to grow itself. In order to increase its visibility as an expert institute on smart lighting design and solutions, to enlarge its range of scientific disciplines and knowledge and to effectively use experimental infrastructure that is available within the region, ILI seeks partnerships with other academic centers of knowledge in its vicinity.

Readers that are interested in exploring such a partnership are invited to contact us. We hope that through these partnerships ILI will further grow as an internationally renowned institute on smart lighting.

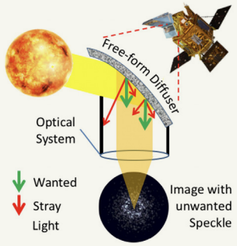


Figure 1A

(A) *Earth-observing detectors, as in the TROPOMI satellite use the sun as a calibration source with a diffuser to direct and homogenize the light. However, this leads to non-homogeneous illumination and undesirable local heating as well as stray light from the instrument or space craft that ruins the calibration. A freeform scattering architecture could solve these problems and reduce size and weight of the optical parts, enabling cheaper and miniaturized satellites.*

*(**B**): Metrology system in a wafer stepper: To find the overlay between stacked chip layers, the positions of marks (M1, M2) are compared. However, marks (M2) in deeper layers are hidden by complex-formed layers that scatter light, blur the desired diffraction, and hinder chip precision. Freeform scattering methods aim to distinguish hidden marks.*

*(**C**) LED bulb. White light emanating from the LEDs is scattered by the free-form diffuser. Presently, diffuser design is based on trial-and-error. With freeform scattering optics, its surface thickness and shape can be designed to realize a desired diffuse yet non-Lambertian angular intensity distribution as described in application norms.*

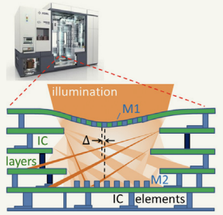


Figure 1B

Figure 1C

Figure 1. Devices whose functionality strongly benefits from freeform scattering optics.

WILBERT IJZERMAN | COMPUTATIONAL ILLUMINATION OPTICS (M&CS)

Freeform Scattering Optics

INTRODUCTION

How to transport light efficiently from A to B? This question is the central challenge in the functionality of everyday devices such as cameras, projectors, lighting systems, and even optically secured bank cards. When light travels from point A to B through a transparent medium with macroscopic, optionally curved, surfaces it follows a path that - following the famous principle of Fermat (1658) - has an optical length which is an extremum. This changes fundamentally when the medium contains microscopic particles that scatter light. The technologically relevant question "what happens when both macroscopic curved interfaces and nanophotonic scattering media appear simultaneously", has remained unaddressed and unanswered yet. The interplay between microscopic scattering and refraction or reflection by macroscopic freeform surfaces (surfaces with an arbitrary shape) offers new, largely unexplored, opportunities and solutions of diverse technological problems, as shown in *Figure 1*.

THE FREEFORM SCATTERING OPTICS PROJECT

In this project, the UTwente, TU-Delft and TU/e and the partners ASML, Focal, Lumileds, Signify, SCHOTT, and TNO, work closely together. In Eindhoven the PhD students Lotte Romijn, Maikel Bertens, Simon Kronberg and Robert van Gestel are part of this project.
Traditional (forward) optical design is a process of trial and error. The 3D geometry of lens and/or mirror surfaces are defined in a CAD tool, and the energy distribution emitted by the source is prescribed. Subsequently, the resulting energy distribution on a target screen is calculated using ray-tracing; rays of light are followed through the 3D geometry from source to target screen using the laws of reflection and refraction (Snell's law). If the obtained energy distribution on the target screen is different from the desired distribution, the 3D geometry of lens and mirror surfaces is adapted and the whole process starts again.

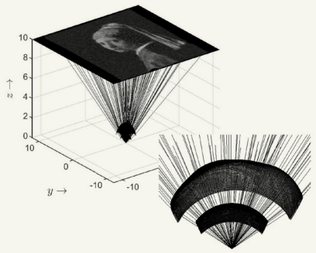


Figure 2A
Result of an inverse optical problem. At the bottom right an enlargement of the two (convex) freeform surfaces used in this example.

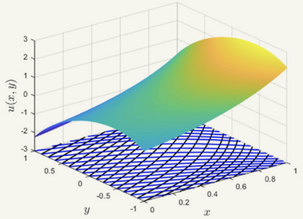


Figure 2B
A solution of a hyperbolic Monge-Ampere equation using the method of characteristics. The corresponding optical surface is saddle shaped.

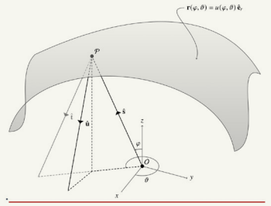


Figure 2C illustrates scattering for a (2D) freeform optical surfaces and a point source.

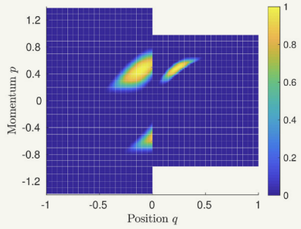


Figure 2D illlustrates the energy distribution in an optical system obtained by solving the Liouville equation.

Figure 2.

In the work of Lotte and Maikel, we take a different approach. We derive a partial differential equation that describes optical surface(s) given the energy distribution of the source and the desired target. Solving this partial differential equation will give us the optical surface(s) directly.
This partial differential equation is of the Monge-Ampère type. These types of partial differential equations are difficult to solve and in the last decade we have developed an efficient algorithm for this.
Lotte has extended this approach to a large class of optical systems. Examples are given in *Figure 2.a.* She developed a general mathematical framework that classifies all basic systems for point sources and parallel beams and she has shown that she can solve several of these using an improved algorithm. In the future, this approach will allow us to design optical systems with multiple optical surfaces and a new PhD student Teun van Roosmalen will work on this in a different project.
Next to the (convex or concave) optical solutions that Lotte calculates there also exist saddle-shaped solutions for the inverse problem. There is very little literature on finding these solutions and, so, it is a very challenging task. In this project, Maikel is working on an algo-rithm to calculate these optical surfaces. First results are shown in *Figure 2.b.*

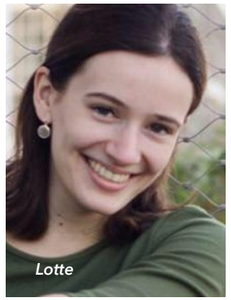
In the work of Lotte and Maikel, we assume that the optical surfaces are perfectly smooth. In practise, there are multiple sources of imperfections, such as scratches due to the chisels used in mould production. These scratches results in scattering of the light; a single light ray splits in multiple light rays and the energy is distributed over a region on the target plane. There are sometimes advantages of scattering, however, such that we may want to control it rather than remove it, for example to disguise the point-like nature of LEDs. Simon is working on including scattering in our inverse optical design strategies. Some first results are shown in *Figure 2.c.*

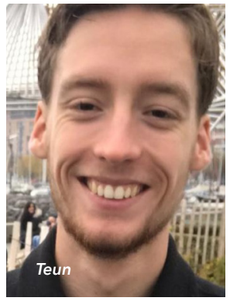
Finally, Robert works on a novel simulation method, based on the Liouville equation, for optical systems. Using such a simulation method would be faster than ray-tracing simulation methods and save a lot of time for optical engineers. The traditional ray-tracing method available in commercial simulation tools uses a Monte-Carlo approach and consequently, to reduce the simulation error by a factor two, the computational time increases by a factor two at least. Furthermore, the approach of Robert would allow to include volume scattering (a lens with embedded scattering particles) in a very natural way and potentially also reduce the simulation time for these systems.

The interplay between microscopic scattering and refraction or reflection by macroscopic freeform surfaces offers new, largely unexplored, opportunities and solutions of diverse technological problems.

Details and results of these work packages can be found at the website of the project: https://www.freeformscatteringoptics.com/ and at the website of the Optics group: https://www.win.tue.nl/~martijna/Optics/.


Maikel


Lotte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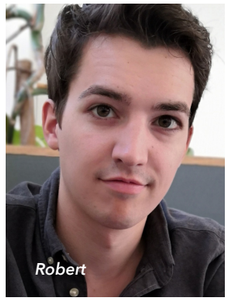

Robert

ILI Top Publications

Saeed, A., Salim, F.D., Ozcelebi, T., Lukkien J.J. (2021/1), Federated Self-Supervised Learning of Multisensor Representations for Embedded Intelligence, *IEEE Internet of Things Journal, vol. 8, no. 2, pp. 1030-1040*

Liu, Q., Cheng L., Alves R., Ozcelebi, T., Kuipers, F., Xu G., Lukkien J.J., Chen S. (2021/4), Cluster-based flow control in hybrid software-defined wireless sensor networks, *Elsevier Computer Networks Journal, v. 187*

Filosa, C., ten Thije Boonkkamp, J.H.M. and Ijzerman W.L. (2021), Inverse ray mapping in phase space for two-dimensional reflective optical systems, *Journal of Mathematics for Industry 11, issue 4*

Romijn L.B., Anthonissen M.J.H., ten Thije Boonkkamp, J.H.M. Ijzerman W.L. (2021), The generating-function approach for double freeform lens design, *Journal of the Optical Society of America A, 38, issue 3, 356 – 368*

Romijn L.B., Anthonissen M.J.H., ten Thije Boonkkamp, J.H.M. Ijzerman W.L. (2021), An iterative least-squares method for generated Jacobian equations in freeform optical design, *SIAM Journal on Scientific Computing 43, issue 2, B298 – B322*

Van Duijnhoven, J. Aarts M.P.J., Kort H.S.M. (2020/12), Personal lighting conditions of office workers: An exploratory field study, *Lighting Research and Technology*

Van Duijnhoven, J., Aarts M.P.J., van den Heuvel E.R., Kort H.S.M. (2020/12), The identification of variables influencing personal lighting conditions of office workers, *Lighting Research and Technology*

Böhmer, M. N., Valstar, M. J., Aarts, M. P. J., Bindels, P. J. E., Oppewal, A., Someren, E. J. W., & Festen, D. A. M. (2021). Shedding light on light exposure in elderly with intellectual disabilities. *Journal of Intellectual Disability Research, 65(4), 361–372.*

Druijff-van de Woestijne, G.B., McConchie, H., de Kort, Y.A.W., Licitra, G., Zhang, C., Overeem, S.,Smolders, K.C.H.J. (in press). Behavioural biometrics: using smartphone keyboard activity as a proxy for rest-activity patterns. *Journal of Sleep Research*

Kompier, M., Smolders, K.C.H.J., & Kort, Y.A.W. de (in press). Abrupt light transitions in illuminance and correlated colour temperature result in different temporal dynamics and interindividual variability for sensation, comfort and alertness. *Plos One.*

Peeters, S.T., Smolders, K.C.H.J. & de Kort, Y.A.W. (in press). Less is more? Effects of more vs less electric light on alertness, mood, sleep and appraisals of light– A field study in an operational office. *Journal of Environmental Psychology.*

Ru, T, Smolders, K. C. H. J., Chen, G. & Zhou, G., de Kort, Y. A. W. (in press). Diurnal effects of illuminance on performance: Exploring the moderating role of cognitive domain and task difficulty. *Lighting Research and Technology.*

Kompier, M., Smolders, K.C.H.J., & Kort, Y.A.W. de (2020). A systematic literature review on the rationale for and effects of dynamic light scenarios. *Building & Environment, 186, 107326, 12pp.*

Peeters, S.T., Smolders, K.C.H.J., & Kort, Y.A.W. de (2020). What you set is (not) what you get: How a light intervention in the field translates to personal light exposure. *Building & Environment, 185, 107288.*

Schlangen, L.J.M., Price, L.L.A. (2021). The Lighting Environment, Its Metrology, and Non-visual Responses, Frontiers in Neurology 12(235). *https://www.frontiersin.org/article/10.3389/fneur.2021.624861*

Schlangen, L.J.M. in a team of 85 international co-authors (2020), Dark and Quiet Skies for Science and Society Report and Recommendations On-line Workshop. United Nations Office for Outer Space Affairs, International Astronomical Union, Instituto de Astrofísica de Canarias, NOIRLab, 2020; Chapter 5 Bio-environment Report; pp. 92-117. *https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf*

"It all starts with imagination. If you can't imagine the future, you will not be able to create it!"

INTERVIEW | DAAN ROOSEGAARDE AND ANJA DIELEMAN (WUR) BY MICHIEL DE BOER (MOESASJI)

Dreamscape GROW, an instigator of (light) innovation

PHOTOS: ROB'S REALITY

"Light is communication, a language, communication at 300.000 km per second, what a power!" says Daan Roosegaarde. "For me this has an imaginative value, a poetic quality. We humans are very sensitive to light. So are plants. And since GROW, I have learned that you can even design light-recipes. You can 'cook' with light. That is a power we must use, if you ask me!"

THE PLACES THAT FEED US

Artist, designer and futurist Daan Roosegaarde has a clear fascination for light. With his latest projects GROW and Urban Sun he explores new ways of using light. And this has overwhelming outcomes. GROW has reached over 650 million viewers worldwide.
Roosegaarde: "When Rabobank CEO, Wiebe Draaijer, contacted me for their artist-in-residence program and asked me if I was interested in looking into our food and food production as a theme, I was immediately intrigued by the question. We started visiting the places that feed us. The huge spaces, empty lands in The Netherlands where crops grow. So beautiful. That's where the first ideas emerged. I foremost wanted to make an artwork that would display the beauty of these places."

MESMERIZING QUALITY

Roosegaarde and his team found an enthusiastic leek grower and turned his field of 20.000 square meters into a dreamscape of mesmerizing blue and red lights, slowly moving and shimmering over the tops of the crops.
Roosegaarde: "We stood for days on those meadows to get the installation right. And the result was astonishing. Dennis (the farmer) couldn't stop looking at this dance of light on his fields. The installation distributes precision lighting, focused horizontally in a controlled area, over the leek plants, causing no light pollution. We used types of blue and red light for their specific beneficial qualities to crop growing. And we used ultraviolet light that triggers the plant defense mechanisms, reducing the need for pesticides."

NEW TERRITORY

"I discovered the world of light-recipes in discussions with scientist Anja Dieleman from the Wageningen University & Research. It is amazing how light is increasingly used to enhance growing and plant productivity. And we are only at the beginning of discovering this new world. I am not stating that our GROW installation is a practice that farmers can start using tomorrow. This is a work of art, a new perspective, an invitation to explore a new territory."

WORLD TOUR

GROW, carefully captured in a 3-minute movie (you can watch it at studioroosegaarde.net), got millions of views around. The agricultural world could appreciate the project as Roosegaarde received positive reactions from France to Peru and from Dubai to Australia. Roosegaarde:

"GROW will be traveling the world in the upcoming years. And it will feature various design-based light-recipes for different species of crops and therefore have different appearances. I am very curious what it will bring."

VIRUS CLEANER

GROW was also a steppingstone to Roosegaarde's latest project Urban Sun, a new dreamscape that is getting an equal amount of attention worldwide. Urban Sun is an artificial sun that cleans (public) spaces of the coronavirus by using a strong 222nm (far-UVC) light beam that is safe for the human skin and eyes. It acts as an additional layer of protection to current government rules and aims to inspire hope. When Roosegaarde stumbled upon this scientific discovery of David Brenner (2018) he immediately teamed up with scientists, virus experts and designers and designed the very first Urban Sun. Urban Sun's initial launch took place alongside Rotterdam's most iconic landmark, the Erasmus Bridge. The project debuts as a movie with the potential for worldwide future exhibits.

IMAGINE

Roosegaarde: "These two projects are the first in the series of DreamScapes. Imaginative artworks that act as dreams and turn into reality for a new and better future. I don't consider myself as a scientist or an engineer of the future, but as a designer and storyteller. Often people display innovation as a difficulty. I find that a misconception. We can innovate today, every day! And it all starts with imagination. If you can't imagine the future, you will not be able to create it!"

ANJA DIELEMAN (WUR):

LED provoked a complete new field of research

Art and science

"What Roosegaarde does perfectly is portraying the beauty of agriculture. GROW refers to a major development in agri-culture, of using light to enhance crop growth", Dieleman states.

Lighting for plants

"Over the last 40 years, we have been using the typical white-green light of high-pressure sodium lamps in greenhouses, originally developed for street lighting. However, these lamps are not very energy efficient," Anja Dieleman explains. "Therefore, over the last decade the interest in LED lighting has increased considerably. Another advantage is that LEDs can give any colour that is desired for an optimal crop growth. With that, a completely new field of research has emerged, in which we just start to discover the effects of light colours on plants".

Sustainable food production

"Crop growth depends on a lot of factors and light is just one of them. There is also temperature, CO2-level, substrate, irrigation, et cetera. In finding a perfect growth-recipe for a plant we have to take into account all those aspects. That allows us to produce a sustainable crop, with a minimal amount of water, energy and pesticides.

Inspiration

The Netherlands have always pioneered in getting the most out of every square meter. This places our country and agricultural community at the forefront of technological developments in enhancing plant productivity and product quality. I have had a number of discussions with Daan Roose-gaarde on the developments and technologies in our industry, a general back-ground of the current and future use of lighting in horticulture. It is nice to have been a source of inspiration for such an impactful artwork."

Anja Dieleman
Sr. Researcher Physiology at Wageningen University & Research

WIL SCHILDERS | DEPARTMENT OF MATHEMATICS AND COMPUTER SCIENCE

The AI-TWILIGHT project

AI powered Digital twin for lighting infrastructure in the context of front-end Industry 4.0

In the past two and a half decades, owing to the development of high efficiency colour and white LEDs suitable for illumination purposes, a "LEDification" process has taken place that dramatically changed the entire lighting industry and turned it into a solid-state lighting (SSL) industry.

LED light sources are technologically more complex, with properties much less understood by end-users than the main features of conventional light sources. Besides, every LED type has its own, specific features with many possible design parameters. Designing LED luminaires has become much more challenging than the design of luminaires before the SSL era, involving mechanical, optical, electrical/electronic and thermal design. In terms of LED operation, these domains have strong, mutual influence. The effect of the temperature is the most important issue to handle: not only the amount and the spectrum of the emitted light depends on the temperature of the active region of an LED device, but the expected useful lifetime is also strongly affected. In general, the higher the temperature, the lower the efficiency and the shorter the expected product lifetime.

Figure 1 summarizes the scope of AI-TWILIGHT, as well as the leap forward compared to the DELPHI4LED project. Compared to the latter project, several renowned German partners have joined the consortium.

From the foregoing it will be clear that the design of LED luminaires needs a multi-domain approach and due to its complexity, it cannot be performed without strong simulation support. The approach must include proper multi-domain models and simulation tools that are able to use these models. To make the computer-supported LED luminaire design process a daily practice at luminaire makers, complete design and simulation workflows (similar to the IC design flows used in microelectronics for decades) are needed. This has already been recognized by a former European consortium of large and small companies from the SSL industry and other partners within the Delphi4LED H2020 ECSEL project *(https://www.delphi4LED.org)* led by Signify. The project proposed the first, test based, generic Spice-compatible chip level multi-domain LED model, a compact thermal model of LED packages and modelling methodologies of LED luminaires along with a complete, LED luminaire development workflow. Using this workflow, benefits during LED luminaire development (such as reduction of costs and time-to-market) were proven through actual industrial designs. Using the terminology common in the Industry 4.0 context, the aforementioned simulation models are multi-domain Digital Twins of the LEDs and luminaires.

The solid-state lighting market is now taking another leap by addressing connected lighting, digitisation and Industry 4.0. In order to satisfy the corresponding demands of the SSL industry, the conventional approach of classical physics-based models fitted to the necessary amount of test data has to be replaced by new paradigms. The primary reason is that the cost of obtaining sets of LED lifetime test data covering 6,000-10,000 hours of operating time for a representative LED population is impedingly high. The new, innovative approach employed in the AI-TWILIGHT project is based on applying modern mathematical and artificial intelligence methods to drastically reduce the amount of test data needed and to widen the predictive power of the LED multi-domain models.

The proposed LED models completed with ageing and the models of LED driver modules will be turned into real Digital Twins, applicable not only for the design phase but also usable during the in-field operation of an LED product in order to represent its true behaviour under real-life application conditions, according to the luminaires' actual mission profiles. Combined with cyber physical system approaches (sensors and communications interfaces) the LED products can learn their own mission profile history. With this data fed into the LED Digital Twins with enhanced predictive capabilities, AI-TWILIGHT aims to create Self-Learning Digital Twins (SLDT) of LED-based luminaires that can be used for health monitoring and predictive maintenance purposes. The project, led by Genevieve Martin of Signify, combines world leading industry partners representing the product and the application sides of the value chain. The academic partners focus on the development of the Digital Twins and its self-learning capabilities and the methodology, how to derive the parameters from data sets.

AI-TWILIGHT will start on May 1, 2021, and a website will be available soon.

ILI SHORT

Mariëlle Aarts elected as new member of the Daylight Academy Steering Committee

The Daylight Academy (DLA) is an international membership organization initiated by the Velux Stiftung and bringing together scientists from all backgrounds, architects, engineers and other professionals involved in daylight research or with a strong interest in daylight related topics. By organizing networking events, supporting collaborative activities and providing a platform for connection and exchange among the different disciplines and fields of expertise working on daylight, the Academy wants to initiate cooperation, innovation and new knowledge. Such inter-disciplinary exchange has the potential to be a catalyst for creativity, novelty and development. The aim is to strengthen daylight research and its applications for the benefit of humanity and nature.

Mariëlle Aarts rewarded for Exemplary Research 2020

The research of ILI Core team member Mariëlle Aarts (Building Lighting) was rewarded for *"Exemplary Research 2020"* by the Department of the Built Environment. You can watch her pitch starting at 22 minutes 45: *https://www.youtube.com/watch?v=7eLMV_uRJ-Q*

MARIEKE VAN BEURDEN | PROGRAM DIRECTOR
HUMAN VITALITY & TECHNOLOGY TU/E

Opening Workplace Vitality Hub at the High Tech Campus

FITT, a research and innovation program for vitality in the working environmentstrategy that ensures office workers' comfort

Nowadays, where we often spend many hours in front of our screens, a vital working environment is not always a given. For employers in the Brainport region, a vital environment is becoming increasingly important to attract and retain people and to prevent absenteeism. Technology plays an important role here, which is why expert partners Fontys, imec, TU/e and TNO (FITT) are developing a research and innovation program for vitality in the working environment. FITT, together with the High Tech Campus, is working on the realization of the Workplace Vitality Hub (opening June 2021). This hub will be located in a building where expectations for a healthy working environment for users have been set very high. Upon completion, it will meet the Well Gold standard of the International Well Building Institute.

BRAINPORT THE MOST VITAL

In the region, vitality and a healthy lifestyle are important themes on which large and small companies collaborate. An excellent example of this is the PSV-Brainport partnership in which Philips, ASML, VDL, Jumbo, Swinkels and the High Tech Campus, together with PSV aim to increase the vitality of their employees and, by extension, the wider population. The initiative of the business network of the Oranje-Rood Hockey Club with many regional (SME) companies, which specifically focusses on vitality, also shows that the subject is of essential importance to many sectors and types of organizations.

On the one hand, this is in line with the need for companies in the region to attract and retain (technical) talent, and therefore to profile themselves as a good employer. On the other hand, the attention for the vitality theme is driven by the transition from Healthcare to Care for Health. Prevention as a means to reverse the increase of chronic diseases and in doing so, keep costs under control. More exercise, mental resilience and a healthy diet are a few of the key ingredients needed. Evidently, the importance of a healthy lifestyle has only increased over the past year.

INTERACTION BETWEEN HUMANS AND BUILDINGS

The core of the FITT vision is a future working environment where intuitive technology encourages more exercise, supports people to get the best out of themselves, connects people and thus prevents health problems and increases productivity. The challenge here is to establish an optimal interaction between people and their working environment. We achieve this by making smart use of sensor data and AI. Through a digital twin, information about the properties of a building, such as lighting, ventilation and air quality is combined with information in the personal twin about the characteristics, personal motivations and references

of the people in that building. Through user-centric data representation and closed-loop coaching, people receive personalized and contextualized nudges to support their vitality.
When it comes to health, light obviously plays an important role in the office environment. For example, studies are conducted to determine how a person's light requirements can be adjusted based on key strike patterns and how personalized light can stimulate alertness and concentration.

THE INNOVATION CYCLE

Validating and further developing innovations requires an environment where tests can be carried out at a relevant scale under controlled circumstances. The goal of the Workplace Vitality Hub is to make validated vitality solutions and the underlying technologies available to public and private parties in the region and beyond. To this end, a sequence of activities is specified that must be optimally aligned:

Let's create the healthy workplace of the future together!

*1. **Experimenting:** through the knowledge and technology buildup at the FITT partners, vitality concepts are considered to determine which have reached the right stage to be included in the real-life setting of the Hub.*

*2. **Embedding:** combining input from the FITT partners and other parties from the region in a way that is mutually compatible and functions within the high-quality infrastructure of the Workplace Vitality Hub, is a time-consuming but essential step. This ensures that data flows and Privacy-by-Design, for example, are up to par during further upscaling, to enable a closed-loop response to available information.*

*3. **Roll-out:** scaling up from a few prototypes to semi-products that can be deployed in conjunction with businesses across the entire floor, or even end users' locations. Tests are carried out at scale to see whether the developed solutions also have a demonstrable effect, and new knowledge questions are formulated.*

*4. **Valorizing:** working solutions are marketed with parties from the region, to make sure that they become available to end users. There is evidence demonstrating that investing in the solution actually pays off.*

*5. **Translating:** the solutions can also be used in other environments. For instance, concrete interest is already being shown in whether and how these concepts can be translated to the factory floor and the home environment.*

*6. **Experiencing:** a location where the resulting solutions can be experienced will be needed to increase visibility and promote participation from the region.*

This makes the Workplace Vitality Hub a network that brings together all stakeholders with different interests and roles; in their role as an employer, as a supplier of technology / infrastructure in office environments, as a provider of innovative solutions and vitality programs in the working environment.

ILI SHORT

Walsh Weston Award 2020 from the Society of Light and Lighting

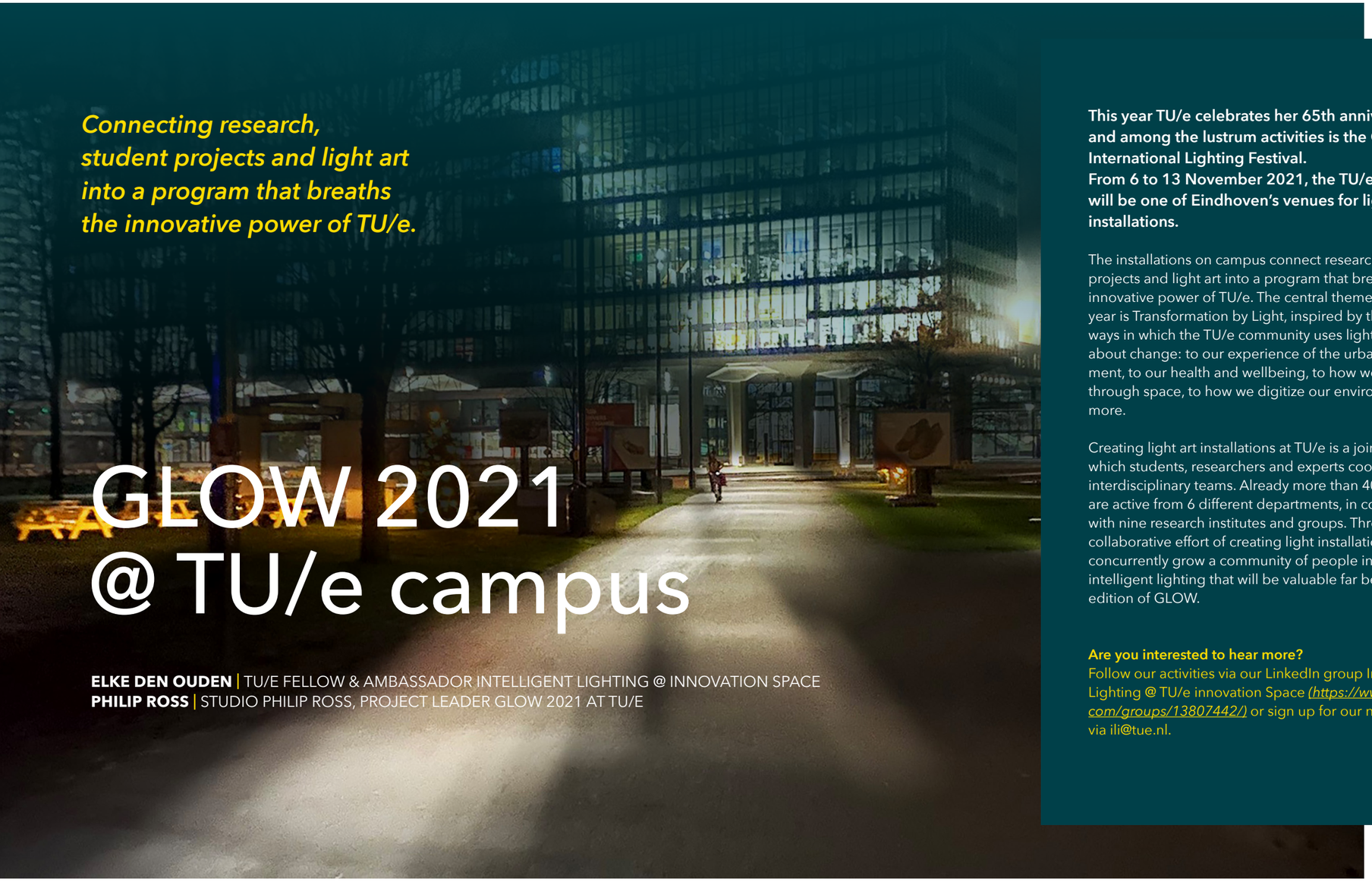
The article "Teasing apart office illumination: isolating the effects of task illuminance on office workers" in Lighting Research and Technology, 52 (8), 944-958 has won the Walsh Weston Award 2020 from the Society of Light and Lighting. First author is Adrie de Vries, ILI PhD candidate. Co-writers are Jan L. Souman and Yvonne de Kort.

Task illuminance is one of the most used parameters in office lighting design and is often used as a 'single number criterion' to verify that a lighting design meets the requirements. Although other parameters, such as wall luminance, are often highly correlated with task illuminance, not taking these explicitly into account means critical user criteria such as comfort and satisfaction are left to chance. In this study, we investigated the effect of varying desk illuminance (150 to 1500 lx) while keeping wall luminance constant, isolating the effects of illuminance on the desk and eye on office users' overall perception of the space, their mental state and their performance (visual and cognitive). While both visual acuity (paper-based) and perceived brightness increased significantly with higher desk illuminance, the room's attractiveness did not. Even though illuminance at the eye increased considerably with desk illuminance (from 118 lx to 796 lx), only minor effects were found on subjective alertness and cognitive performance. This suggests that focusing on horizontal task illuminance as a design parameter is appropriate in view of visual acuity but has little to no effect on the space's attractiveness, nor on cognitive performance or mental state of the office worker.

News from The LIGHTCAP project

The LIGHTCAP project intends to contribute to the body of scientific knowledge on the relationship between light and Cognition, attention and perception (CAP), by preparing the next generation of experts studying truly intelligent, human-centric lighting. This work will result in a new generation of interdisciplinary researchers able to grasp the implications of their findings for other fields.

LIGHTCAP is now running full throttle, with all 15 PhD positions filled. We had a great 3-day first training event with 12 lectures from international experts on topics ranging from fMRI to field studies. The training events are generally also open to researchers outside the consortium, so if you are interested in joining, contact Laurens Schrijnemakers, or visit our website: *https://lightcap.eu/*



Connecting research, student projects and light art into a program that breaths the innovative power of TU/e.

GLOW 2021 @ TU/e campus

ELKE DEN OUDEN | TU/E FELLOW & AMBASSADOR INTELLIGENT LIGHTING @ INNOVATION SPACE
PHILIP ROSS | STUDIO PHILIP ROSS, PROJECT LEADER GLOW 2021 AT TU/E

This year TU/e celebrates her 65th anniversary and among the lustrum activities is the GLOW International Lighting Festival.
From 6 to 13 November 2021, the TU/e campus will be one of Eindhoven's venues for light installations.

The installations on campus connect research, student projects and light art into a program that breaths the innovative power of TU/e. The central theme for this year is Transformation by Light, inspired by the many ways in which the TU/e community uses light to bring about change: to our experience of the urban environment, to our health and wellbeing, to how we move through space, to how we digitize our environment, and more.

Creating light art installations at TU/e is a joint effort in which students, researchers and experts cooperate in interdisciplinary teams. Already more than 40 students are active from 6 different departments, in collaboration with nine research institutes and groups. Through the collaborative effort of creating light installations, we concurrently grow a community of people interested in intelligent lighting that will be valuable far beyond this edition of GLOW.

Are you interested to hear more?
Follow our activities via our LinkedIn group Intelligent Lighting @ TU/e innovation Space *(https://www.linkedin.com/groups/13807442/)* or sign up for our newsletter via ili@tue.nl.

ILI SHORT

Series of webinars Smart-Space project

The SMART-SPACE project partners organized a series of three short webinars to learn more about the potential of Smart Public Lighting. What could smart public lighting mean for your city? How will it change your cities public lighting policy? How to engage citizens and stakeholders in the design and the evaluation of the public lighting? How can we, by the use of a smart light system, maximize the carbon reduction while keeping citizens safe and comfortable? Elke den Ouden and Rianne Valkenburg both were speakers on these events.

The first two webinars have already taken place in April, but you can join the last free webinar on Thursday 3 June from 10h:00 till 11h30. The title is Creating a smart light system: Some lesson learned from the SMART-SPACE project

For program, updates and registration look at https://www.nweurope.eu/projects/project-search/smart-space-smart-sustainable-public-spaces-across-the-nwe-region/events/series-of-webinars-invitation/

ILI PhD theses

Lining up for innovation: Exploring alignment dynamics of innovation across boundaries
Wouter van Galen (IE&IS, ITEM-group) 19 May 2021. Supervisors: Sjoerd Romme, Bob Walrave, Sharon Dolmans and Elke den Ouden.

JEAN-PAUL LINNARTZ | SIGNAL PROCESSING SYSTEMS GROUP (ELECTRICAL ENGINEERING)

When Human Centric Lighting gets Personal

The wealth of insights in how light influences our wellbeing, our comfort and our productivity is still barely exploited in lighting control systems. Can we make quantified models of how humans experience light, such that automated systems can interpret these? Future smart lighting systems may predict what the impact of a certain light recipe will be, by tracking a digital model of the user. That would allow an optimization across various aspects, such as a healthy trade-off between desired alertness, comfort and sleep quality at night. This was the vision at the start of the Optilight project. Now that Optilight is reaching its final stage, ILI magazine reflects on the insights generated in the project.

"Human behavior and experience cannot simply be described by a set of mathematical equations." During the early phases of the project that was a frequently heard critique on the ambition of Optilight. However, project leader prof. Jean-Paul Linnartz comes from a research area where mathematical models of human perception are commonly used in algorithms and where this has led to great innovations: taking a smartphone JPG selfie, listening to MP3 Internet radio, or watching Netflix would not have been possible without elaborate models of how people perceive music and movies.

By allowing some distortion where an exact reproduction is not perceptually relevant, it became possible to carry movies over wireless links with limited capacity. But to use perceptual models for lighting control, multiple scientific challenges remain: firstly, there is a huge variability among different people and secondly, sensor data come with large inaccuracies, particularly if privacy and comfort of the user prohibits intrusive observations. Monitoring full sleep-wake patterns in daily life would be far too obtrusive, even if we refrain from using the clinical standards. Thirdly, light's effects on visual experience, on alertness, and on sleep all follow temporally, spatially, and spectrally different pathways.

The combination of uncertainty in observations in real-world systems but having a wealth of insights from studies in controlled lab conditions, can well be addressed by scientific methods from the field of statistical signal processing. To build upon existing knowledge, Optilight has successfully tested the feasibility of creating a "digital twin" of the human that adheres to validated chronobiological principles and that on a day-to-day basis learns about an individual's biological clock phase and their chronotype. This digital twin was used to predict and to anticipate the impact of various light recipes.

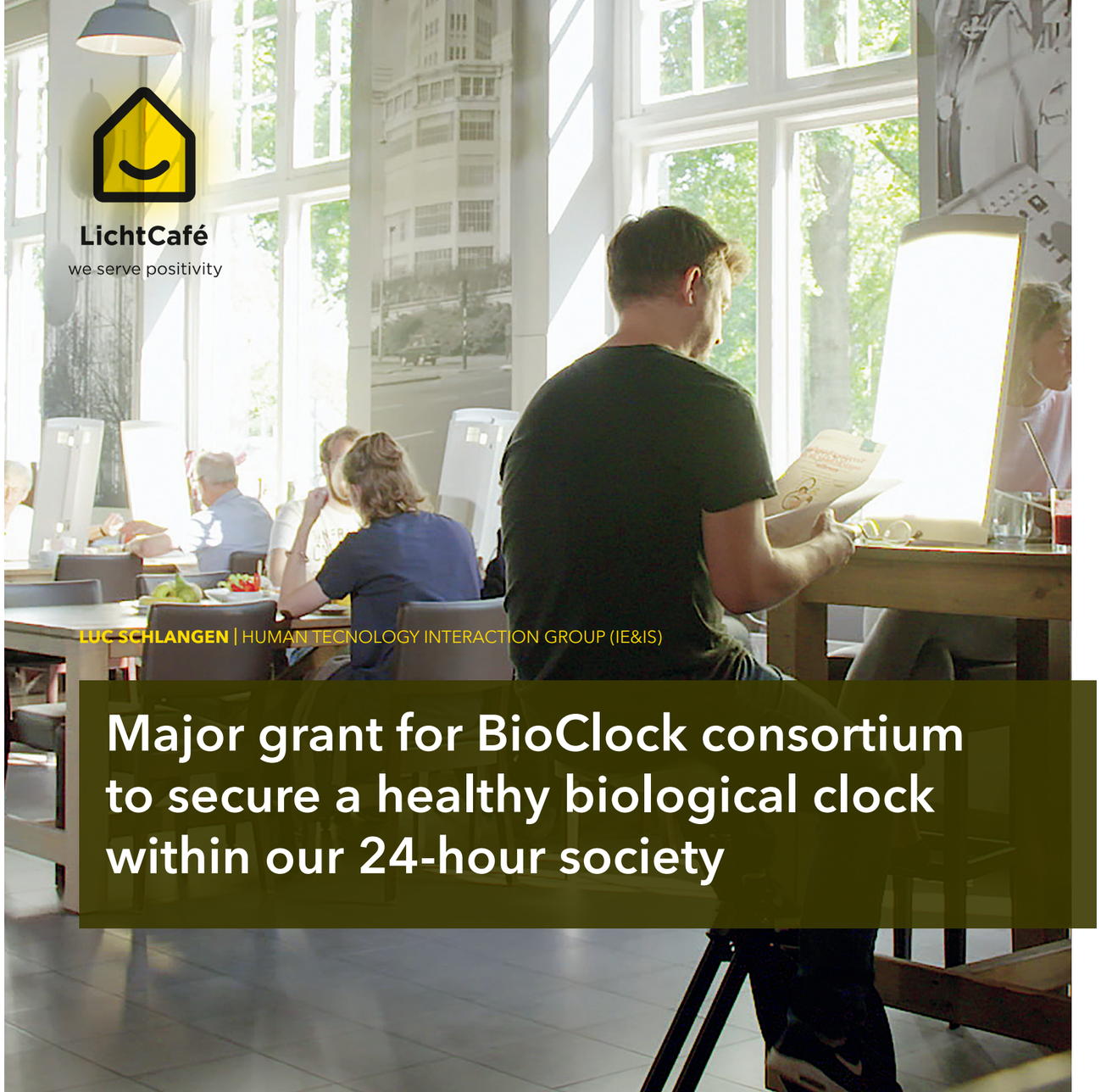
Future light recipes are tested on the digital model (instead of the real person) and this allows to select optimal light recipes for the individual based on his/her particular needs and his/her responses and sensitivity to light input.

In the past years, the lighting research community has gained much more confidence in the use of mathematical circadian models, according to Dr. Chara Papatsimpa. We now see that major journals such as IEEE Transactions on Biomedical Engineering and Nature Scientific Reports accept theoretical work to predict the effects of smart lighting control. A key breakthrough is that the mathematical abstraction lends itself much better for use in lighting control algorithms than a repertoire of user tests under controlled lab conditions.

Results up to now clearly show that a "one size fits all" approach to Human Centric Lighting cannot fully deliver the significant benefits that improved lighting may yield. What works very well for one individual may be counter-productive for others. Prof. Yvonne de Kort initially was skeptical about the use of mathematical models for predicting human behavior. "But we see that the biological clock models can be powerful in explaining differences in the effect of light recipes on sleep timing. Our analyses for instance show that a light recipe's positive effects on a specific subset of participant can be counterproductive for other participants. This should now motivate us to develop similar models for predicting also acutely alerting effects, and for predicting users' preferences in terms of the visual experience".

A lesson learned is that Human Centric Lighting needs to be personalized. By taking specific preferences and chronobiological parameters of the individual into account light recipes become significantly more effective. But as the impact of light exposure is a slow and subtle processes, the effects on the specific users are preferably tracked over longer periods. A second important lesson learned is that research designs in psychological research can be tuned such that they more easily allow for the subsequent development of mathematical abstractions.

Within ILI, the expertise on human interaction, and signal processing, the role of light in buildings and the architecture of lighting control systems is available. This created a unique basis for a project like Optilight. For Jean-Paul Linnartz, also a research fellow at Signify, the Optilight insights are a clear example of combining biological knowledge from the lighting domain with smart self-learning algorithms. Traditionally, the research area of statistical signal processing allows the use of knowledge and insights from the lighting domain. It avoids that algorithms have to start building artificial intelligence from scratch. In lighting, hundreds of papers describe the impact of light under various conditions, it would be naïve not to use that expertise explicitly in the algorithms. In Optilight, the team found out how to exploit existing knowledge from chronobiology to steer circadian effects with light. Optilight, funded by NWO and Signify made scientifically recognized steps towards using these in advanced lighting control.



LUC SCHLANGEN | HUMAN TECNOLOGY INTERACTION GROUP (IE&IS)

Major grant for BioClock consortium to secure a healthy biological clock within our 24-hour society

A Dutch research consortium received a 9.7 million euro grant for a six-year research program that aims to restore and enhance the health of the biological clock in humans and ecosystems.

The daily light-dark cycle has resulted in the evolution of a biological clock that allows organisms to generate a 24-hour (circadian) rhythmicity in their physiology and behavior. Light exposure, food intake and physical activity are important cues for regulating the precision, timing and stability of the biological clock, thus ensuring its adaptation and synchronization to the natural environment across the seasons. Our modern 24-hour society is highly disruptive for the internal biological clock: (i) work times, social schedules, and sleep patterns are increasingly variable and irregular, (ii) we spend very little time outdoors under natural daylight, and (iii) commonly adopt artificial light in our evenings and nights. This increases the risk of diseases such as depression, cancer and diabetes. Moreover, it compromises our sleep, cognitive functioning, and threatens biodiversity in our natural environment.

Numerous studies have identified biological clock disruption as a clear threat to both public health and entire ecosystems. Night shift work is known to increase the risk of type 2 diabetes, certain types of cancer, immune dysfunction and cardiovascular disease. Moreover, light usually is the main synchronizer of the internal biological clock and in sensitive ecosystems even very low levels of light pollution can be a threat to biodiversity.

The BioClock consortium will foster a sustainable living environment in which a healthy biological clock function is preserved within humans and ecosystems, thus promoting health, quality of life and biodiversity. The consortium is highly interdisciplinary and includes molecular biologists, neuroscientists, ecologists, clinicians, psychologists as well as partners from education, local governments, policy makers, environmental organisations and industry.

The main aims of the consortium are to:

- Promote a healthy biological clock across society and in particular populations at risk, such as the aged and young, students and shift workers. Activities include the development of innovative lighting strategies, activity- and diet-related lifestyle interventions, personalised work schedules, and education programmes
- Improve clinical outcomes in patients throughout the healthcare system, for instance by optimizing time of treatment, by designing clock-enhancing tools, by augmenting light-dark cycles within intensive care units and by developing chrono-therapeutic interventions
- Develop sustainable, non-invasive strategies to preserve clock function in plants, insects, animals and ecosystems in urban, rural and natural areas, and protect biodiversity in the presence of light pollution.

Within the consortium the TU/e researchers Yvonne de Kort and Luc Schlangen will collaborate with the mental healthcare clinics in the Eindhoven and Leiden regions (GGzE and LUBEC) to implement and optimize light therapy and chronotherapeutic treatments as a means to enhance recovery, well-being and sleep in depressed patients.

The BioClock consortium will be funded by the program of the Dutch National Research Agenda (NWA) of the Dutch National research council (NOW). The consortium consists of eight universities and dozens of members from industry and the public and semi-public sector such as RIVM, municipalities, environmental organizations and occupational health services. The consortium coordinators are LUMC researchers Joke Meijer and Laura Kervezee, and the activities will start in the second half of 2021.

ILI New employees

HOSSEIN MAHDIAN
PDEng Software Technology program (M&CS)

I received my Bachelor's and Master's degrees in Information Technology in Iran. In my master's thesis, I worked on a machine learning problem. After graduation, I worked as a software developer in enterprise software companies mainly in the banking and capital market industry. During this period, I grew interests in software architecture, design and tried to keep myself up to date by following the state of the art topics in computer science including IoT and machine learning.

During the first year of my PDEng program, I participated in three in-house projects related to machine learning to gain more experience in applying the knowledge of system architecture and design in the projects. For the final project, I am working on the IntelLight system design project which includes designing an intelligent lighting system using IoT and machine learning.

After PDEng, I want to continue my journey in the design and development of intelligent software-based systems.

MYRTA GKAINTATZI MASOUTI
PhD LIGHTCAP project, Building Lighting (BE)

I started my academic journey by studying civil engineering in Aristotle University of Thessaloniki, Greece. From that, I developed an analytical way of thinking and a curiosity for designing sustainable buildings. After finishing my degree in Greece, I moved to Aarhus in Denmark where I studied how different indoor climate parameters, such as daylighting, electric lighting, thermal comfort and air quality, affect occupants' satisfaction, health and performance.

Shortly after completing my masters, I started working as a sustainability engineer, where my job was to make sure that daylight, energy use and thermal comfort are considered during architectural competitions. At the same time, I started a position as a research assistant at the lighting design group of Aarhus University. This experience made me passionate about research and made it clear for me that my next step would be a deep dive into lighting research by starting a PhD.

With this PhD, I hope to contribute with my work to new findings in the field of lighting and learn more about the effects on people's health and well-being.

ALI MAHMOUDI
PhD IntelLIght project (M&CS)

I started my academic journey by obtaining a bachelor's in mechanical engineering at the Amirkabir University of Technology. During this period, I focused on dynamical systems and, in particular nonlinear dynamics of bipedal walking.

Afterward, I studied mechatronics engineering for my master's at the University of Tehran. During my master's studies, I participated in several research projects ranging from robotics to artificial intelligence. For my thesis, I designed a learning algorithm to classify sequentially arriving data based on probabilistic neural networks.

Recently, I have started my Ph.D. at the Eindhoven University of Technology. My project is a part of the IntelLight project in collaboration with Signify. This project aims to use artificial intelligence for indoor context recognition, providing the environment with appropriate lighting while being robust and privacy-preserving.

ÖZGE KARAMAN MADAN
PhD Building Lighting (BE)

I obtained my Bachelor's degree in Architecture from Middle East Technical University (Ankara) and worked for two years as an architect in an architectural office. I obtained my Master's degree in Building Science at the same university while working as a research assistant. In my thesis, I worked on energy-efficient occupancy-based lighting control systems focusing on the improvement of occupant satisfaction.

As of February 2021, I am a PhD student in the Department of Built Environment as a member of Building Lighting Group, supervised by Mariëlle Aarts and Juliëtte van Duijnhoven. I am interested in lighting and lighting design and their effects on humans and architectural design. In my PhD project, I want to explore more the relationship between light, space and humans to understand the experience and perception of space.

ANTONIO BARION
PhD Computational Illumination Optics group (M&CS)

After obtaining my BSc degree in Mathematics at the University of Trento (Italy), I worked for six months as an intern in the Reasearch and Development department of Roechling (a company working in the automotive sector). This experience consolidated my interest in Applied Mathematics. In November 2020 I completed my MSc degree in Applied Mathematics at the TU Delft. The focus of my thesis was the numerical modelling of the healing process of skin grafts after burn injuries.

In January 2021 I joined the Computational Illumination Optics group at the TU Eindhoven. Aim of my project is to gain a better mathematical understanding of aberrations and how to treat them in the context of inverse methods. Currently I am focusing on the application of Lie methods to describe aberrations of third order, or higher, in optical systems and on how to relate them to more traditionally described aberrations, e.g. the Seidel aberrations.

Retirement Evert van Loenen

ILI Core team member Evert van Loenen, from the Building Lighting group and specialized in Smart Lighting, has retired since January 2021. At his online farewell party many colleagues were present to thank him for his work and to wish him all the best.

Tanir Ozcelebi guest editor MDPI Electronics Journal

Tanir Ozcelebi is guest editing a special issue of the MDPI Electronics journal. The topic of the special issue is *"Intelligent IoT Systems"*. You can find more information at https://www.mdpi.com/journal/electronics/special_issues/IIS_electronics

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