Intelligent Lighting Institute | Edition 11, May 2019

ILIMAGAZINE

> 10 YEARS LIVING LIGHT LABS

> PRIVACYPRESERVING CONTEXT RECOGNITION

> ATLAS MUSTN'T BECOME AN EXPERIMENTAL MAZE

> CAN WE SCALE UP WIRELESS LIGHTING CONTROL?

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 2019 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 extremely pleased to present to you the 11th edition of our ILI Magazine. Since its last edition in November 2018 much has happened and I hope that after reading the various contributions in this magazine you will once again agree with me that many exciting and promising developments have been happening.

Amongst others you will be informed about some of the latest relevant developments (in historical perspective) in our various R&D programs and our R&D infrastructures annex Living Labs basically forming the basis of our new scientific discoveries & (technological) innovations related to Light & Lighting for various application domains, in particular Health.

You will also get a flavor of the 2018 edition of ILIAD, our annual public outreach event as well as initial information on its 2019 edition.

Pleasant reading!

ILI PhD theses

Intelligence in an office lighting system Xin Wang. December 11, 2018. Advisors: prof.dr.ir. J.P.M.G. Linnartz, dr.ir. T.J. Tjalkens

Experiments on the physics of pulsed plasma jets Marc van der Schans, December 19, 2018 Advisors: prof. dr. ir. W.L. Ijzerman, prof. der. ir. G.M.W. Kroesen, dr. ir. S. Nijdam

Modelling visibility of temporal light artefacts Stroboscopic visibility measure – understanding how people experience LED-light fluctuation Małgorzata Perz, February 5, 2019. Advisors: prof. dr. I.E.J. Heynderickx, dr. I. Vogels, dr. Dragan Sekulovski (Signify)

PLANNED DEFENSES:

- Charikleia Papatsimpa
  Department of Electrical Engineering, May 27, 2019
- Christel de Bakker
  Department of Built Environment, June 4, 2019
- Sanae Chraibi
  Department of Built Environment, June 6, 2019

"To the best of our knowledge Atlas is globally the biggest indoor Living Lab"
Ingrid Heynderickx
Scientific Director

INGRID HEYNDERICKX | SCIENTIFIC DIRECTOR

ILI's Living Labs

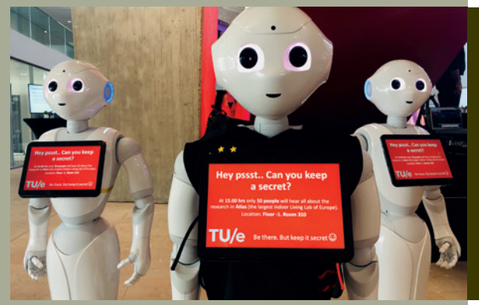
On March 21st 2019, ILI opened its new Living Lab, the Atlas building. Atlas is the new main building at the campus of TU/e, housing the University Board, the TU/e support staff and the departments Industrial Design and Industrial Engineering & Innovation Sciences.

Floors 4 up till 11 are equipped with 4400 Signify Trueline LED luminaires with an IP address that together form an Internet-of-Things backbone. Smart adaptive technology together with user-friendly interactivity for individual control enable a sustainable environment in terms of energy use in combination with comfort and well-being for students and employees.

To the best of our knowledge Atlas is globally the biggest indoor Living Lab. First preparations for this Living Lab started more than two years ago, with the renovation plans of the Atlas building. Apart from planning and realizing the infrastructure, effort had to be dedicated to establishing a responsible Research Data Use Policy.

A team consisting of representatives of the inhabitants, representatives of the installers and a project manager extensively discussed how the data of the Living Lab should be stored and used. With this policy in place, ILI is ready to start experimenting with intelligent adaptive light that should safe energy, yet at the same time create a comfortable and effective environment for the inhabitants. We are also proud that Atlas Living Lab is now mentioned as one of the 14 most important large experimental infrastructures at the website of TU/e.

The opening of the Atlas Living Lab was considered the right moment to reflect on the lessons learned in 10-years Living Lab research within ILI. A team of Core ILI members prepared a document, consisting of a summary for each Living Lab we used in the last 10 years. Per lab the responsible people gave an overview on the type of experiments done, the lessons learned and conclusions for the future. A more extended reflection on the document is given later in this magazine. I hope you enjoy reading it.



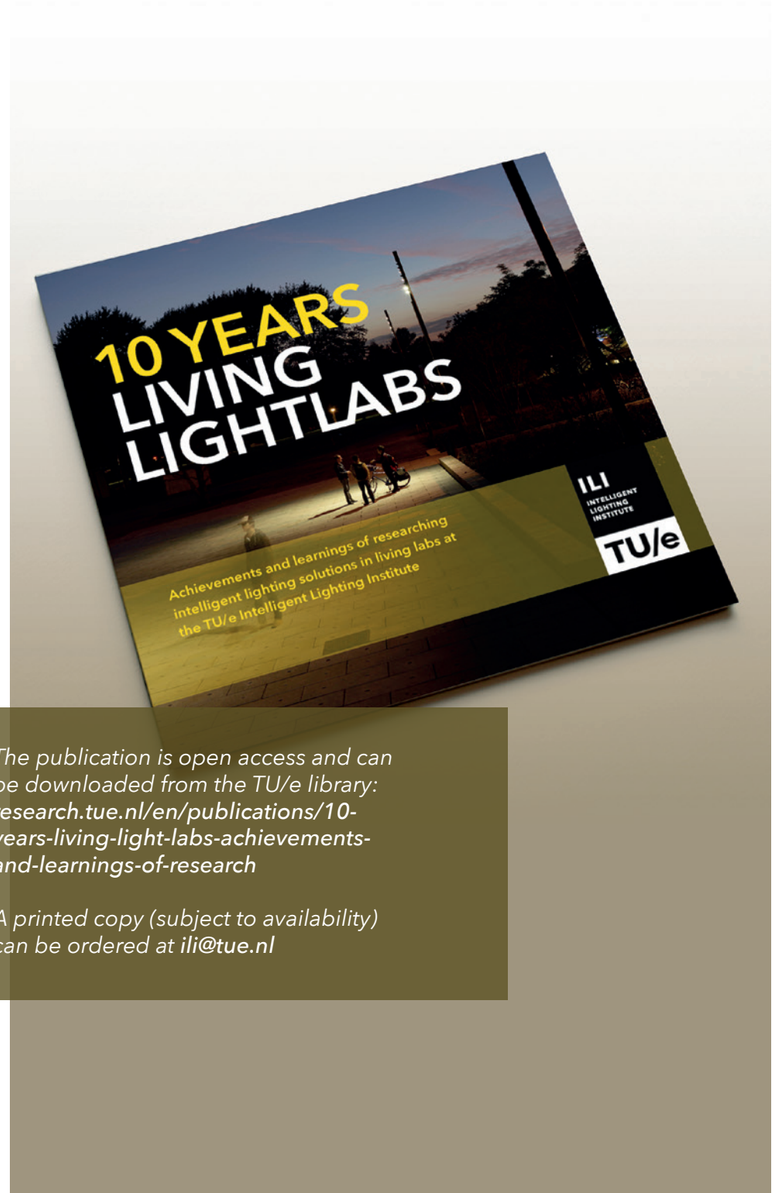
ELKE DEN OUDEN | MANAGER LIVING LIGHT LABS ILI

10 years Living Light Labs

With the opening of Atlas Living Lab on March 21st ILI added a state-of-the art research lab to the TU/e facilities. The living lab is the largest indoor living lab in Europe. Eight floors are equipped with a smart energy-saving lighting system and smart climate systems, that enable us to research and develop intelligent technologies for health, wellbeing and sustainability.

Conducting research in living labs is not new to ILI. Ever since its establishment in 2009 we involved users in our research in a variety of real-life settings. Over the years we have started new labs, stopped labs because of different reasons and extended existing living labs. As with all innovative approaches it was not always easy. Doing research 'in the wild' is inherently difficult as there are many influences that cannot be controlled. Nevertheless, we persisted because it enables us to follow the effect of lighting on humans for periods of weeks, months or even years. It allows us to co-create solutions with users and stakeholders. And it is paramount to also quantify the impact of intelligent lighting solutions in real contexts, where the lighting actually matters.

The opening of the Atlas Living Lab triggered us to collect and share the learnings and achievements of 10 years of researching intelligent lighting solutions in living labs. In a collective effort we provide an overview of the multiple living labs for different environmental contexts, together with the do's and don'ts we experienced along the way. The result is an 88-page publication that is meant to share our knowledge and insights. We hope our learnings inspire many people to join us in researching intelligent lighting 'in the wild'.



The publication is open access and can be downloaded from the TU/e library: ***research.tue.nl/en/publications/10-years-living-light-labs-achievements-and-learnings-of-research***

A printed copy (subject to availability) can be ordered at ***ili@tue.nl***

MAY 2019 - NOVEMBER 2019

Calendar

May 14, 2019 OVLNL Innovation Platform and Knowledge Cafe on 'Developments in Connectivity and Mobility and its impact on Public Lighting'. TU/e campus Eindhoven. **More information on: www.innovatieplatformigov.nl**

May 16, 2019 Internationale dag van het licht: NSVV Inspiratiemiddag nieuwe ontwikkelingen (in Dutch) Location: Amsterdam

June 4, 2019 13:00h - 14:50h Office lighting: today and tomorrow. Mini-symposium as part of the public doctoral defense program of Christel de Bakker and Sanae Chraibi, organized by the Building Lighting Group in collaboration with ILI. Location: Zwarte Doos TU/e campus

June 10 – 12, 2019 Optical Design and Fabrication Congress 2019, Freeform Optics, Washington DC, USA, Illumination freeform design using Monge-Ampere equations (invited talk Jan ten Thije Boonkkamp)

September 30 – October 4 ENUMATH 2019, Egmond aan Zee, The Netherlands, Numerical methods for Monge-Ampere equations (minisymposium)

October 20 -23, 2019 Optical Design and Testing IX (Conference PA106)-Spie Photonics Asia, Hangzhou, China, Monge-Ampere models for illumination freeform optics (invited talk Jan ten Thije Boonkkamp)

October 23 – 26, 2019 8th Professional Lighting Design Convention Lighting designers, architects, researchers, universities, industry and clients use PLDC as a platform to meet, learn about the latest developments in lighting design, and discuss the future of the lighting profession. Location: Rotterdam

November 13 + 14, 2019 LED + ELEKTRO Location: Brabanthallen Den Bosch

November, 2019 ILIAD Public Outreach event 2019 and Holst Lecture Location: Eindhoven

November 9-16 GLOW festival 2019 Location: city center Eindhoven

DR. IR. PHILIP ROSS | STUDIO PHILIP ROSS
DR. ANTAL HAANS | TU/E HTI & INTELLIGENT LIGHTING INSTITUTE
STEFFEN HARTMEYER | TU/E MASTER STUDENT HUMAN TECHNOLOGY INTERACTION

Did Gibson bring light to life?

Photo: @eu_roman
Model: @i.am.metamorphosis

What if light is more than a facilitator of human perception, but has perceptive powers of itself?

You can find a video of Gibson here: studiophilipross.nl/work#/2018-gibson/

The Glow 2018 art installation Gibson explored the concept of perceptive light: What if light is more than a facilitator of human perception, but has perceptive powers of itself? Next to being an art installation, it was also a field experiment. We examined how people experienced lights that portrayed different perceptive behaviours. Did the light seem alive to people in some way? This article gives an impression of the study and its results.

Gibson consists of twenty bright moving light beams, distributed over a 70m walkway, shining from 6m high downwards to where the crowd walks. The light beams are equipped with sensing capabilities, so that they can register when something enters it, at what distance it enters, and on which side. The sensing area of each light beam coincides approximately with the beam width. As a result, the light beams can move around the area beneath them to explore their surroundings. This perceptive behaviour is modelled after the active concept of perception as described by ecological psychologist J.J. Gibson. Compare it with the way you would move your finger to explore the tactile properties of a surface. The interested reader is referred to the Glow edition of ILI Magazine for a detailed description of the set-up.

In our study, we investigated whether visitors of the Gibson light installation perceived the moving light beams as animate. A perception of light as a living, perhaps even sentient entity is not obvious. However, already in the 1940's Heider and Simmel[1] demonstrated that people tend to experience simple moving objects such as triangles and circles as animate; ascribing purpose and intention to their movements. Could this phenomenon also hold for light that moves in interaction with people in their environment?

In our between-subject experiment, we compared two different perceptive light behaviours based on different motion cues described in the literature—one designed as a courtship behaviour, the other as more aggressive conduct—, against a control condition in which the light reacted in a more mechanical manner comparable to a pendulum. Participants were visitors of Glow, of which 131 were interviewed. In a first open format question they were asked to describe their experience of interacting with the light beams in their own words. Subsequently, they completed 6 self-report items each tapping into the extent to which animacy-related attributes were ascribed to the light beams: being alive, being able to perceive the world, behaving with purpose, being able to think, being able to plan, and having emotions[2].

Participants' responses to the open format question (translated from Dutch by the authors) yielded large individual differences, ranging from mere mechanical descriptions "Light balls with a lot of noise" through animacy "Spinning lights, on sound. Reminds me of animals, or a machine, a robot or something that is moving." to emotions being ascribed to the light beams "I got the feeling of walking into a nest… of a mother bird, that they follow you, and then they become angry or happy."

On the self-report items, even the control pendulum condition was rated highly on such attributes as 'being alive', with a mean of 4.0 (SD = 0.61) on a 1 to 5 scale. However, the experimental light scenarios—designed to display positive and negative intentions—were rated higher on 'having emotions' and 'behaving with purpose' than the control condition to a statistically significant extent, with $\chi 2(1) \geq 4.5$ and $p = 0.03$ (Kruskal-Wallis H test). There were no statistically significant differences between the two experimental lighting scenarios.

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Our findings thus support that the light in Gibson, especially when programmed to exhibit motion cues that reflect intentionality, was, by the majority of the participants indeed perceived as an animate and sentient entity. Our research simultaneously highlights the difficulties of doing research in the wild, and we plan to replicate our findings in more controlled laboratory studies, where, for example, the interaction with the light beams will not be obstructed by the presence of others people.

Animacy is an interesting dimension of light, and of possible benefit to intelligent lighting design. It could offer a new interaction paradigm for specific intelligent lighting systems, for example in the emerging field of social lighting. For more information, please contact the authors.

[1] **Heider, F. & Simmel, M. (1944).** An experimental study of apparent behavior. Am J Psychol, 57, 243-249.
[2] **Fukuda, H. & Ueda, K. (2010).** Interaction with a moving object affects one's perception of its animacy. Int J of Soc Robotics, 2, 187.

Gibson was supported by the Intelligent Lighting Institute and designed by Philip Ross with sound by Joep le Blanc.

Photo: Christian van Dooren

INTERVIEW | **GUNTER BOMBAERTS** (TU/E PHILOSOPHY AND ETHICS) **BY MICHIEL DE BOER** (MOESASJI)

Is co-creation the magic potion for (lighting) innovations?

To cope with the environmental and societal challenges ahead, the European Commission wants to speed-up and scale-up innovation. The SCALINGS research project is aimed at sustaining the growth of Europe's innovative power by enhancing the wider use of co-creation and open innovation. A field of expertise that fits philosopher Gunter Bombaerts like a glove. As an assistant professor of Philosophy & Ethics at the TU/e, Industrial Engineering & Innovation Sciences department, he is participating in SCALINGS and here shines a light on the characteristics, limits and advantages of co-creation.

Co-creation is a working methodology which originates from the IT domain where projects tend to be complex, flexible and the user plays a major role in evaluating quality. From the year 2000 onwards, co-creation has been developed by a large number of professionals and organizations worldwide with the aim of building better products and improving business. Bombaerts: "The European Commission has identified the potential of co-creation working methods and wants to enhance the usage of co-creation to speed up the outcomes. Of course, there are both successes and failures in this area. Moreover, you can ask yourself: what is good co-creation? And is it always the best thing for everyone? The available literature in this field mentions dialogue, access, risk assessment, and transparency (DART) as crucial criteria, but, if you ask me, this is looking too much on the bright side of things. The starting point is usually: co-creation is fantastic. And secondly, the value creation is generally expressed as monetary value for the company itself. To me as a philosopher, there are many more values involved: trust, sharing ownership and revenue, co-working, social cohesion, to name just a few. This brings me to an important point for the success of co-creation: what works here, doesn't necessarily work elsewhere."

OBSERVING PHASE: SECRETS OF SUCCESS

To unravel the characteristics of successful co-creation, Bombaerts is working together with people such as sociologists, economists and legal experts from 10 European countries that are involved in the multidisciplinary research project. The first aim is to

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reveal the (social-economic) factors that influence success. Bombaerts: “This is the observing phase. Within SCALINGS we are currently compiling a list of all (social economic) factors that influence co-creation. We are doing this by examining forty co-creation projects throughout Europe. One of these projects is ‘Jouw Licht op 040’ (loosely translated in ‘Your Light on Eindhoven’) which has an interesting set of co-creation aspects. It also has the advantage of being located in Eindhoven. This is a relatively small town with great social cohesion and a heritage in lighting development and lighting manufacturing. I think that the sense of community is a strong connecting element in both Eindhoven and in this project. It makes clear that these are circumstances you cannot copy one-on-one to other places is the world. If you transpose the same working methodology to say Amsterdam or Barcelona, it might work, but it has far more chance of failing.”

UPSCALING PHASE: BEYOND THE TOOLBOX

Bombaerts: “The second phase is about the translation. Here we aim to design a model that can be used to forecast results and to plan an effective co-creation strategy. We want to go beyond the toolbox. Over the past decades, many toolboxes have been designed for almost every process. Yet too often these toolboxes try to fill a gap that is defined as generic, but in fact isn’t. So we are striving to define a model with a number of parameters that helps to predict and install the right processes for your situation. That can help answer questions like: We want to run a co-creation project on the design of city lighting in Barcelona. The scale differs from Eindhoven and so does the social cohesion, so what buttons do we need to push to make it into a success?”

Co-creation is a working methodology which originates from the IT domain where projects tend to be complex, flexible and the user plays a major role in evaluating quality.

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HOW TO CHOOSE AND USE CO-CREATION?

With the emergence of highly controllable and programmable led lighting, a new era in lighting has arisen. However, what it means to us as humans, how we respond to it, and what we would like it to be, is yet to be determined. Since lighting influences humans on a mere subconscious level, co-creation, in the sense of having users participate in research, development and implementation of lighting systems, might be an attractive route. Bombaerts: "True. Co-creation offers interesting opportunities for the development of lighting systems and design. However, it is always good to consider what form and what level of co-creation you should choose. A project in a single neighbourhood is different from designing an intelligent lighting system for a city, which has many more and more diverse stakeholders, and leads to a few considerations:

A few considerations on co-creation projects

■ Building Trust | Co-creation thrives when there is clarity and transparency about the target and process, and everybody respects the rules along the way. Yet, complete transparency is very difficult to realize and maintain throughout the project. Whose system is it truly? Who is liable when it goes wrong? If there is profit, who receives it? What is the benefit to participate in it? These are all important questions to ask yourself beforehand.

■ Ownership vs. Clout | Ownership is one of the great challenges of co-creation. People will have to invest their time and attention into the project. First: how do you realize ownership? And next: how do you balance it against clout? Of course, you do want to move forward in your project. If you have strong 'owners' they can make minor details very important, thus taking too much time to debate them, slowing down decision making.

■ Product vs. Empowerment | What is your actual target? Is it just getting the project done? In case of government and community projects, it could also be about improving social cohesion in a neighbourhood or creating stronger and more involved citizens. Is that case, it is good to also consider where and how a project ends. In the world of co-creation, a lot of projects come to an end abruptly, leaving the participants orphaned and empty-handed.

■ Light vs. Life | What is the scope of the co-creation process? Investing in intense participation, for instance to change the quality of the ring road in Eindhoven with lights alone, might be experienced as limited. Maybe discussions on the use of cars and public transport, or on the infrastructure as a whole, are then more radical and efficient?

■ Time vs. Result | You can't keep on talking eternally. How do you manage the desired process steps in time? Where do you stop a phase while keeping the participants on-board for the next?

■ Cooperativity vs. Individuality | A completely homogenous group works fastest for mutual understanding and decision making, however projects also benefit from a certain level of individuality, egoism and resistance. There is some interesting research around 'no-sayers' who actually improve the outcomes in projects. People that question everything: the intentions, the goals and the process, often also bring out the essence: 'what is the value of what we're doing here?'

Bombaerts: *"Compared to traditionally managed projects, you shift from a situation that is complex to a situation that is even more complex. The number of actors increases and you bring non-specialists, such as citizens and/or users on-board. Moreover, there is the promise to these participants that they are able to influence the process, methods and outcomes. Yet, co-creation offers many opportunities as opposed to the traditional Decide & Defend way of working: building trust, improving social cohesion, using the perspective of others, and gaining support for decisions that influence society. In general, you could say: if the level of delicacy increases, co-creation is a preferable route."*

Jouw Licht op 040

Your light on Eindhoven

The City Lighting Roadmap 2030 of the municipality of Eindhoven comprises a number of co-creation development projects. In pilot areas in five different neighbourhoods in Eindhoven, citizens and professional parties (among which Signify and Heijmans) have joined forces to create intelligent lighting solutions that increase safety and wellbeing. The outcomes of the pilot-projects will provide the knowledge, experience and inspiration for future city lighting upgrades throughout the city.

Further information:
www.Jouwlichtop040.nl
www.scalings.eu

TANIR OZCELEBI | ILI PROGRAM
LEADER BRIGHT ENVIRONMENTS

Privacy-preserving context recognition

The Internet of Things (IoT), a technology that connects humans, Things and data to each other and to the Internet, is becoming a part of our daily lives. This is a phenomenon that is so massive, Cisco predicts that, by 2022, the number of devices (Things) connected to the Internet will be nearly 30 billion and there will be nearly 15 billion pure Machine-to-Machine (M2M) connections over the Internet.

Collecting, storing and processing users' data for AI model development or at runtime for context recognition are privacy sensitive tasks.

One would expect that with this trend comes an extra-ordinary list of life-changing IoT services and products. This is only partly true. It turns out that the majority of the current IoT offerings with a clear profitable business model are those that utilize users' data. Typically, data giants provide a service like car navigation software for free, in exchange for personal data, which then can be used for personalized advertisements and other things that have monetary value. Clearly, it seems to be difficult to convince end users and especially the consumer market to pay a subscription fee for "nice to have" services that are in no way essential for their lives. Almost no individual wants to or can afford to pay for an IoT-enabled toothbrush that connects to a paid cloud analytics service to give feedback on how well its user is brushing her teeth with tips for improvement. Interestingly, most users are willing to use such a service for free, in exchange for their data. Needless to say, a vast majority of these users are uninformed with respect to what can be done with their data.

Intelligent lighting, for example, is one of the leading technologies that can benefit from the IoT. In order for intelligent lighting control to accommodate user preferences in different contexts, algorithms are needed to infer, and perhaps even predict ahead of time, a user's context. Artificial Intelligence (AI) approaches such as Machine Learning (ML) are popularly used in solutions to this. IoT connectivity makes AI solutions even more interesting since it enables much more contextual information around a user by unlocking data from all sorts of IoT-enabled sensors (not necessarily owned by the user) and from the Internet. There are, however, a couple of serious problems with this. The first one is of a practical nature. It is cumbersome to collect ground-truth data from users about their context, making it difficult to train a supervised machine learning model for context recognition. A lot of the publicly available data sets out there are quite small, imbalanced and noisy. The second problem is of a more fundamental nature. Collecting, storing and processing users' data for AI

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model development or at runtime for context recognition are privacy sensitive tasks.

In the Bright Environments research program of TU/e's Intelligent Lighting Institute (ILI) and the Internet of Data research program of Data Science Center Eindhoven (DSCE) two privacy protection principles fuel the context recognition research: 1) disallowing crowdsourcing the collection of privacy sensitive data for building AI models and 2) preventing privacy sensitive data from getting out of the managerial domain of its owner at runtime, e.g. for cloud analysis. We believe living by these principles does not necessarily mean that we have to sacrifice personalization of intelligent services of such systems. The necessary innovations for building systems that live by these principles include efficient real-time local processing of data (including training) on resource-constrained networked embedded systems, cryptography and obfuscation under low resource budgets, as well as novel interaction styles that hide past interactions while enabling personal control. Until now we have been able to develop accurate data analytics solutions that utilize purely synthetic data for training, hiding users' personal data completely from the training server. Furthermore, we are actively working on federated learning models and the corresponding deployment on real systems of users. Federated learning defines a distributed ML framework for building AI models that are highly personalized and, at the same time, privacy conservative. This is because personalization in federated learning happens only at the users' side, with almost no personal data directly getting exposed to external parties, e.g. to a cloud server. Instead, the model parameters chosen by a user's system locally represent a personalized version of the global ML model, which is continuously updated. We spend a lot of effort in searching good trade-off points when it comes to the computational cost and context recognition performance of such models.

Our work in this domain is mainly carried out in the SCOTT project. SCOTT (www.scott-project.eu) has received funding from the Electronic Component Systems for European Leadership Joint Undertaking under grant agreement No 737422.

This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Austria, Spain, Finland, Ireland, Sweden, Germany, Poland, Portugal, Netherlands, Belgium, Norway.

ILI Top Publications

Stokkermans, M. G. M., Vogels, I. M. L. C., de Kort, Y. A. W. & Heynderickx, I. E. J., A comparison of methodologies to investigate the influence of light on the atmosphere of a space, *LEUKOS: The Journal of the Illuminating Engineering Society of North America. 14, 3, p. 167-191 (2018)*

de Bakker, C., Aarts, M., Kort, H., & Rosemann, A., The feasibility of highly granular lighting control in open-plan offices: Exploring the comfort and energy saving potential. *Building and Environment, 142, 427-438 (2018)*

N.K. Yadav, J.H.M. ten Thije Boonkkamp and W.L. Ijzerman, Computation of double freeform optical surfaces using a Monge-*Ampere solver: application to beam shaping, Optics Communications 439, 251 – 259 (2019)*

Lashina, T., van der Vleuten-Chraibi, S., Despenic, M., Shrubsole, P., Rosemann, A. & van Loenen, E., A comparison of lighting control strategies for open offices, *Building and Environment. 149, p. 68-78 (Feb 2019)*

Kruisselbrink, T. W., van Duijnhoven, J., Dangol, R. & Rosemann, A. L. P., Improving lighting quality by practical measurements of the luminance distribution, *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018) - Volume X, Advances in Intelligent Systems and Computing, vol. 827, p. 190-198 (Jan 2019)*

van Duijnhoven, J., Burgmans, M. J. H., Aarts, M. P. J., Rosemann, A. L. P. & Kort, H. S. M., Personal lighting conditions to obtain more evidence in light effect studies, *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018) - Volume X, Advances in Intelligent Systems and Computing, vol. 827, p. 110-121 (Jan 2019)*

Lashina, T., Chraibi, S., Despenic, M., Shrubsole, P., Rosemann, A. & van Loenen, E., Sharing lighting control in an open office: doing one's best to avoid conflict, *Building and Environment. 148, p. 1-10 (15 Jan 2019)*

van Duijnhoven, J., Aarts, M. P. J., Aries, M. B. C., Rosemann, A. L. P. & Kort, H. S. M., Systematic review on the interaction between office light conditions and occupational health: elucidating gaps and methodological issues, *Indoor and Built Environment. 28, 2, p. 152-174 (2019)*

Ru, T., de Kort, Y. A. W., Smolders, K. C. H. J., Chen, Q. & Zhou, G., NIF effects of illuminance and correlated color temperature of office light on alertness, mood, and performance across cognitive domains, *Building and Environment. 149, p. 253-263 (1 Feb 2019)*

Perz, M., Modelling visibility of temporal light artefacts, *Eindhoven: Technische Universiteit Eindhoven. 162 p. (5 Feb 2019)*

den Ouden, E., Haans, A., Ross, P., van Essen, H., de Kort, Y. & Brankaert, R., 10 years living light labs: achievements and learnings of researching intelligent lighting solutions in living labs at the TU/e Intelligent Lighting Institute, *Eindhoven: Technische Universiteit Eindhoven. 85 p, (21 Mar 2019)*

van de Werff, T.C.F., van Lotringen C., van Essen, H.A., Eggen, J.H., Design Considerations for Interactive Office Lighting: Interface Characteristics, Shared and Hybrid Control, *CHI '19 Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, New York: Association for Computing Machinery, Inc, 14 p. (4 May 2019)*

HAROLD WEFFERS | OPERATIONAL MANAGER ILI

2018 edition of ILIAD

The 2018 edition of ILIAD, our annual public outreach event, was not held at TU/e, but for the first time at Plaza Futura in Natlab on Strijp-S (the historic site where in 1923 Philips Natuurkundig Laboratorium, Philips Research was located).

The audience consisting of people from academia, industry, and (regional) government was presented with a full day of presentations by academic researchers and industrial practitioners of (strategic) partners of ILI. We welcomed mr. Walter Werner of Werner Management Services, mr. Stefan Bäumer of TNO and mr. Wouter van Marken Lichtenbelt of Maastricht University as invited speakers.
Next to a number of leading researchers also a number of (new) young talented first-stage researchers were given the opportunity to present their challenging R&D for societally relevant (technological) innovations.

Aside of the presentations there was also ample room for one-on-one interaction (at the various posters) and networking during the breaks, the lunch and the reception at the end of the event.
All in all, it was again a very lively day with lots of meaningful discussions on the need for more societally relevant (technological) innovations on Light & Lighting for various application domains such as Health.

We hope to see you again at ILIAD and the Holst symposium in November 2019.

It was a very lively day with lots of meaningful discussions.

MARIËLLE AARTS, ALEXANDER ROSEMANN, EVERT VAN LOENEN, HELIANTHE KORT |
BUILDING LIGHTING TU/E

Creating Healthy Environments Hospitals (CHEC)

One of the major societal challenges we are facing today is the sustainable transformation of healthcare in terms of costs and availability of staff. With an expected growth in the number of patients the consequence is to identify options to optimize the employability and the retention of care professionals. Hereby we refer to comfort, well-being, work pleasure and safety, appreciation, health, work performance, etc.

The project "Creating Healthy Environments Hospitals" (CHEH) aims to identify environmental conditions which improve the retention, and to support the tasks of the nursing staff. This project is part of the Spark Impuls II program where the BPS groups “Building Lighting” and “Building Performance” closely collaborate with the research group “Technology for Healthcare Innovations” of the Utrecht University of Applied Sciences.

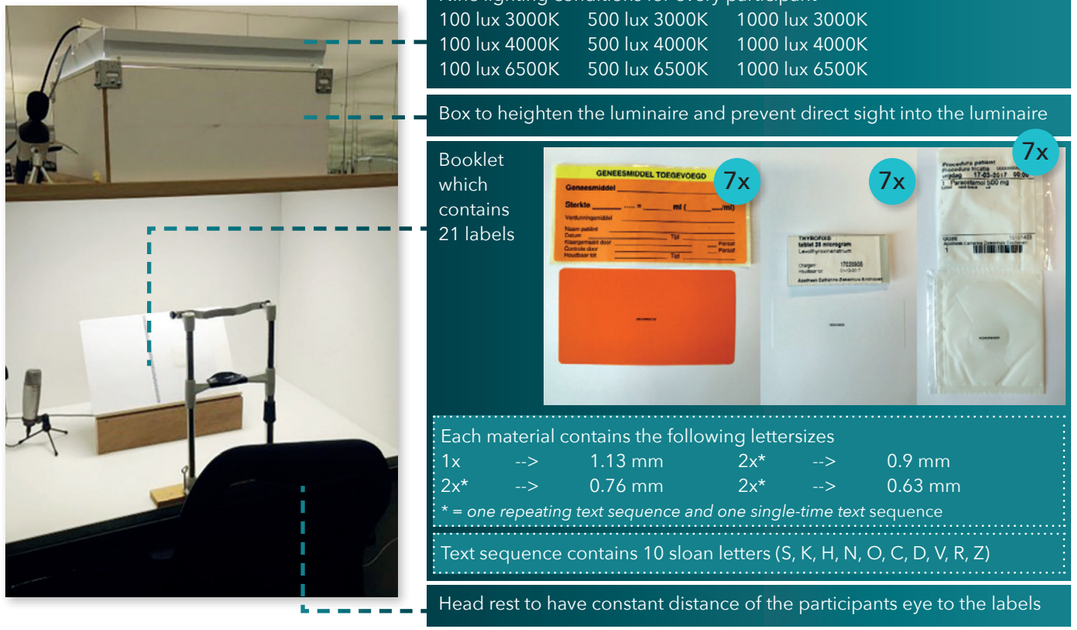
Based on interviews, observations, surveys, light measurements in several hospitals (M.P.J. Aarts & Kort, 2017), and a review of the literature, the following, light related, relevant topics were identified:

1. **Medication errors and light**
2. **Impact of light on nightshift work**
3. **Impact of daylight in hospitals.**

The results of the studies on nightshift work, and daylight in hospitals are still in progress and will be presented in a later issue.

MEDICATION ERRORS AND LIGHT.

In hospitals, medication follows a complex path before attaining the targeted patient. In this process human mistakes occur. Missed doses, missed medications or wrong medication are the primary errors. These can result into a life threatening situation for patients. Human mistakes might originate from a too high workload, from distractions or interruptions by colleagues, or inappropriate lighting. The lighting environment impacts the visual performance as well as the non-image forming aspects like alertness. Medication errors are more pronounced during night shifts, when light levels are kept dim to support the sleep quality of the patients. Practice has shown that under dim light conditions it is more strenuous to read labels, check infusion fluids and to stay alert. This becomes even worth for nurses whose sight is deteriorated due to presbyopia and eye fatigue due to biological ageing. Therefore it is crucial to have a lighting situation that enhances the (visual) performance of nurses managing. To identify which lighting condition best supports the visual performance, an experiment was conducted to assess the number of reading errors on three different, normally used medication labels (Mariëlle P.J. Aarts, Craenmehr, Rosemann, van Loenen, & Kort, 2019). 40 Women participated in the experiment of which half were younger people (18-30 years old) and half were older people (55-67 years old). In total 9 different light conditions were offered to the participants. Set-up see Figure 1



Concluded was that lighting has an impact on the number of errors and that older people make more mistakes than younger people. The type of label has an impact on the number of errors made. For font sizes < 4.5pt (Arial), reading medication labels (Blister, Baxter and Orange) under illuminance levels of 100lx, will lead to significantly more errors than E ≥ 500lx. The light condition that generates the least errors for the total test population, all font sizes, and all different materials was the one with an illuminance of 1000lx and a Tcp of 4000K. People with an insufficient Visual Acuity (VA) benefit most from a higher illuminance, especially for Orange labels, used

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for infusion fluids. When the VA is sufficient to good, and the font size is as recommended for medication labels (Arial Capital ≥ 4.5pt) the impact of the lighting on number of errors is limited for all of the age groups. In a follow-up study the impact of light with people with a lower VA will be addressed since not every person's VA is well-corrected.

The minimum requirement according to the international standard (NEN-12464) were not always met, based on light measurements in medication rooms in several hospitals (see Figure 1). This means that a potential for errors is introduced. The results of the surveys among the nurses working under these conditions, demonstrates that many are not aware of the impact lighting could have on their daily work. In addition, nurses are less aware about the fact that the combination between small print and dim light conditions can lead to fatigue and errors.

REFERENCES **Aarts, M. P. J., Craenmehr, G., Rosemann, A. L. P., van Loenen, E. J., & Kort, H. S. M.** (2019). Light for patient safety: Impact of light on reading errors of medication labels. International Journal of Industrial Ergonomics, 71, 145–154. http://doi.org/10.1016/J.ERGON.2019.03.004 **Aarts, M. P. J., & Kort, H. S. M.** (2017). Lighting conditions in hospital medication rooms and nurses appraisal. In Healthy Buildings 2017 Europe. Lublin, Poland.

Concluded was that lighting has an impact on the number of errors and that older people make more mistakes than younger people.

ILI SHORT

Ice skating with intelligent lighting at TU/e Christmas Market

Last Christmas TU/e had a Christmas Market in the roofed area of the Market Hall. There we could use the ILI infrastructure there to create an interactive skating experience.
Students could skate on a real ice skating rink. The skaters were followed with colored light beams and their movements on the ice were pictured on a large screen. Antal Haans and his team created a nice atmosphere. Special thanks to Sako Arts of Wolfpack, Joris Willems (Applied Physics) and Bert Maas of Studio Lucifer.

INTERVIEW BY **MONIQUE VAN DE VEN** (CURSOR) | **INGRID HEYNDERICKX** (SCIENTIFIC DIRECTOR ILI), **ELKE DEN OUDEN** (MANAGER OF THE ILI LIVING LIGHT LABS) AND **PHILIP ROSS** (PROJECT LEADER ATLAS LIVING LAB)

Atlas mustn't become an experimental maze

Staking their life on it would be going a little too far, but the initiators are pretty sure that TU/e's Atlas building could very well become the largest indoor living lab in Europe. Eight floors of the renovated building are not only providing the daily workspace of many hundreds of students and employees, soon they will also become the stage for the Atlas Living Lab. Experiment under conditions as natural as possible without making unwitting guinea pigs of the building's occupants; that is what researchers can do in Atlas as of this spring. But not just anyone.

The lab extends from floor 4 through to floor 11; at the heart of the technical infrastructure here lies a 'connected office' light system produced by Signify, a combination of smart energy-saving LED luminaires (each with its own IP address) and sophisticated mini sensors and detectors that record movements. If extra sensors, for example, are needed for experiments, they can be added, with the necessary approval.

ETHICS COMMITTEE

To gain this approval researchers must be clear-minded and well-organized ahead of time; the doors of Atlas are certainly not thrown open for just any experiment. Every research proposal - short-term or lengthy, small scale or, for example, spread over multiple floors, originating in-house or from external parties - is put through a process in which TU/e's Ethics Committee assesses and weighs up each individual aspect. Furthermore, in agreement with lab coordinator Nasir Abed, steps are taken to ensure that studies do not overlap or influence one another.

Den Ouden: "First of all, a research proposal is discussed. What does this person want to do, for what purpose and for how long? And are all the floors involved, or could only one wing be used? What does this person plan to publish and what not?" Moreover, every research study must have a certain relevance to TU/e and any 'strain' that might be put on people in the building must be worth it. Or, as Heynderickx puts it jovially: "We don't want to become an experimental maze".

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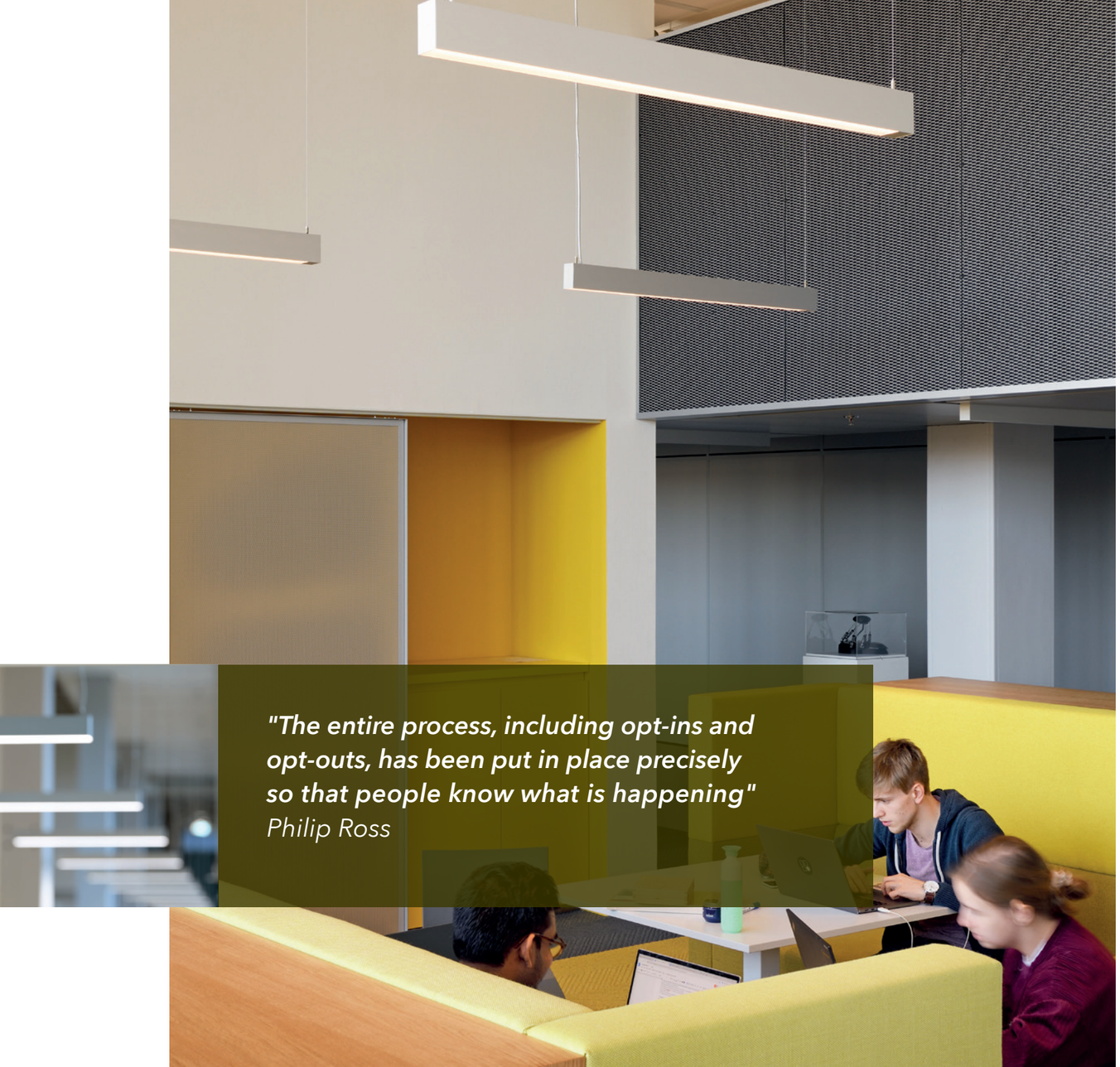


"The entire process, including opt-ins and opt-outs, has been put in place precisely so that people know what is happening"
Philip Ross

First and foremost, the building occupants (both students and employees) will always be informed shortly in advance of an experiment - individually or as a group, depending in part on the nature and extent of the planned research. Furthermore, especially where some degree of disruption to their everyday work may be expected, they always have the choice whether or not to participate - likewise the opportunity to, say, work temporarily in another wing or on another floor, where no experiment is running.

AVOIDANCE

Valuable input regarding this was also provided by the feedback round the initiators held with the University Council, the Services Council, the Departmental Councils, trade unions, and others.
Another aspect that was (and still is) given plenty of attention is the policy governing the data collected - with the European privacy law (AVG), the Netherlands Code of Conduct for Research Integrity and the TU/e Code of Scientific Conduct providing the framework.

Come what may, no data will be collected without students and employees being notified in advance, and in principle no data (not even combined data) will be traceable to a particular individual - unless he or she has expressly consented to this. “Nor will we browse through data that is being continuously gathered on another server for the purposes of managing the building. The entire process, including opt-ins and opt-outs, has been put in place precisely so that people know what is happening,” Ross emphasizes.

TRANSPARENCY ABOUT RESULTS

This is one reason, says the researcher, why it is considered important that findings are shared with the people in the building. “We are part of an academic community, so people here tend to be interested in research results of this kind anyway. Communication on this topic must be transparent.” Not that all the raw research data will be dumped on the internet, Heynderickx hastens to add, “but to a certain extent we will most definitely disseminate the results, but without it being possible to trace them back to individual persons”.
Ingrid Heynderickx hopes that the first experiment in the Atlas Living Lab will be running before this coming summer. The laboratory was officially opened on March 21st, at the same time as the festive opening of the renovated building.

This is a shortened version of a Cursor Interview. You can read the full article here:
https://www.cursor.tue.nl/en/background/2019/maart/week-2/atlas-mustnt-become-an-experimental-maze/

KARIN SMOLDERS | HUMAN TECHNOLOGY INTERACTION TU/E

Light to fight addiction

Research has shown that light is an ambient and unobtrusive tool which can – if well-timed, and provided with the right intensity (in particular parts of the spectrum) – support healthy sleep-wake patterns and benefit daytime functioning. While chronotherapy (e.g., light interventions or behavioral instructions) has been shown to benefit persons suffering from a diverse range of clinical disorders (such as SAD, burnout, prenatal depression), it hasn't been tested among Alcohol Use Disorder (AUD) patients in a placebo-controlled study, despite clear indications for its potential to support these patients in their fight against alcohol. In fact, a healthy light and sleep hygiene are likely of crucial importance for persons suffering from AUD given the detrimental effects of alcohol abuse on sleep and self-control.

AUD is a chronic relapsing mental disorder with devastating personal, societal and economic consequences (Nutt, King, & Philips, 2010; van Amsterdam, Nutt, Philips, & van den Brink, 2015). This disorder is one of the most common forms of addiction, and is characterized by a high relapse rate. AUD patients often suffer from disturbed sleep-wake patterns, and may experience challenges related to their self-control (e.g., Brower, 2003; Conroy et al., 2006; Foster et al., 1998; Foster & Peters, 1999). As sleep problems, circadian misalignment, and reduced self-control have been implicated to increase alcohol consumption, this may lead to a negative spiral. As shown by the relatively high relapse rates among AUD patients, this negative spiral is difficult to break. A potential promising solution to counteract this negative spiral is the use of a healthy light regime which – in addition to standard care – promotes structure and provides rest and energy at the right moments during the day. In turn, this will likely also reduce and/or stabilize alcohol consumption and cravings among persons suffering from AUD.

OUT-OF-THE-BOX PROJECT

In the project 'Light to Fight Addiction', funded by ZonMw (Off Road), we aim address this by performing a randomized, controlled trial with an intelligent lighting intervention among outpatients suffering from AUD. We take up this challenge together with addiction clinics (Novadic Kentron and Arkin/Jellinek), Signify and Utrecht University, and assess the effectiveness of an integrated, user-tailored and dynamic lighting solution to support patients suffering from chronic alcohol dependency in their fight against addiction by facilitating sleep and self-control. To this end, we will perform a large-scale study employing a lighting intervention in the living environment of AUD patients by replacing the light bulbs in existing armatures with smart light bulbs. After the lighting intervention, patients will be monitored for 12 weeks by means of ecological momentary assessment and short checklists during the weekly visits of the caregivers. Patients in the intervention group (N=30) will receive behavioural instructions (about sleep-wake timing) combined with user-tailored, dynamic lighting aimed to facilitate adherence to these instructions and to increase self-control and mood during daytime, while patients in the placebo group (N=30) will only receive behavioural instructions with standard light settings. The lighting intervention consists of dawn/dusk simulation, combined with a higher intensity level during daytime and gradual dimming in the evening in the living room and bedroom.

MULTIDISCIPLINARY, INNOVATIVE APPROACH IN ADDICTION CARE

Due to the innovative use of lighting technology and assessment tools (integrating person-worn sensors, smartphone apps to administer notifications for short questionnaires and melatonin sampling) in addiction care, we aim to gain insights in the potential of an integrated lighting solution to support patients with AUD in their fight against alcohol, and shine light on the underlying mechanisms and temporal development of those effects. By integrating knowledge and expertise in the domain of lighting research, chronobiology and psychology in addiction care, the ambition is to provide adjunctive therapy to patients which is not experienced as therapy because it is integrated in their living environment, and therefore easy to adhere to.

van Amsterdam, J., Nutt, D, Philips, D., & van den Brink, W. (2015). European rating of drug harms. Journal of Psychopharmacology, 29, 655-660. Doi: 10.1177/0269881115581980

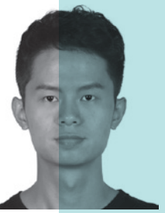
Brower, K. J. (2003). Insomnia, alcoholism and relapse. Sleep Medicine Reviews, 7(6), 523-539. Doi: 10.1016/S1087-0792(03)90005-0

Conroy, D. A., Arnedt, J. T., Brower, K. J., Strobbe, S., Consens, F., Hoffmann, R., & Armitage, R. (2006). Perception of sleep in recovering alcohol-dependent patients with insomnia: Relationship with future drinking. Alcoholism: Clinical and Experimental Research, 30(12), 1992-1999. Doi: 10.1111/j.1530-0277.2006.00245.x

Foster, J. H., Marshall, E. J., & Peters, T. J. (1998). Predictors of relapse to heavy drinking in alcohol dependent subjects following alcohol detoxification: The role of quality of life measures, ethnicity, social class, cigarette and drug use. Addiction Biology, 3, 333-343. Doi: 10.1080/13556219872146

Foster, J. H., & Peters, T. J. (1999). Impaired sleep in alcohol misusers and dependent alcoholics and the impact upon outcome. Alcoholism: Clinical and Experimental Research, 23(6), 1044-1051. Doi: 10.1111/j.1530-0277.1999.tb04223.x

Nutt, D. J., King, L. A., & Philips, L. D. (2010). Drug harms in the UK: a multicriteria decision analysis. Lancet, 376, 1558–1565. Doi: 10.1016/S0140-6736(10)61462-6



ILI New employees

MAAIKE KOMPIER
PhD candidate HTI

Both my Bachelor and my Master's degree I completed within the school of Innovation Sciences at the Eindhoven University of Technology. Quite early in my Bachelor it was the interaction between people and the built environment that caught my interest. Especially, the wellbeing of people in indoor environments triggers me.
Since May 1st, 2018 I work in the Human Technology Interaction Group within a multidisciplinary project named DYNKA: 'Dynamic Indoor Climate and Lighting for Offices.' DYNKA is a project funded by the Top consortia for Knowledge and Innovation in Urban Energy. This project focuses on the question to what extent the interaction of LED lighting and ambient temperature affects the energy consumption required for heating or cooling, while improving health and well-being. The main objective is realizing an optimal indoor climate in offices through a combination of dynamic lighting and dynamic indoor temperature throughout the day that ensures a healthy and productive office environment and also realizes energy savings. My main focus currently are short-term effects of dynamic lighting on alertness, visual and thermal comfort and thermoregulation.

DIEGO SCARPANTI
PhD candidate visiting from University of Verona

After receiving my Bachelor's degree in Psychological Sciences of Development, Personality, and Interpersonal Relationships, in University of Padova (Italy), I did my Master's degree at University of Verona (Italy) in Human Resources Training and Development.
The focus of my thesis was on the relationship between Light and the construct of Restorativeness.

In 2017 I started my PhD course in University of Verona with the supervision of Prof. Margherita Pasini. The topic of my research project is still on Light and Restorativeness. In the same time, the research project is a part of an international collaboration with Eindhoven University of Technology: in this organization I benefit of the supervision of Prof. Yvonne de Kort and Prof. Karin Smolders, both part of Industrial Engineering & Innovation Sciences in TU/e. I'm going to stay in this organization for a total of 12 months. We aim to gain better understanding on the relationship between Light, Restorativeness and the aesthetic preference for light installations.

SAM KHABIR
PDEng Smart Space project

Sam is trained in architecture, urban design and spatial planning. In 2013, he graduated with distinction from the EMU, a joint European post-graduate Master's program between the four leading European institutions in research and education in the field of urban planning, namely KU Leuven, IUAV Venezia, TU Delft and UPC Barcelona.
His research interests are mainly grounded in the economic sustainability, as well as the socio-spatial dynamics of urbanization with a particular focus on the East & South-East Asia that persuaded him to join Peking University as a scholar in 2016. With a keen interest in the concept of joint value creation and user involvement in the development of technological solutions and its implications for the replicability of smart city solutions, Sam subsequently joined the TU/e as a researcher to investigate the replication potential for smart street lighting solutions in Smart Space, an EU-funded project in the NW Europe region.

YOANNA IVANOVA
PhD Maastricht University

After receiving my BSc in Kinesiology and Health Sciences at York University (Toronto, Canada), I followed the research master in Health Sciences at Maastricht University. I was always interested in learning more about what keeps people healthy and through my bachelor's and master's I've learned about the effects of exercise and diet on human health. For my PhD I wanted to go on a bit of a different route and study the working environment and how it can be designed to keep people healthy. And so as of September 2018, I am working as a PhD Candidate on the project 'DYNamisch licht en binnen-klimaat voor KAntoren' (DYNKA), supervised by prof. dr. Wouter van Marken Lichtenbelt and dr. ir. Rick Kramer. In DYNKA, we study the health and productivity effects of interacting dynamic light and dynamic temperature conditions over the day on office workers. Furthermore, we explore and aim to quantify the energy saving potential of dynamic indoor conditions.

WEI LUO
PhD Maastricht University

I received my B.Sc. degree from Xi'an University of Architecture and Technology, China after which I did my masters in Tianjin University, also in China in the field of gas supply, ventilation and air conditioning engineering. My final thesis was entitled 'The effect of heat acclimation in various thermal environments on thermal perception, physiology and the fight-or-flight response'.
These experiences increased my curiosity in human thermoregulation and the interaction between humans and their environments. Therefore, after my masters, I decided to move to the Netherlands, where I now pursue my PhD. My project, PERDYNKA ('Personal Control of Dynamic Indoor Climate for Offices'), aims to investigate the influence of individual control of LED light and ambient temperature on thermal perception, physiology and cognitive performance. I am currently supervised by prof. dr. Wouter van Marken Lichtenbelt (MU), prof. dr. ir. Yvonne de Kort (TU/e) and dr. ir. Rick Kramer (MU).

ILI SHORT

Social events with Young ILI

On November 30th Thomas van de Werff, Samantha Peeters, Lotte Romijn, Xiangzhen Kong and Christel de Bakker organized the kick off Young ILI event with drinks and a pub quiz for PhDs, PDEngs and other young researchers of ILI at the Hubble Café.

RADIO INTERVIEW

Mariëlle Aarts on (the lack of) daylight

In the night of December 20, 2018, NPO radio 1 did an interview with assistant professor Building Lighting and member of the ILI Sound Lighting program Mariëlle Aarts. You can listen to this interview here (in Dutch).

www.nporadio1.nl/wat-het-daglicht-niet-verdragen-kan/onderwerpen/484405-licht-en-wetenschap

ILI SHORT

Stratumseind Living Lab on BBC World Hacks

On December 16, 2018, BBC World Hacks did an item on Stratumseind Living Lab titled: 'Can This Smart Street Stop Drinkers Getting Violent?' You hear Tinus Kanters of Eindhoven municipality and Project manager of Stratumseind Living Lab being interviewed.

bbc.co.uk/programmes/w3cswvs4

Marielle Aarts in De Groene Amsterdammer

De zon zie ik in het weekend:
groene.nl/artikel/de-zon-zie-ik-in-het-weekend

ILI SHORT

Gosia Perz awarded a PhD, with distinction

Light emitted by LED's can flicker or exhibit a stroboscopic effect, which can lead to annoyance, fatigue and even headaches. Malgorzata (Gosia) Perz, ILI PhD and employee of Signify, did her research on determining the characteristics of light at which the human eye no longer perceives these unwanted effects. The model developed allows lighting manufacturers to test for these undesirable effects while designing their LED products.
On February 5th Gosia Perz defended her theses "Modelling visibility of temporal light artefacts". Her promotor was Prof. Dr. Ingrid Heynderickx and her co-promotors were Dr. Ingrid Vogels (TU/e) and Dr. Dragan Sekulovski (Signify). She was awarded 'with distinction'.

Her research was given quite some attention in the media. Here you can listen to an interview with Gosia on BNR radio.
bnr.nl/podcast/wetenschap-vandaag/10368790/model-moet-einde-maken-aan-vervelend-knippereffect-van-led-lamp

MAHMOUD TALEBI | ILI PHD M&CS
ADVISORS - **JEAN-PAUL LINNARTZ AND JAN FRISO GROOTE**

Can we scale up Wireless Lighting Control?

TU/e PhD Mahmoud Talebi has found a mathematical method to predict the performance of large radio networks up to ten times more accurately than previously achieved. Wireless networks are getting larger and larger and carry ever more data. The scalability of networks is a major concern for the entire telecom industry, and many technical solutions are being proposed to improve our future networks. But do these work? There is an imminent need to understand to what extent networks can be scaled up to carry the data for the upcoming Internet of Things or new massive wireless control of large lighting installations.

The growth of the use of radio communications has been faster than the Moore's law, that is, the radio traffic grows faster than the processing power of micro-electronic circuits. The Internet of things will be the next wave that might congest the radio traffic, with a predicted 50 Billion wireless devices soon.

Already we see that large sensor networks are being deployed. Signify deploys large wireless networks that controls the lights in a building, with hundreds of nodes connected. We see a demand for wireless networks in lighting control in smart building, but also in Industry 4.0 factories, with robots and drones communicating at high speed. However, the available radio spectrum is limited so severe, that congestion is feared. A crunch of the spectrum is foreseen unless we find ways to better utilize the bandwidth.
The scalability of wireless networks has been a topic of intense studies and the outcomes are highly relevant to carry more traffic, as needed in future. Yet the complexity of such analysis, in particular if one needs to consider all the aspects of the communication protocols, makes it a challenge to do reliably.

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MATHEMATICAL THEORY OF MEAN-FIELDS

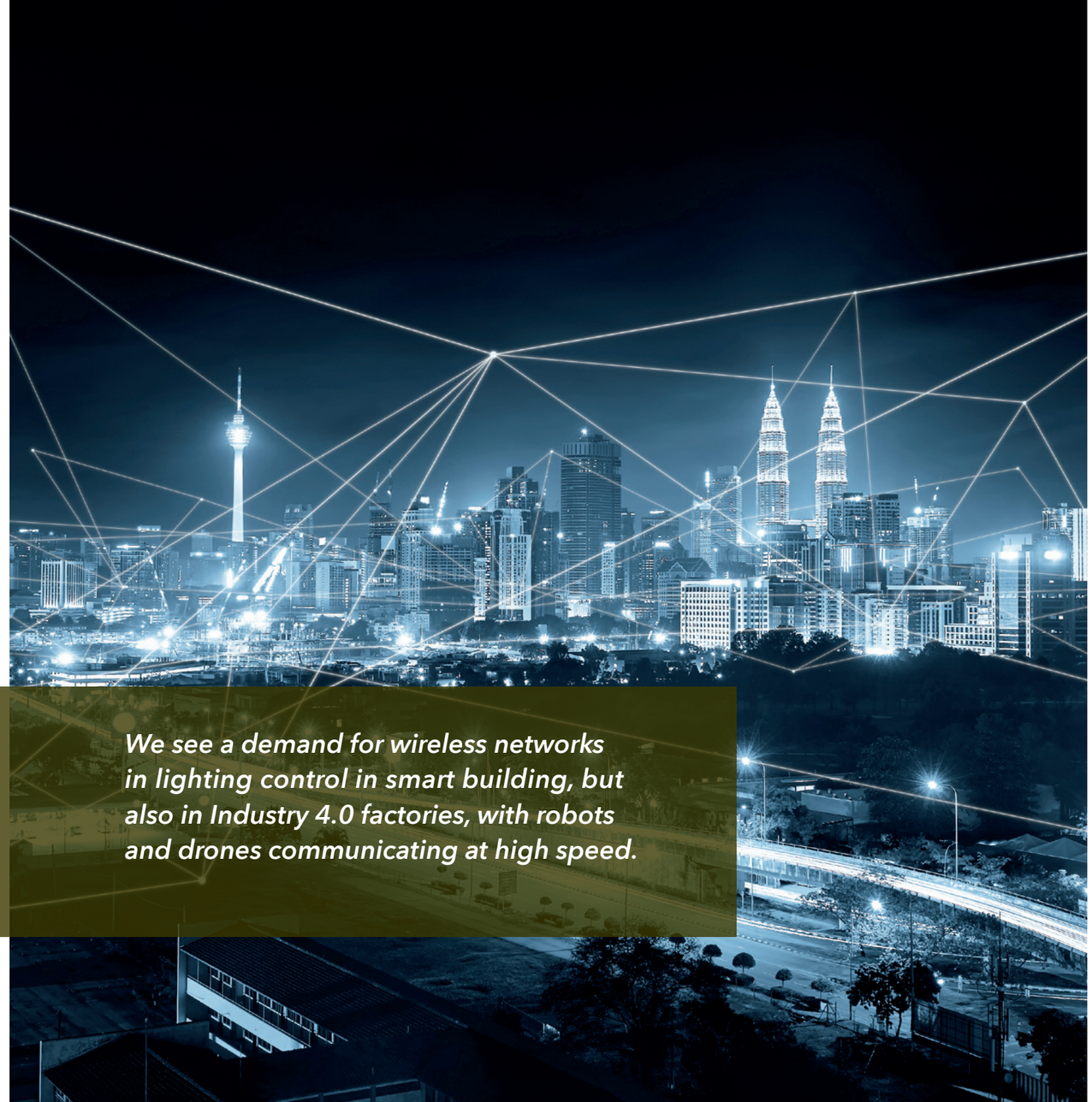
The mathematical theory of mean-fields appears to be very attractive. It offers a reasonable compromise to capture the details of radio protocols and the environment, it allows fast computations that do not depend on the precise size of the networks and facilitates the study of trends. Yet these mean-filed analyses had two problems, but Talebi resolved these. The accuracy was not very good, deviations of up to 40% were commonly noticed. A second problem is that the existing mean-field theory was not yet suited to model the dynamically changing interference environment. The patterns of interference, for instance the difference between a regular short burst of traffic, as in video conferencing of the instantaneous download of an entire HD movie has a distinct different impact on the performance seen by all other users. In a lighting control network, where all luminaires have small low-power radio transceivers on board, these see bursts of WiFi interference as a wave that pushes many of its nodes into a back-log modes, where all parties want to transmit as soon as the channel is free again. For the first time, such non-stationary behavior has now been analyzed and the mathematical correctness of the analysis approach was proven.

BREAKTHROUGH

The breakthrough in Mahmoud's work is that he managed to reduce the error from 40% to 4% in the networks that he studied. Secondly, he was able to capture the effects of bursts of interference, which pushes all nodes temporarily into a backlog position, followed by a competitive struggle of all nodes to repair their backlog. These waves of periods of poor performance are very typical for radio networks and were not well modelled before.

The essence of the story is that the mean-field theory approximates the behavior of a collection of many nodes as a set of differential equation. Thereby, nodes are no longer counted as individuals, but treated as quantities of real numbers. That works well for a large number of nodes, but the performance of the network critically depends on event in which either zero, one, or multiple nodes transmit simultaneously. These event results in an idle channel, a successful transmission or a destructive collision of interfering transmissions. The transition from the large-scale behavior of many nodes, zooming into the microscopic interaction between a small numbers of nodes is enabled by Mahmoud's works.

Many investigations thus far lacked the ability to model the dynamics of interference, and the new results from Mahmoud Talebi are an important step forward to make better networks that carry the very diverse traffic of the future, not only lighting control to millions of lamps, but also building control messages from tiny sensors, co-existing with HD video traffic.



We see a demand for wireless networks in lighting control in smart building, but also in Industry 4.0 factories, with robots and drones communicating at high speed.

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