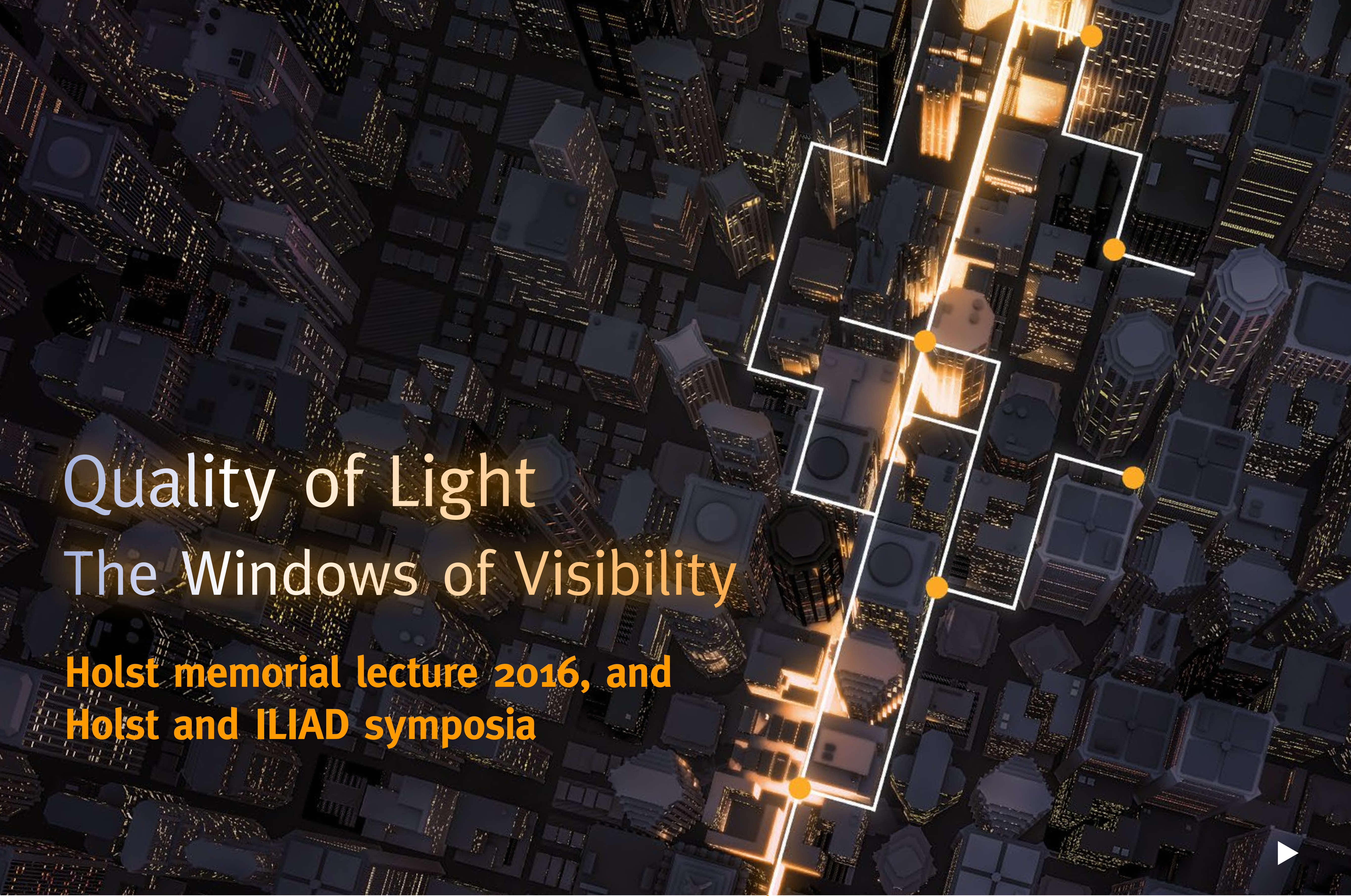


Quality of Light
The Windows of Visibility

Holst memorial lecture 2016, and
Holst and ILIAD symposia

Technische Universiteit **Eindhoven** University of Technology

PHILIPS

Intelligent Lighting Institute

Quality of Light
The Windows of Visibility

Holst memorial lecture 2016, and Holst and ILIAD symposia
Philips & TU/e

Contact:
Published by the Holst Committee,
Eindhoven, the Netherlands,
May 2017

Website: www.tue.nl
E-mail: conferences@tue.nl

A catalogue record is available from the Eindhoven University of Technology Library

ISBN: 978-90-386-4304-5

Foreword

The Holst Memorial Lecture and Symposium were organized by Philips Lighting Research and the Technische Universiteit Eindhoven (TU/e). On Thursday 17 November, the Holst Lecture 2016, the 40th since 1977, was given by Andrew B. Watson. Watson received the Holst Memorial Lecture Award 2016 for his important contributions to vision research. In his Holst Lecture he reflected on his work as a Senior Scientist for Vision Research at NASA Ames Research Center, Moffett Field.

Symposium Quality of Light

While the Memorial Lecture by Andrew B. Watson focused on achievements in vision research, the preceding Symposium covered four topics. Four eminent speakers, all leading academic and industrial professionals from different disciplines, each addressed a specific aspect of light, ranging from consumer and entertainment lighting, horticulture, semantic lighting to virtual city planning and light rendering.

ILIAD 16

Preceding the Holst Symposium, the TU/e's Intelligent Lighting Institute (ILI) organized its annual public outreach event ILIAD. Researchers connected to ILI presented current and upcoming research and innovation projects in Intelligent Lighting and its applications in Health and Well-being, focusing on the strategic partnership between TU/e and Philips Lighting. Poster presentations were part of ILLIAD 2016.

Click here for a Video registration of the event ▶

Andrew B. Watson (Holst Memorial Lecture Award 2016). Photo Rob Stork

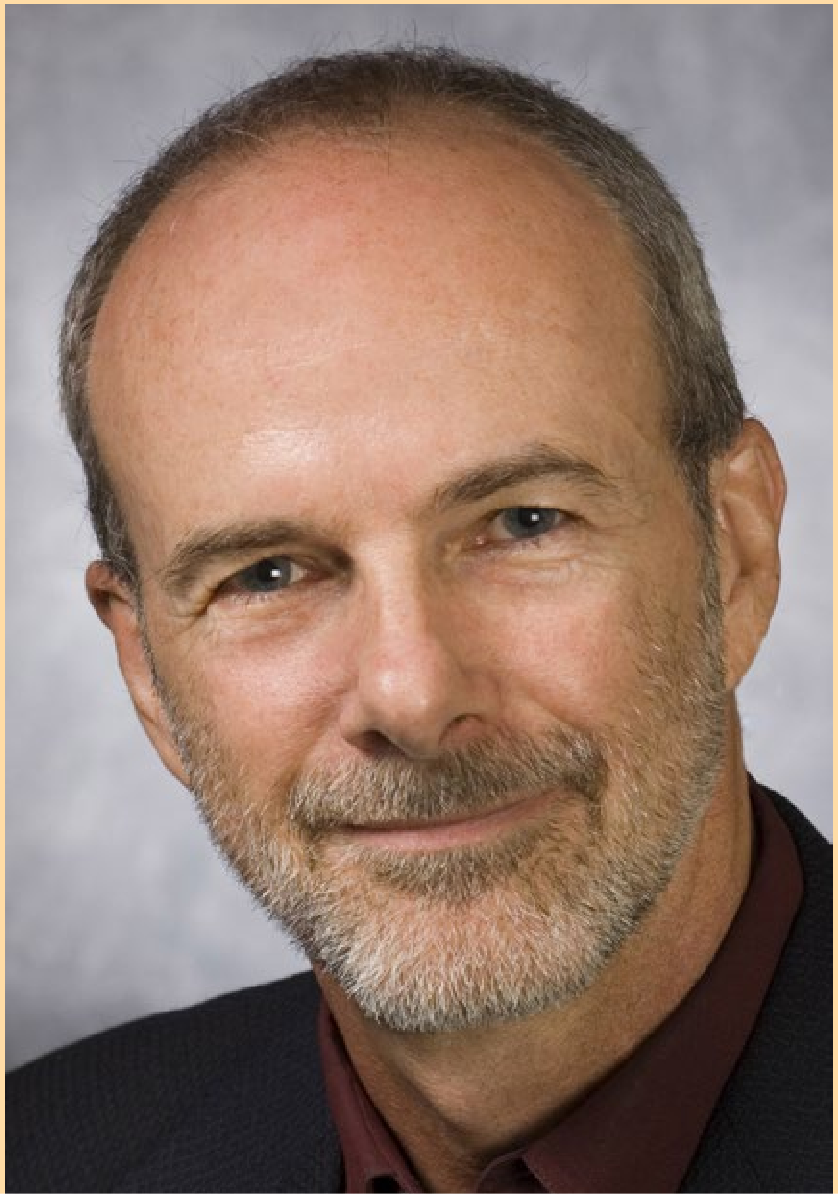
Content

1

The Windows of Visibility

Andrew B. Watson

Currently working as Senior Scientist at Apple, until recently Andrew Blanchard Watson (4 November, 1951, Washington D.C.) was the Senior Scientist for Vision Research and Director of the Vision Group at NASA Ames Research Center, Moffet Field, California. He studied perceptual psychology and physiology at Columbia University and the University of Pennsylvania (PhD. 1977), and did postdoctoral research at Cambridge and Stanford Universities. Watson conducts research on visual perception and its application to coding, understanding, and display of visual information. He is the author of over 100 scientific papers on human vision, visual neuroscience, image quality and digital imaging. He has five patents, in image compression, video quality and detection of artifacts in display manufacturing. In 2001, he founded the Journal of Vision



1

The human visual system consists of a complex series of processing steps, through which the information available to the eye is continually whittled down to produce the image we ultimately see. This process can be thought of as a series of windows, through which the light passes. Each window selects elements of the visual signal at the expense of others. Only through this process of winnowing does vision function properly, allowing selection of the most relevant information. A better understanding of this process has important implications for the design of visual and imaging technologies.

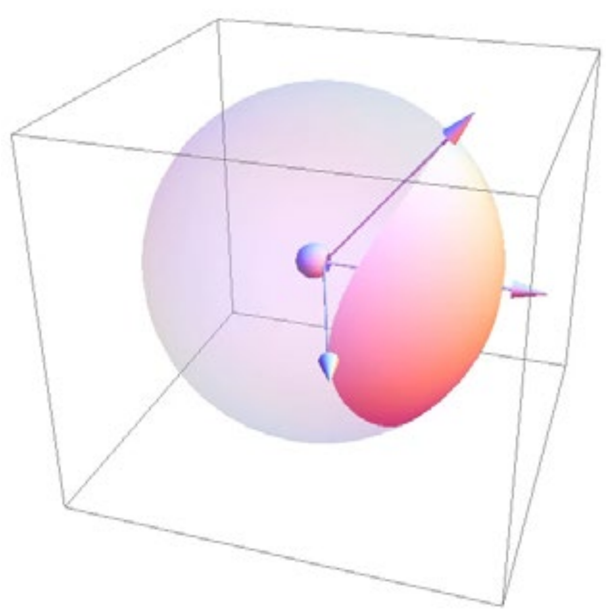


Figure 1 The field of view window

Visual processing

The first window between the external world and the visual system is the field of view. The human eye can only absorb light coming from a certain range of angles, so the field of view is the extent of the observable world that is available to the eye at any moment. This is a limitation that plays a key role in the design of visual technologies meant to mimic human vision, such as virtual reality systems.

Photons from within the field of view are then filtered through the eye to create the retinal image, a map projected onto the back of the eye which records the direction from which each photon originated. A second, optical window, mediates the sorting of these photons, and identifies their source.

From this retinal image, light is next absorbed by retinal photoreceptors known as rods and cones. The bandwidth absorbance capabilities of these receptors further squeezes the signal: Only light within a specific wavelength range will pass this wavelength window. Thus, while different light sources may have drastically different wavelength spectra, many will appear similar to the human eye because large portions are outside this wavelength window.

The visual system is also limited in terms of the intensity of light it can process. Although the eye can operate over a wide range of luminance, from dark night to bright day, it can only effectively do so within a small portion of this range at any moment (the intensity window), adapting to each region of the spectrum as necessary. Indeed, we do not truly respond to light intensity, but rather to relative differences in luminance, that is, to contrast. Early on in the visual process the retinal neurons transform light intensity into a contrast image, which represents the differences in luminance between specific points and their surroundings.

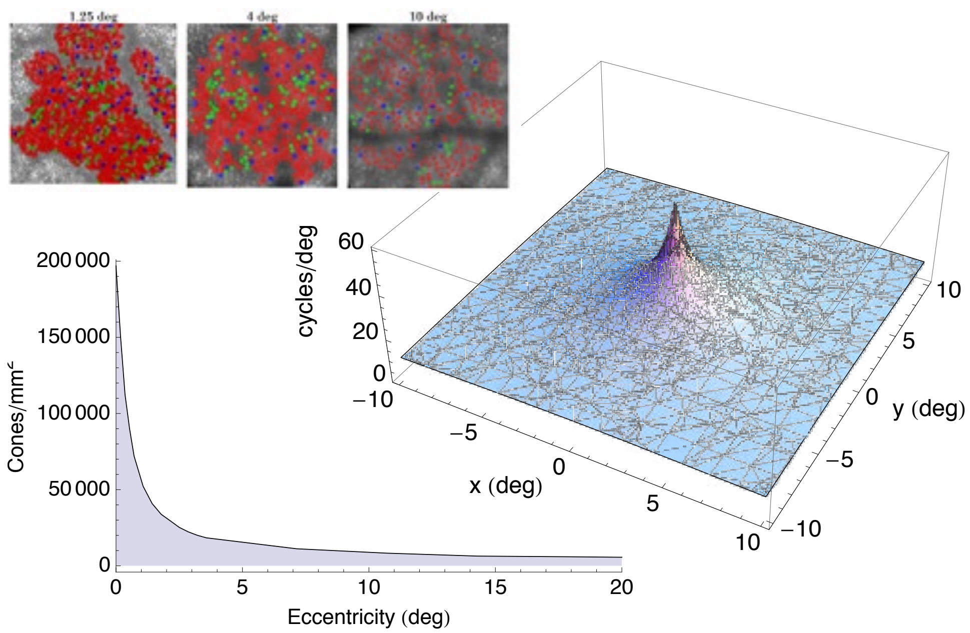


Figure 2 The window of fixation

The anatomical organization of photoreceptors in the eye imposes another limitation on the processing of visual information. Photoreceptor density is greatest around the fovea, the point of clearest vision. This accounts for the maximum spatial resolution at the point of fixation (the centre of our gaze), creating a very limited spike of high resolution vision within the field of view. The marked decrease in cone density with distance away from fovea means that resolution decreases away from the point of fixation. In other words, it is like an image in which the centre is detailed, but the level of detail fades toward the edges.

The neural component

The aforementioned windows relate specifically to the visual processing within the eye. But the windowing continues beyond the eye. Information that does not make it to the optic nerve - that is that never gets carried to the brain - will obviously not form part of what we ultimately see. What is or is not passed from the eye to the optic nerve is determined by the action of the output neurons of the visual system, the retinal ganglion cells (RGCs). Their sampling capacity is the crucial limiter of the resolution of the visual system. At the fovea, there is a one-to-one relationship between photoreceptors and RGCs: there is no loss in resolution when information is passed from the former to the latter. However, there are fewer RGCs for every cone in more peripheral areas. The RGCs must collect information from multiple surrounding cones, resulting in a further decrease in the resolution of these areas.

The images arriving in the brain are then subject to further processing. In the same way that musical sounds can be deconstructed into pure tones, images can be deconstructed into individual elements known as sinusoids, each of which varies in terms of, spatial amplitude, frequency and orientation. Smaller details, for example, correspond to more rapid sinusoidal variations, and coarser detail to slower changing variations. These sinusoids can be used to measure sensitivity of the visual system to detail of different scales in images. Limits to this sensitivity mean that details in images with a specific frequency need to have a certain amplitude (or contrast with the environment) in order to be seen to the human eye.

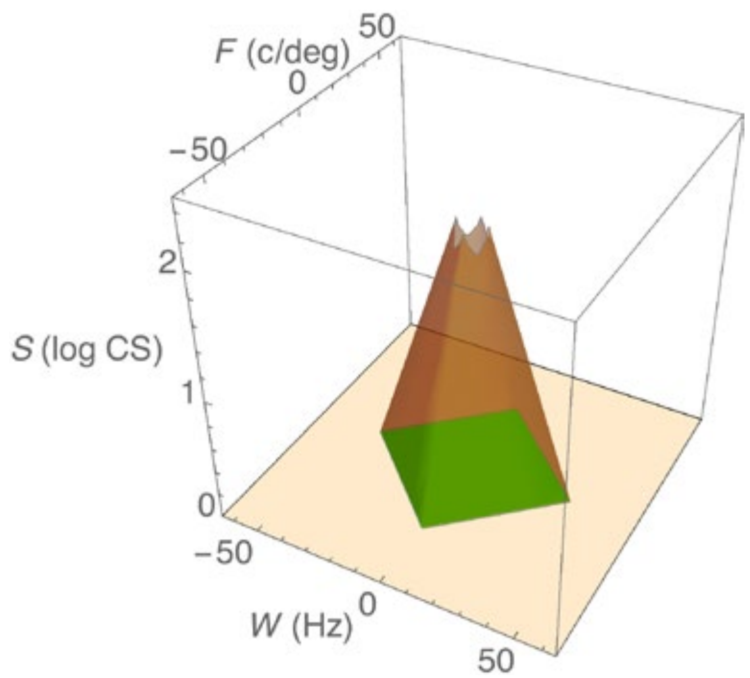


Figure 3 The pyramid of visibility

Similarly, the visual system is limited in terms of its sensitivity to image fluctuations in time. A series of images changing over time can be Fourier-transformed into a series of temporal sinusoids.

The spatial and temporal frequencies affect each other, so that smaller details become invisible at higher rates of fluctuation. By measuring our sensitivity to these types of patterns we get insight into the ability of the human visual system to process the interaction between spatial and temporal sinusoids and model the spatiotemporal visibility. The result is an elegantly simple rectangular pyramid depicting the linear trade-off between spatial and temporal frequencies. Everything that falls within the bounds of this pyramid is visible to the human observer, and everything outside this pyramid is invisible.

This construct has proven invaluable in designing imaging technologies, in which a key goal is to produce visible information, and ensure the removal of any visible artefacts. Of particular importance is the floor of this pyramid, known as the window of visibility. This is a square representing the total range of spatial and temporal frequencies that can be seen, regardless of contrast. This simple model is well behaved in response to changes in contrast, luminance, and spatial and temporal frequency, and therefore can be used to perform very simple engineering calculations; for example, to determine whether certain types of displays with limited contrast will show motion artefacts, spatial sampling artefacts, flicker, etc.

Ensuring the right quality of images

Knowledge of each of the processes involved in filtering visual information to produce a definitive image in the brain - and being able to model them with considerable accuracy - can be applied to design, development, and quality control of visualisation technologies. Thus for a given display, we can use a series of computational tools or algorithms to create the corresponding neural image, a representation of the image on the optic nerve travelling to the brain. A key application of this sort of modelling is in compressing visual information. Presenting images on devices such as phones and tablets, or via streamed TV means striking balance between the quality of the image and the quantity of data taken to encode it. While the amount of data needed to represent an image can be minimised using compression, excessive compression will degrade the image. A model of the visual system can be used to determine the optimum level of compression to retain the perceived quality of the image.

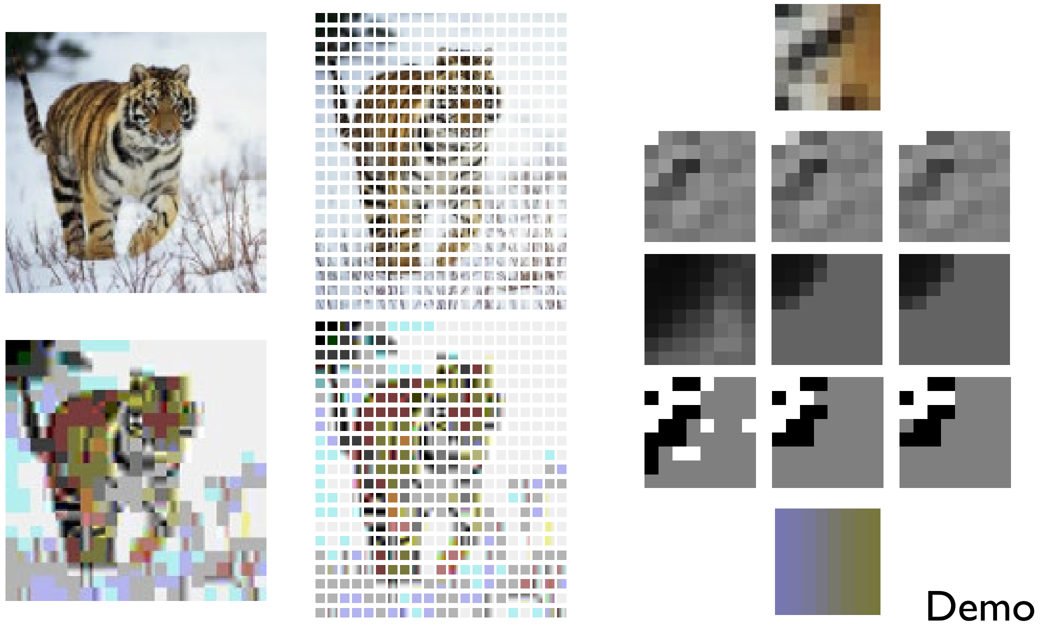


Figure 4 JPEG compression

Take the ubiquitous JPEG image as an example. Compressing a JPEG involves dividing the image into blocks of 8 × 8 pixels. Each of the 64 component pixels in such a block encodes a given frequency. Since the human visual system is more sensitive to low frequencies, the accuracy of rendition of high frequencies can be selectively reduced without causing noticeable deterioration in image quality. This is done using quantisation matrices, which are like a series of dials that can be modulated to alter the accuracy with which each frequency is rendered. The 8 × 8-pixel blocks are reconstructed to produce the compressed version of the original image. The more the image is compressed, the greater the range of frequencies affected, and the more likely it is that lower, visible frequencies will be affected, resulting in visible artefacts. However, a model of the sensitivity of the visual system to different spatial frequencies can be used to guide the adjustment performed by the quantisation matrices, thus rendering a final product in which the artefacts remain outside of the threshold of sensitivity of the visual system. DCTune is one example of a technology that uses this approach to achieve maximum “lossless” compression on an image-by-image basis.

The window of visibility can also be used to calculate the optimal conditions for the frame-rate of moving pictures. These have always relied on the stroboscopic effect, whereby a sequence of still images is displayed at a rate that leads the visual system to stitch them together into a rendition that appears smooth. Determining what constitutes “smooth”, in terms of the number of frames shown per second can be computed using the pyramid of visibility. A shorter shutter time induces more flicker at a given frame rate than a longer shutter time (but this doesn’t matter at sufficiently high frame rates). A longer shutter time reduces the visibility of flicker, but at the expense of motion blur. How to balance both can be deduced from the pyramid of visibility. While opening the shutter for longer allows for smoother appearing motion on film, it also increases motion blur, an artefact that can be eliminated using the pyramid of visibility. Similarly, jerkiness in film is caused when replicas of the spectrum are produced at intervals of the frame rate that fall within the window of visibility. This artefact can be eliminated by adjusting the frame rate to push these replicas outside the window of visibility.

1

Controlling the quality of displays

Between phones, tablets, television screens, and monitors, a mind-boggling number of displays are produced and purchased every year. While quality control was previously carried out by human observers, the sheer numbers involved mean this is no longer feasible. Moreover, the human eye is notoriously subjective. The window of visibility can be applied to automate the process of display inspection by creating a system that is no less sensitive than the human visual system, but also no more sensitive -- as there is no need to correct errors that humans cannot see. This is achieved using spatial standard observer defect analysis (SSODA), which runs images through various filters and technologies to produce a "just noticeable difference map" indicating the presence, location, and size of any defects. SSODA has proven highly valuable for manufacturers to ensure quality control.

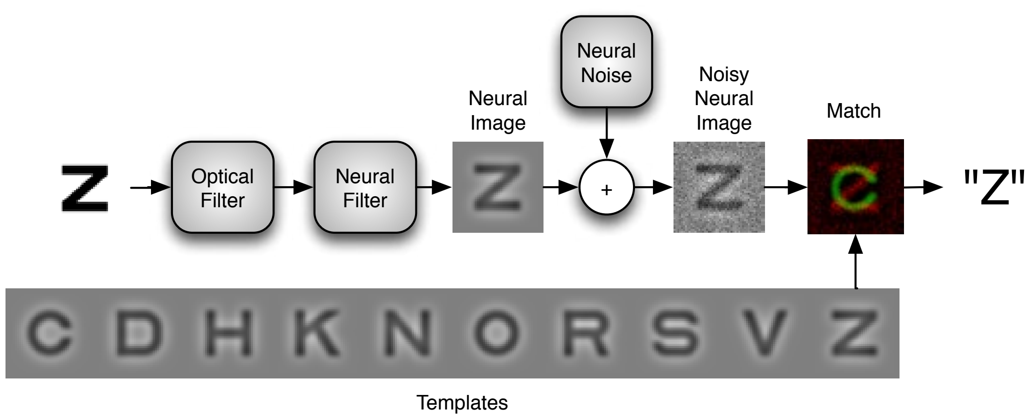


Figure 5 Template model for ensuring adequate display representation for human observers

Another use of the window of visibility is in the development of task-based imaging systems. One such example is an electronic imaging system, consisting of a camera and a display, used by the US Navy to replace older optical submarine periscopes. A template model was used to develop an automated system that could identify small watercraft at varying distances and with different levels of visual interference. This system was initially tested using letters, given their low complexity and the abundant literature on the human ability to identify letters. Thus, a target image was run through a number of optical and neural filters to simulate the human visual system, and neural noise added to the image. Finally, a template matching operation was performed, and the final match scored as correct or incorrect. The result was a 100% correct overall score, after which the system was further optimized using more complex images.

Displays of all kinds play increasingly important and ubiquitous roles in our lives. By harnessing our ever-expanding knowledge of how the human visual system filters and interprets visual signals, the processes by which information is captured, rendered, processed, and displayed can be progressively improved.

1 Watson, A. B., & Ahumada, A. J., Jr. (2012), Modeling acuity for optotypes varying in complexity. Journal of Vision. 12(10), 1-19.
2 Watson, A. B., & Ahumada, A. J., Jr. (2008), Predicting visual acuity from wavefront aberrations. Journal of Vision. 8(4), 1-19

LEDs: Revolution in Horticultural Plant Production?

Leo F.M. Marcelis
Professor Horticulture & Product Physiology at Wageningen UR

Leo Marcelis is head of the Chair group Horticulture and Product Physiology.
The chair group Horticulture & Product Physiology of Wageningen University (the Netherlands) is the only academic group focused on horticulture in the Netherlands and holds a strong position in horticultural research and education. Our research and education focuses on physiology of production and product quality in horticulture.
The chair group consists of 10 permanent staff members, about 20 PhD candidates and postdocs and a number of guest researchers. Each year about 25 students conduct their thesis study (a 6-month research) at our group.

2

Producing sufficient crops to feed the growing population of the world will require new, more efficient approaches to plant production that are sustainable and energy efficient, and maximize the use of space. Since this entails the production of plants in indoor, closed systems, independent of the surrounding environment, the use of artificial lighting is fundamental to success. The light emitting diode, or LED, is a crucial player in a horticultural revolution that is already underway.

The current global population currently stands at around 7 billion, a figure projected to increase to 9.5 billion by 2050. This means a 60% increase in food demand by 2050, and underscores the pressing need for efficient horticultural technologies to boost food production. But producing larger quantities of food is just one aspect of this challenge. The problem needs to be tackled in a manner that guarantees the quality and sustainability of the food sold to consumers. It means producing crops in a more water-efficient manner, and reducing dependency on fossil fuels. Crucially, these criteria must be fulfilled while ensuring that the food retains its taste and offers high nutritional value. And to further complicate matters, all this must be achieved while keeping production as local as possible, to minimise transport overheads for feeding large urban centres.

Advances in horticulture

The world-leading Dutch horticulture sector is one of the top sectors of the country's economy, with an export value of €16 billion a year. Moreover, this industry has seen major advances in the last 30 years, resulting in a two-fold increase in the yield of certain crops. These gains have been made thanks to greater control of all aspects of the production process. These include automated control of parameters such as lighting, heat, water supply, cooling, humidity, and CO_2 levels. Vertical farming is another recent and major development in horticulture. This involves producing food indoors in vertically stacked layers, using only artificial light. As such, this system is completely independent of environmental conditions, and allows a greater degree of control over how plants are grown.

However, the manner in which light is used in these systems is critical, and is dependent on a proper understanding of how plants use and respond to light. Photosynthesis, the process by which a plant converts light to energy in the form of sugars, is the driving source of plant growth. Light is absorbed by plants via a variety of photoreceptors, including phytochromes, cryptochromes, and phototropins. These photoreceptors have different sensitivities to the spectrum, and thus absorb light at different frequencies, mediating distinct processes within the plant.

In this scenario the use of light emitting diodes (LEDs) lighting offers major advantages over other lighting solutions. In addition to their greater energy efficiency, the spectrum emitted by LEDs can be tuned according to the differing needs of different plant types, and depending on the characteristics sought in the final product. While traditional lighting systems emitted huge amounts of heat, LEDs produce far less heat radiation, and no near-infrared radiation. This enables greater separation in the control of heating and lighting. It also allows greater freedom in manipulating the position of the light source, which was not possible with heat-emitting light sources that could cause heat damage to the plants.

LED-it be

The LED-it-be research program, financed by Technology Foundation STW, involves 10 companies and five Dutch universities. Through innovative use of LED lighting, the program seeks to reduce energy use in horticulture by at least 50% – although reductions of up to 70% may be attainable. LEDs are about 40-50% more efficient at converting electricity to light than older, high-pressure sodium lamps. So energy saving in other aspects of the horticultural process will be necessary to achieve the overall goal. The objective is therefore to increase the efficiency with which light is converted into horticultural product by 30%, without sacrificing any of the quality attributes of the final product. This will be achieved by enhancing light absorption (by 15%) and photosynthesis (by 10%). Finally, further gains (5%) can be made by improving assimilate partitioning (the distribution of sugars among different organs the leaves, stem, and fruit of a plant). That is, by modulating the light source, the energy can be directed to the organ of interest, such as the fruit, the flower or the leafiness.

Figure 1. Optimizing position of lamps and crop architecture can lead to 15% more crop growth by improvement of light absorption

Tailored lighting solutions

LEDs offer significantly greater flexibility than other light sources when it comes to light placement. Interlighting is the positioning of LEDs among, as opposed to above, plants. It allows for much better vertical distribution of light, and decreases light wastage. The optimal light placement can be determined using mathematical models that simulate the architecture of both the plant and the greenhouse. Taking this modelling approach a step further, it is possible to identify the ideal morphological traits required in a plant to maximize photosynthesis, (e.g. stem length, leaf size, etc.).

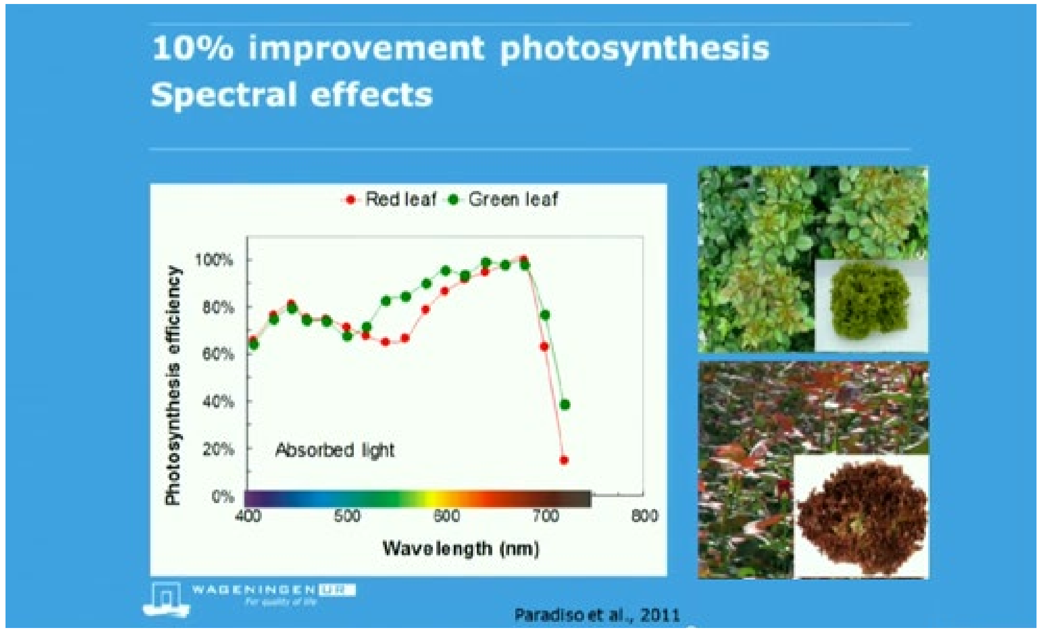


Figure 2 Spectral effects can produce a 10% improvement in photosynthesis

Because LEDs allow the user to control the spectrum emitted, plants can be administered light of specific wavelengths at specific times of the day, in accordance with optimal growth parameters. For example, a short period of exposure to far-red light at the end of the day has been shown to significantly affect plant structure, while the percentage of blue light absorbed can significantly alter plant height. Photosynthesis is also significantly influenced by the light spectrum, and thus can be optimized by modulating the spectrum provided to the plant. For example, while red light alone has counterproductive effects, increasing the proportion of red light to which a plant is exposed enhances photosynthesis.

Crucially, plant growth is not linear, and changes throughout the day. By using chlorophyll fluorescence sensors to provide direct feedback from the plant, activity can be monitored and optimal lighting can be matched with the moments of maximum plant productivity.

More than growth

While optimal growth is a key objective in horticulture, this cannot be achieved at the expense of other parameters, such as disease resistance, taste and nutritional value. Lighting can be used to create conditions in which the development of disease is minimized. This has been demonstrated with mildew, which can be combatted by exposing plants to additional red light during the night. Similarly, close proximity exposure of tomato fruits to light has been shown to substantially increase vitamin C content.

While most research has focused on the effects of light on growing plants, lighting conditions post-harvesting can significantly influence product quality. This has been demonstrated with lettuce stored under light, which is significantly fresher 5 days after harvesting than lettuce stored in darkness.

Through careful control of the many parameters that affect plant growth in controlled systems, an optimal balance can be struck to improve horticultural productivity in order to address the increasing food demands of a growing global population. LED lighting will play a central role in this horticultural revolution, enabling the establishment of sustainable, highly productive, energy efficient vertical farms.

3

Turn on Living: Lighting Experiences with Philips Hue

Filip jan Depauw

Co-Founder of Hue and Head of Business Development, Strategy and Marketing, Philips Connected Lighting, the Netherlands

One of the two founding fathers of Philips Hue, personal wireless lighting. The succesful Philips Hue launch was the start of many more exciting solutions released for the residential market.
Filip jan Depauw has recently moved on from his role as overall marketing responsible of all Hue propositions to being the leader of the Friend of Hue and Developer Program. Previously as global segment director in the retailing and hospitality markets, Filip jan was responsible for setting the long-term strategy for developing lighting solutions for those business segments, and bringing them to market. Joining Philips in June 2008, Filip jan brought with him considerable experience and understanding of all key elements of modern marketing, from portfolio management and communications, to strategy and research. Prior to Philips, Filip jan had spent almost a decade at Electrolux Home Products Europe.

At Electrolux, Filip jan rose to the position of Vice-President Product Marketing and Kitchen, driving innovation for the company's built-in kitchen appliances. Previously, Filip jan worked for AEG as European Brand & Marketing Director, helping develop and execute AEG's brand position. Earlier in his career, Filip jan worked for the bathroom fixtures company American Standard Europe as brand portfolio director, gaining valuable experience in working within both the consumer and professional value chains.

Filip jan began his professional career as a client service executive at Initiative Media, based in Germany, later joining AC Nielsen where he acquired a background in market intelligence and new business initiatives as well as strategic communications. Born in Belgium, Filip jan studied in Antwerp and later completed an MBA in San Francisco, California.

3

Philips Hue is part of the internet of things, and today it is one of the largest connected-device installed-bases globally. Over the last four years, Philips has established this product line, which has a simple lightbulb at its root, but that turns what was 'just' lighting into an experience which is safer, more robust and a lot more fun.

A journey that started with a question

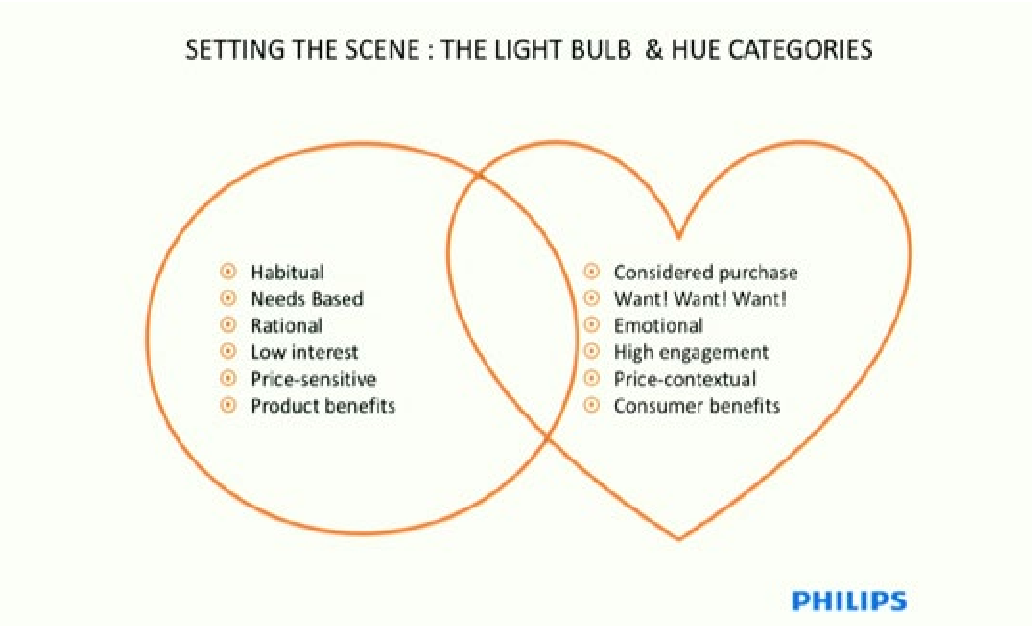
To get to the point of creating Hue, the marketing team needed to answer one question: Why would someone want to connect their lights to the Internet? To find the answer to this they looked at the flexibility presented by the technical possibilities of LED lighting beyond just illumination. They identified four domains of benefit to customers with connected lighting: the roles of light in security in and around the home, and by creating a mood in wellbeing and positivity; and the benefits of linking to data, and in creating ambience. The team worked out these benefits in detail, and after investigating the possibilities with LED lights, they came up with a plan.

While researching the benefits, they looked at what a connected lighting infrastructure should look like. That is, how a consumer should connect to it in a way that was future-proof and secure. This led to rapid prototypes that were tested in Berlin, Shanghai and New York.

The sales model and setting the right price level were also a challenge – and while the decision to sell this experience for USD 199 caused some initial shock, the team believed that through consultative selling and making the benefits clear, it could be done.

Lastly, it was important to discuss how Hue would interact with other devices in the connected home, with the solution potentially needing an open ecosystem. The consequences of such a move made for a lot of interesting discussions within the team.

A comparison was created of what makes Hue different from a traditional lightbulb. It became clear that the focus was on Hue being a 'want' rather than a 'need'. This created the foundation for the team's journey. With the simple slogan 'I want Hue' on the boxes, the product was sent out.



Setting the scene: comparing the features of the light bulb (on the left) and Hue

Why is Hue loved?

Social media was a particularly good place to gauge the reaction to Hue. Feedback expressed both love and hate reactions (much stronger than like or dislike) to the different features Hue had to offer. This helped ensure the solution could be structured with important elements that could ensure satisfaction after spending USD 199. It was paramount, for example, that Hue should be easy and fast to install and use, giving instant gratification. The team also wanted to make sure it was easy to control for the entire family, without one master in charge.

In fact, choice of control is a big part of Hue's success. Even without a smartphone – or when a smartphone is not practical – Hue can be controlled in many different ways.

The 'light recipe' feature on the app was also well received. This allows people to create lighting to suit different scenarios, such as bright light when they need to concentrate, whether it is for cooking or completing their Sudoku; but also to get lighting that can energize or relax – drawing on the large amounts of research data accumulated over the years by Philips lighting.

A wide choice of controlling possibilities is important

Friends of Hue

Consumers' homes are becoming more digitized than ever before, and with this a large number of brands are in the fight for supremacy. In the case of Hue, creating a friendship with these many brands is important, to complement each other's strengths to achieve joint success.

The "Friends of Hue" program allows Hue to integrate with other brands so that consumers can adapt Hue easily to their daily life. For example, if a consumer has a Google Nest thermostat they can partner the products to be aware of when the family is out of the house – when the thermostat is turned down - so the lighting reacts appropriately.

Voice control is another development the Hue team believe will become increasingly popular since its recent launch in the US. This is one of many types of control that Hue works with to make home life more enjoyable, as well as easier.

The developer community has also played a large role in making Hue the success it is today, with over 35,000 people using the open API and SDK. Their creativity at events like hackathons has helped create functionalities within the solution, ranging from sleep to photography applications, which wouldn't have become a reality otherwise.

This has also resulted in connected lighting in the context of entertainment. Hue has partnered up with a number of TV shows, including The Voice and 12 Monkeys, to create choreographed lighting affects which complement the action in the shows, to make a more immersive experience for viewers.

Only the beginning

Hue has been able to open a new chapter for lighting in the home, making the experience one of choice and enjoyment. The team continues to look for ways to take the home lighting category from a need to a want. They are doing this in three ways – by turning on consumers' peace of mind (the feeling of security from the right lighting), by enhancing their moments (to benefit from how light influences wellbeing) and by stimulating their imagination (by making entertainment experiences more immersive).

The goal is to create a happy you, and for a happy you to have more Hues.

Toward semantic and cognitive light

Zary Segall

Zary Segall is an Endowed Chair Professor at The Royal Institute of Technology in Stockholm, Sweden. He is Scientific Director of the Department of Communication at the institute, and Director of its Mobile Media and Services Lab. Prior to joining the Royal Institute of Technology in 2011, Segall was a Professor in Computer Science and Electrical Engineering at the University of Maryland, the University of Oregon, and the Carnegie Mellon University.

Segall is a fellow of the IEEE Computer Society, and a Fulbright Distinguished IT Chair. He has developed theoretical methods and practical systems for parallel processing, highly dependable systems, networking, and wearable information systems. This work led to software licensing to IBM, AT&T, GE and NASA and to applications in parallel processing, NASA missions, air traffic control and telecommunication services. His current research interests are in human-aware wearable computing, and in semantic info-light.

Researchers and innovators around the globe are continuously exploring how to take the role of light beyond illumination. This aims to address one key question: how can light be used to solve problems? A clear understanding of semantic and cognitive light – and of the real-world applications of these concepts – could provide solutions to many important issues in this field.

The difference between semantic and cognitive light

Semantic light differs from conventional 'agnostic' light in that it knows about and responds to humans, to the context of the environment, and to the objects it is illuminating; in other words, it possesses both static and dynamic awareness. For example, imagine a picture placed on a table. An agnostic lamp would simply illuminate the picture in a way that helps us see it more clearly, but a semantic lamp also 'understands' the image. As a result, it might project related material onto the surface around the picture, or move with the picture as you reposition it on the table.

Cognitive light takes the notion of semantic light to the next level. This technology recognizes the semantics and dynamics of the scene, but also understands what the user wishes to accomplish – thereby adding task awareness and problem-solving capabilities.

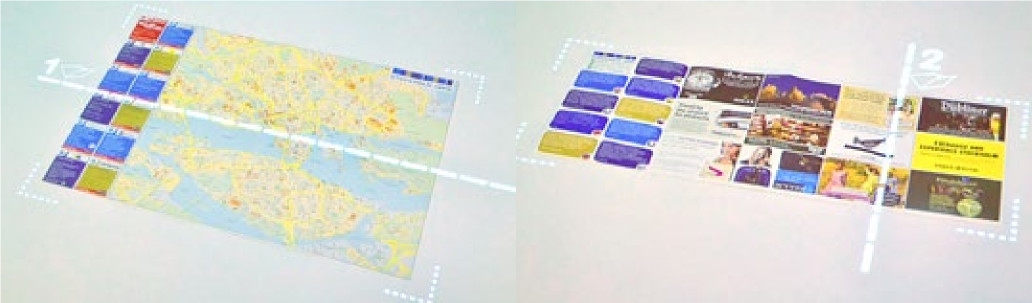
Shaping the Internet of Light

It is easy to see how semantic and cognitive light dovetail with the broader developments of the Internet of Light (IoL). This concept takes objects in an environment and illuminates them with information, and then structures light around them to solve a particular problem.

Autonomous cars are an example of IoL in action, as they use light to understand objects, tasks and contexts. The self-driving artificial intelligence vision has now become a commodity, showing just how much progress has already been made.

In essence, IoL builds on the foundations of the Internet of Things (IoT). Where IoT involves adding sensors, tags and networking to low-cost everyday objects, IoL adds connected intelligence – in the form of semantics and cognition – to everything it illuminates.

Applying IoL in the real world



IoL technology in practice: visual guidance for folding maps

Numerous real-world applications already exist, such as for step-by-step visual guides for people wishing to fold up a map. Many individuals often find it difficult to return a large-scale foldable map to its smallest size, but if a fully folded-out map is placed on a table, the IoL application projects visual instructions onto the map. This clearly shows the user exactly where they are supposed to fold, and in what order; when a fold has been completed successfully, the application recognizes this and displays the next step. The technology could be applied to other walks

IoL technology in practice: guidance for preparing tea

of life; for example, IKEA are interested in leveraging this approach to help its customers assemble their furniture.

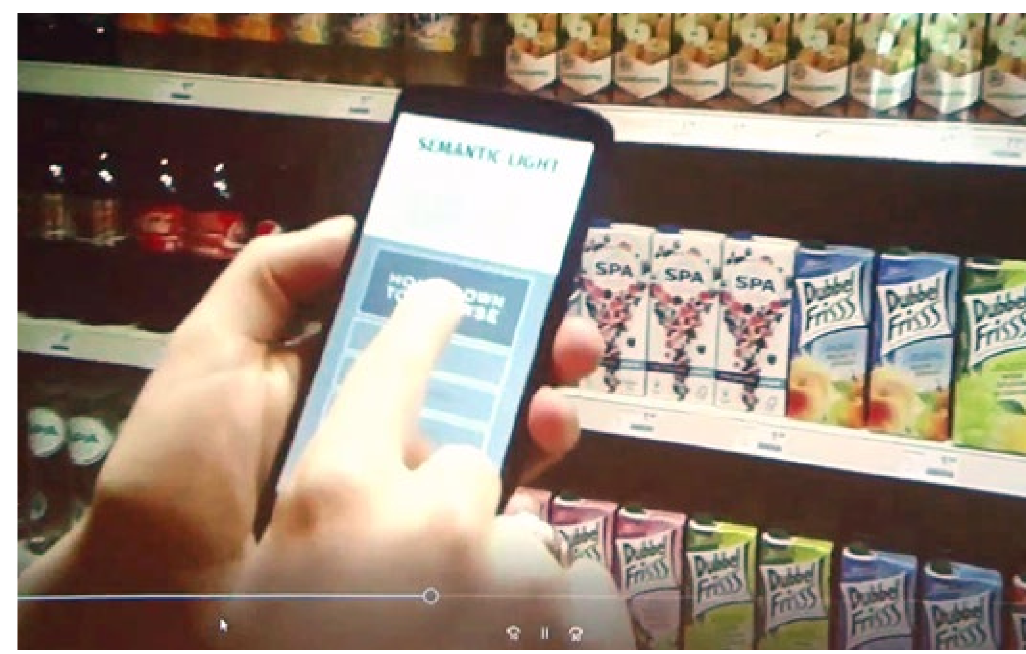
The principles of IoL can also be extended to other applications, such as providing instructions and guidance that help elderly people to correctly and safely prepare pots of tea – thereby allowing them to retain a degree of independence in their own homes.

Connecting physical and digital spaces

IoL innovators are striving to connect the physical space with the digital space. Currently, for instance, many people use web browsers to request and receive information in a purely digital format; but what if browsers could enable digital-to-physical and physical-to-digital data exchange? Major players such as Google, Apple and Amazon are leading the charge to overcome these boundaries and unite the two worlds.

As one example of the process in action, consider a smartphone app that uses light to connect you to a specific item in a store. Pointing your smartphone at the item brings up detailed product information on the phone's screen, and invites you to purchase that product or share it on social media, for instance.

This may sound like science fiction – but in Eindhoven, it is already a reality. At the Philips Lighting Innovation Village, users can access a physical-to-digital browser on their smartphones that is integrated into Philips Lighting. This semantic light capability allows users to obtain information on specific products as they move through the aisles of a store, empowering them to make informed purchasing choices.



Semantic light in action at the Philips Lighting Innovation Village

Structured light

Picture a 3D scene, such as a room. What if there was a luminaire that could understand the room and its contents, but was also able to form its light around a particular object? To investigate what is possible in this field, Segall and his research colleagues are working on a mobile shopping solution that leverages 'spatial transition' technology to implement information from a 2D poster onto a real-life 3D object. In one example, a smartphone user points her device at a two-dimensional photograph on a wall, and the smartphone's light recognizes the content of the image. Consequently, the light 'forms' around objects in the photograph – such as the jacket that one person in the picture is wearing – and the smartphone then uses its mobile connectivity to identify the type and style of the jacket. The user can then project the item of clothing onto a 3D mannequin positioned elsewhere in the room.

Transferring information from a 2D poster to a real-life 3D object

To make these future visions a reality and solve real-world problems, it will be necessary to create light bulbs or other devices that share the intelligence and type of platform needed to operate a self-driving car – plus the ability to structure the light, and to understand exactly what the

The jacket seen in the 2D poster can be visualized on the 3D mannequin

light is seeing. There is real consumer interest in this technology; for example, Beam, a smart bulb which already boasts some of this functionality, is one of the most popular Kickstarter projects running today, having amassed around 20 million US dollars in crowdfunding.

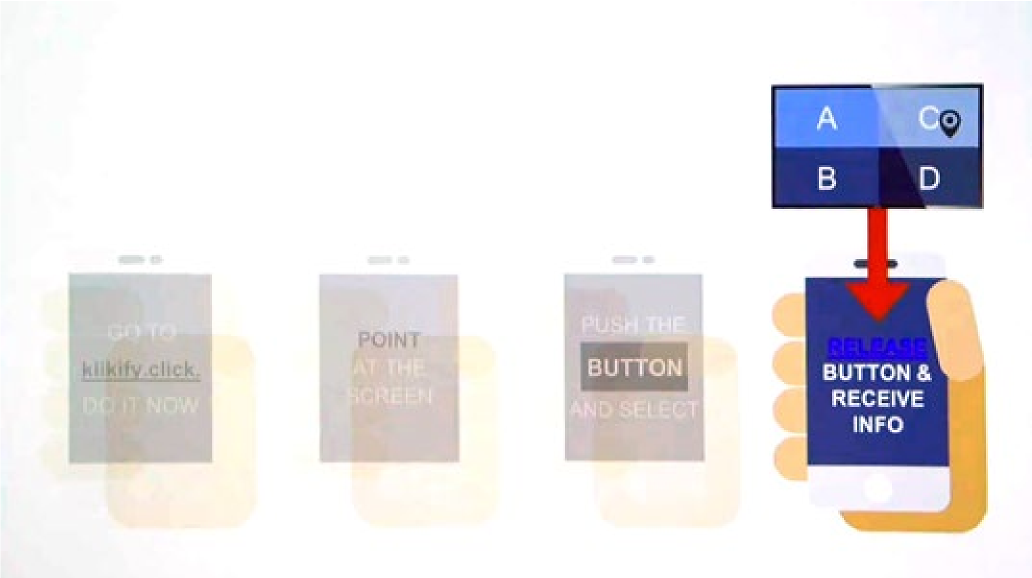
Klikify: Transforming promising concepts into real-world success

In Sweden, research specialists such as Segall are compelled to convert their innovative concepts into employment opportunities. Currently, it would not be possible to implement the structured light concept explained above on a commercial scale, as a suitable luminaire for the task has not yet been developed. Consequently, Segall and his colleagues considered whether they could apply existing technology to video footage, rather than entering the 3D space.

This led to the founding of Selitera, a company whose workforce comprises former students of Segall who have successfully completed PhDs under his tutelage. The Selitera team realized that the two most common device types in the world – screens and phones – are not yet fully connected. This inspired the birth of the *Klikify* concept, which aimed to use light to connect the information in signage screens with the user's personal mobile digital space. The vision was to transform any content on a video screen into an interactive connection with the user's smartphone.

If, for example, an advertising screen shows a video, the user could point their phone at the screen to select a product that appears in the advertisement, and then buy that product or share it with others. To do so, the user accesses a URL (klikify.click) on their smartphone browser, and points their device at a signage screen. This action results in a button appearing in the open browser; if the user holds that button, a pointer appears that can then be directed to a specific area of the signage screen. Once the pointer is hovering over an interesting area of video content, the user simply releases the button to receive information about the content they've selected.

This system works with practically all screens and smartphones with browsers which support the widely-established HTML5 format. There is no need to download any additional apps, and new versions of Google Chrome directly support the system since Google introduced physical pages. *Klikify* capabilities have already been integrated into all LG and Philips signage and smart screens – and the solution uses the same platform that would be used if the right luminaire was available to work in the 3D context. The *Klikify* project therefore represents a real step forward in the quest to unite physical and digital space.



The Klikify concept

Overall, the evidence gathered by Segall and his colleagues indicates that the potential applications of semantic and cognitive light are highly diverse – and not only that, more realistic than many people may have first believed.

Intelligent cities

Kent Larson

Principal Research Scientist, MIT, Boston, USA

Kent Larson is principal research scientist at MIT and director of Changing Places: a joint MIT Department of Architecture and Media Laboratory research consortium. He also runs the associated House_n research group and the MIT Open Source Building Alliance. Current research focuses on strategies for creating responsive places of living via new design/fabrication strategies, defining system level standards for an open source approach to building design and construction, and developing ubiquitous sensing/computation technologies that do useful things for people related to proactive health, energy conservation, communication, and learning. Larson's group, with TIAX LLC, has developed a unique, world-class residential research facility called the PlaceLab to systematically prototype and test new technologies and design concepts in the context of everyday life.

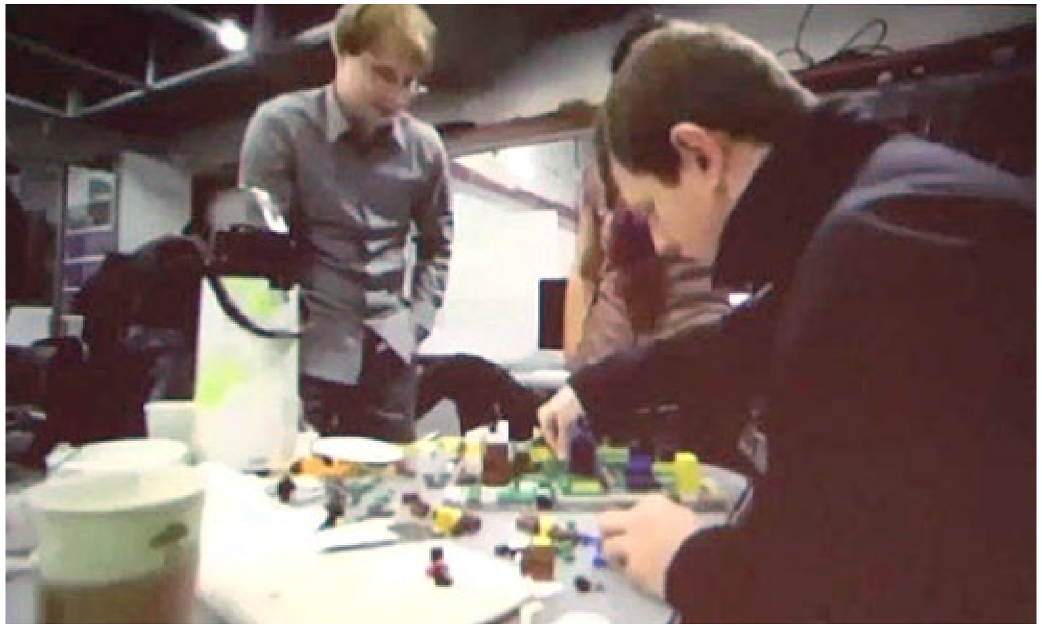
Larson practiced architecture for 15 years in New York City in partnership with Peter L. Gluck, and more recently as Kent Larson, Architects P.C., with work published in Architectural Record, Progressive Architecture, Global Architecture, the New York Times, A+U, and Architectural Digest. His book, Louis I. Kahn: Unbuilt Masterworks was selected as one of the Ten Best Books in Architecture, 2000 by the New York Times Review of Books. Related work was selected by Time magazine as a "Best Design of the Year" project.

As the density of urban environments continues to increase, it is important to maximize the performance and innovation potential of cities across the globe. This entails the development of intelligent concepts that could revolutionize the way we move, and the way we live.

When it comes to urban development, it can be challenging to conceive practical approaches that will optimize land use, but also foster innovation and drive growth. Space is at a premium in many cities – but the need to quickly and affordably accommodate fast-growing populations should not come at the expense of intelligent urban design. As such, city planners must seek to unite density, proximity and diversity. In other words, their designs should achieve the right level of workplace and residential density; the right facilities should be in the right places, where people need them; and their plans must foster the integration of people from diverse backgrounds, giving them platforms to share and grow new ideas.

Tapping into social ties

Urban population growth is set to continue for years to come, and offers enormous opportunities to develop new hubs of innovation. As MIT studies have shown, urban districts which are home to larger numbers of people with strong social connections tend to be the most creative and productive. It therefore seems plausible that increases in human interaction and density could boost innovation potential.



Modelling with data units (Lego bricks)

CityScope

To better capture and analyze the way humans interact with urban districts, researchers from MIT's Changing Places group – led by Kent Larson – developed *CityScope*, a real-time, data-driven simulation platform for decision-making and community engagement. The team found they could use augmented reality to add layers of information to their tangible, Lego-based models, and began to simulate and visualize numerous types of data, including land use and mobility modes, but also less typical data such as venture capital and biotech funding flows. Further, Larson and his team leveraged geo-located tweets as a proxy to track the activity of young people.

ViewCube

The team continues to develop the platform. For example, *CityScope* now supports the integration of sophisticated tools that non-experts can easily use, such as the *ViewCube*, a handheld, drone-like object that the user can 'fly' over a physical model to alter the three-dimensional perspective on a digital screen.

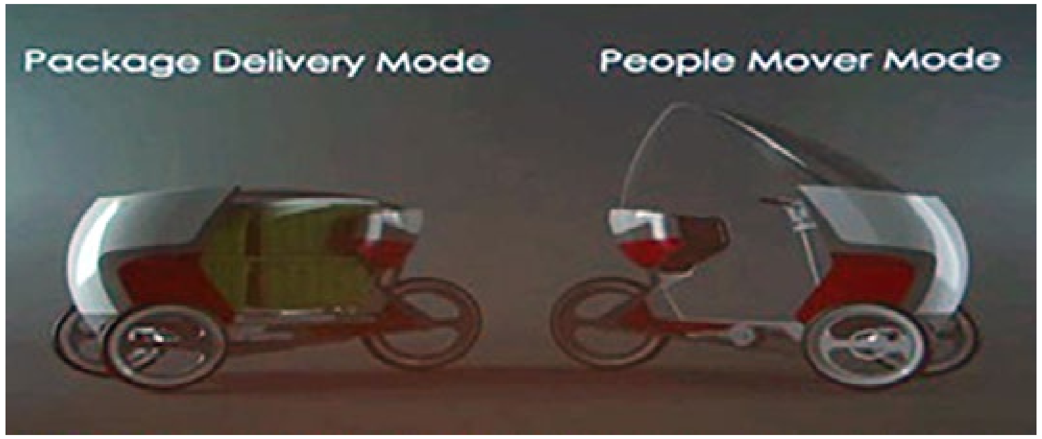
Further, in a quest to make *CityScope* more interactive, the team introduced optically-tagged elements. This approach was first trialed in Riyadh, Saudi Arabia, where a one-square-kilometer district of the city was being redeveloped. Users could toggle between layers of visualization to analyze various factors such as access to daylight, energy flows, and walkable access to parks, workplaces and housing.

CityScope: Riyadh: Daylight, energy and walkability simulation

Mobility-on-demand

Many cities have been developed top-down around private automobiles, resulting in transportation systems that are not conducive to human interaction. Common issues include severe traffic congestion and a constant need to dedicate prime urban real-estate to parking facilities. The Changing Places group sees shared transportation as a fundamental driver of innovation. The group is continuously exploring ways to offer multi-modal mobility in cities, including walking and shared bicycles, and is breaking new ground in the field of autonomous vehicles and on-demand services.

MIT CityCar



PEV2: Persuasive Electric Vehicle (autonomous goods/people mover

Larson's team first developed the MIT *CityCar*, a concept vehicle which featured drive-by-wire wheels and a foldable chassis, and did not contain an engine or transmission. The compact design made it possible to park three or four *CityCars* in a traditional parking bay, and allowed passengers to step directly out of the car, straight onto the sidewalk.

While the concept gained media recognition and even an award from the European Union, it ultimately represented a continuation of the car-centric urban system the group wished to reform. As a consequence, Larson and his colleagues opted to focus on shared autonomous vehicles. This led to the birth of the Persuasive Electric Vehicle (PEV): a driverless, functionally-hybrid tricycle that can move people or goods depending on the time of day. The PEV is intended to be a financially affordable vehicle that takes the 'fear factor' out of autonomous driving by offering clear practical and environmental benefits.

The use of light has an important role to play in ensuring these vehicles integrate safely and effectively into their surroundings; light and color changes, for example, potentially represent the most effective ways of communicating the vehicle's intent to pedestrians.

The MIT team has also modeled the effects that shared-use autonomous vehicles could have on urban environments. Conventional shared vehicles, such as taxis, could greatly reduce private car usage, freeing up land currently required for parking lots. And if those vehicles are autonomous, new benefits arise. For example, sensors could be installed on lampposts and other areas of urban infrastructure, and these could communicate with the vehicles directly. By collecting and sharing the locations of vehicles and people, a comprehensive picture would emerge of the city's specific context. The sensors could then communicate this data to vehicles, making these new forms of mobility potentially more robust and less expensive.

CityHome

City planning, however, is not just about transportation – which is why Larson and his team are also exploring ways to create hyper-efficient urban housing. Currently, young creative people are often priced out of urban property markets, resulting in a drain of innovative talent. But proposed solutions don't just need to be affordable; against a backdrop of increasing urban density, new approaches must also be highly practical.

CityHome 200sf

One possible solution is the *CityHome*, a 200-square-foot (19-square-meter) apartment equipped with architectural robotics, effectively tripling the apartment's functionality. The concept combines transformable furniture with the latest smart technology, building on the foundations of the Internet of Things. By pressing a button – or even through the use of hand gestures – the user can convert the space from a bedroom, to a living room, to a dining room or entertainment area. Furniture that is no longer required simply 'collapses' or folds away, allowing the resident to optimize space use to suit their needs at any given time of day.

The Changing Places group is also exploring a 300-square-foot (28-square-meter) version of the *CityHome*. In this design, walls can move, the bed can be stored in the ceiling thanks to vertical translation, and the interior lighting automatically adjusts to reflect how the apartment is being used.

In all instances, the MIT experts have sought to prototype their designs, even renting out a property as an Airbnb apartment. This has allowed the team to capture valuable real-world data that sheds light on how their ideas are being used in practice.

TerMITes

When developing these urban planning solutions, a top priority is to understand how humans behave in spaces. To this end, the MIT team has developed environmental sensors known as *TerMITes*. Now in their third generation, the sensors can be installed throughout a given environment, enabling the acquisition of data that paves the way for optimized designs. For example, Larson and his colleagues teamed up with IKEA to create a 'Living Lab' in Malmö, Sweden. Here, around 150 *TerMITe* sensors monitor which cabinets and drawers are opened while the user cooks a meal in the kitchen. This highly granular data provides a clear indication of how the space is used, and therefore allows interior designs to be fine-tuned to reflect these usage patterns.

The have also been deployed as part of a lighting project. In an office lab space at the MIT Media Lab, the interior LED lighting was programmed to change dynamically to reflect the different ways in which the room was being used. In a similar way, the Dynamic Personalized Sunlight project involves the use of an articulating mirror to reflect a shaft of natural sunlight into a room; the light shaft follows the room's user around as they complete their activities during the day.

CityFarm

The Changing Places team has also embraced the potential of urban agriculture. The *CityFarm* concept aims to allow food to be produced at or near the point of consumption – using aeroponics, for instance, to provide nutrients and moisture to plants as they grow inside facilities such as offices and potentially canteens. Sensors and instrumentation provide data on the health and status of every plant.

The *Food Computer* concept takes this approach a step further, with systems featuring environmental and lighting controls being installed in schools around the world. The goal is to create a distributed network of farmers experimenting with new ways of producing food, sharing their data via the cloud so that others can benefit from their experiences.

Urban Living Labs

Returning to the topic of urban infrastructures that promote innovation, the MIT researchers have developed *Urban Living Labs* in cities across the globe, from the USA, to Europe, to south-east Asia. The goal of this project is to test and evaluate innovation in real-life urban environments.

An example of this initiative can be found in Hamburg, Germany, where the local community has been actively engaged in integrating thousands of incoming refugees. At the start of the project, the city's mayor stated three conditions for the proposed developments: there should be no ghettos; the community should be involved in the decision as to where houses are built, in a bottom-up approach; and every district would have to share equally, irrespective of affluence.

Citizens of Hamburg evaluate possible sites in their district, using maps color-coded according to zoning, ownership, environmental conditions, etc.

Local residents participated in workshops that explored diverse scenarios in an iterative way, using *CityScope* tables. The community was highly engaged, and opposition to immigrants significantly decreased. Overall, the mayor was delighted by the response. In fact, the *Urban Living Labs* approach has inspired positive competition between districts to achieve the greatest success.

Now, the MIT team is focusing specifically on the Rothenburgsort district of Hamburg. The aim is to leverage *CityScope* to develop a district that brings together young German entrepreneurs and creative, innovative refugees. Given that Syrian refugees in Germany are starting companies at a rate five times greater than native Germans, it is easy to see why cities like Hamburg are eager to harness this potential.

A further successful *Urban Living Labs* project is underway in the Pyrenean principality of Andorra. Larson and his research colleagues have access to three years' worth of CDR, Wi-Fi and social media data for the whole country, and are visualizing this fine-grain information. Further, the team built a *CityScope* model of Andorra, and abstracted a successful neighborhood layout in Barcelona to build an agent-based model that could simulate how communities would interact within the city, based on their ages. The group has also created tools that can visualize diverse metrics such as diversity, density, traffic, energy and lighting in real time.

Moreover, Larson's team has created a tool that allows real-time projection of land use scenarios within the city, giving them a visual sense of where people would tend to meet and interact, according to the density of certain types of building. The team can also combine conceptual and perceptual models – so if they make density-related adjustments to the tangible *CityScope* model, they can simultaneously view a simulation of how their alterations would affect the city's landscape.

The overarching goal of the MIT Media Lab's Changing Places group is clear. Drawing on successful models such as Amsterdam city center, the group hopes to create cities that promote creative human interaction, rather than the more common planning models that privilege machines and cars. In this regard, Kent Larson and his team are returning to the first principles of urban design – creating spaces that promote mobility, communication and innovation.

ILIAD introduction

Ingrid Heynderickx

Dedicated to light

The mission of TU/e's Intelligent Lighting Institute (ILI) is to form a scientific community that is dedicated to creating holistic lighting solutions. These solutions are designed to address real-world needs and challenges related to the topic. Staff and students from the institute concentrate on combining innovative technologies to smart lighting solutions that serve individuals users as well as companies or cities. As such their goal is not to develop new lighting technology, but to apply existing light sources in new optical or smart systems.

Teamwork is key

ILI takes a multi-disciplinary, multi-functional approach that involves experts from many different fields. The institute's teams of post-doctorate, PhD, Masters and Bachelor students plus permanent staff apply concept-driven, evidence-based methodologies to respond to complex issues. Moreover, they deploy real-life testbeds to try out their solutions, closely monitoring the results to feed in to future projects.

The projects are often large-scale and long-term, and this requires input from additional sources. To this end, ILI has established a number of public/private partnerships to support its research. The most successful and long-standing of these is with Philips.

Currently, ILI runs three programs: Lighting by Design, Sound Lighting and Bright Environments. In parallel, Philips has set up three flagship lighting topics that dovetail with these programs: Optics and Rendering (which relates to Lighting by Design); Light for Health and Wellbeing (which is closely connected to Sound Lighting); and Digital Lighting Infrastructures (which is related to Bright Environments).

At present, ILI is defining a new roadmap for a program called Data-Driven Services. Today's connected lighting solutions collect large volumes of data. This new program is designed to focus on using and extracting value from the data to optimize future lighting concepts.

All of these joint flagship topics are coordinated by an ILI program manager and a Philips employee. This close collaboration fosters knowledge transfer. For example, research performed by ILI feeds into new solutions from Philips Lighting. Similarly, new trends or challenges identified by Philips are addressed by researchers who work to deliver fresh ideas for solving them.

6

Real-world testbeds

Where possible, staff and students at ILI use real-life testbeds to pilot their solutions and align them with public needs. One of these is the Atlas Building on the TU/e campus. This is undergoing refurbishment until around 2018 when ILI will begin performing research and collecting valuable data there.

A second important testbed is the Eindhoven 2030 Program which will be implemented across five districts of the city. This collaborative project involving teams from Philips and TU/e aims to deploy intelligent lighting solutions to make a difference to Eindhoven residents' lives.

7

Lighting beyond illumination in a future city perspective

Kees van der Klauw
Senior Vice President, Philips Lighting

Kees van der Klauw joined Philips after obtaining his PhD in Electrical and Electronics Engineering at the University of Delft. At Philips, he has held various management positions within the Flat Panel Display division, Philips Consumer Lifestyle, Philips Lighting and Philips Research. In 2015, he became chairman of the Alliance for Internet of Things Innovation.

The world of lighting is evolving at an unprecedented pace. After 100 years of ‘living in the darkness’, the industry is emerging fast – with state-of-the-art technologies creating new opportunities to achieve long-held ambitions and objectives in this field. A particular focus area is the development of future cities – with lighting, and lighting infrastructure, set to play a pivotal role in the urban environments of tomorrow.

High-quality, efficient lighting is integral to any urban landscape. To make cities livable and manageable, urban planners must consider the role that light has to play. With this in mind, Kees van der Klauw and his Philips Lighting colleagues are exploring ways to create the urban lighting systems of the future.

When it comes to the resources and expertise needed to turn visions into reality, Philips Lighting has strong foundations. The company is the global leader in its field, achieving sales of 7.5 billion euros in 2015 and employing 34,000 people worldwide in 70 countries. Moreover, it is number one in LEDs – which accounted for 56% of its lighting sales in Q3 2016 – and in developing connected lighting systems and services. Philips Lighting is highly regarded in the business space with B2B representing 75% of sales, but the company is also active in the consumer segment – allowing the company to gain valuable experience in both sectors.

The LED market has advanced at an astonishing rate in recent years, both in terms of technology and sales. But while moving from conventional light sources to LEDs is a relatively small step for a company such as Philips Lighting, the jump into the world of electronics and information technology is far more significant. This world moves ten times faster than the traditional world of lighting – and it is a path that van der Klauw and his team are eager to pursue.

The challenges of urbanization

It is predicted that 60% of the world's population will be living in cities by 2030. This poses real challenges for urban planners, who face the task of

Energy-efficient light in the Middle East

creating huge cities that are livable and easy to manage. Energy is a major consideration, especially given that cities currently use 75% of all the primary energy in the world. And with up to 40% of that energy in some cities being consumed by lighting infrastructure, it is clear that the current footprint of lighting is not sustainable – making it all the more essential to incorporate efficient lighting systems into future urban designs.

As cities continue to develop and expand, the world will need more and more light. This light, however, also needs to be energy-efficient; conventional methods would simply cause too much damage to the planet if deployed on the scales required in the future. With that in mind, Philips recently launched a series of bulbs with an efficiency of 200 lumens per watt – 10 times more efficient than conventional lighting. These lamps will replace some 75-80% of lighting currently installed in the Middle East region.

Bay Bridge, San Francisco

In addition to more light and more energy-efficiency, the world also needs more digital light; in other words, applications that go beyond the traditional 'on/off' concept, where light represents more than a mere alternative to darkness. Today, it is already possible to create light sources that communicate with smartphone devices to exchange context-sensitive information, depending on what light sources are in the user's line of sight. Against the backdrop of an 'always-on' society, where 97% of people already have a mobile phone subscription and 47% have access to mobile data, cities that embrace this connectivity will surely be best placed to grow successfully and sustainably.

Connected lighting

Many opportunities exist to create intelligent lighting systems. However, very little urban lighting infrastructure has actually been converted to LED technology, and even less has been designed for the digital age. For this infrastructure to support processes such as information exchange, it needs to be fully connected – yet less than 2% of installed light systems are currently at that stage. To reap the benefits of connected lighting, however, it is important to build a platform that can be consistently implemented in cities around the globe.

A lighting vision for the next decade can be built on three key pillars. The first priority is to develop 'the right light': smart, attractive, human-centric light that meets the needs of individual people and purposes. Second, to pursue connected operations; in other words, retrofitting existing lighting systems and installing new ones, and monitoring how these systems are used in the field. Third, to continuously evolve applications – using a mesh network of relatively simple sensors to create a source of rich, fine-grain information, where lighting is fully integrated into a city's technical ecosystem.

As an example of what is possible even today, Philips recently completed a project on Bay Bridge in San Francisco. The bridge was turned into a light sculpture where the light patterns change depending on the wind and weather conditions. This project aimed to show that urban lighting is not just about efficiency; it is also about making cities attractive, safe places to live.

The smart city of 2030

Van der Klauw and his colleagues have considered how cities may look in 2030 – less than 15 years from now. One key feature of the 'future city' could be high-quality connected lighting that streams data between millions of devices. For example, this would enable autonomous vehicles to navigate roads safely thanks to a supply of live situational data from nearby street lights, augmenting the vehicle's on-board sensors. Limited urban space, meanwhile, could lead to more public spaces being developed underground – with lighting that mimics natural daylight. Digital light systems could help drones to navigate and deliver items, while vertical 'urban farms' could be developed beneath the city, requiring less water and no pesticides while greatly reducing 'farm-to-fork' distances. And in the home, lighting could synchronize with everything – projecting occupants' needs and complementing their wellbeing.

Public spaces underground – with drones and droids navigating using intelligent lighting technology

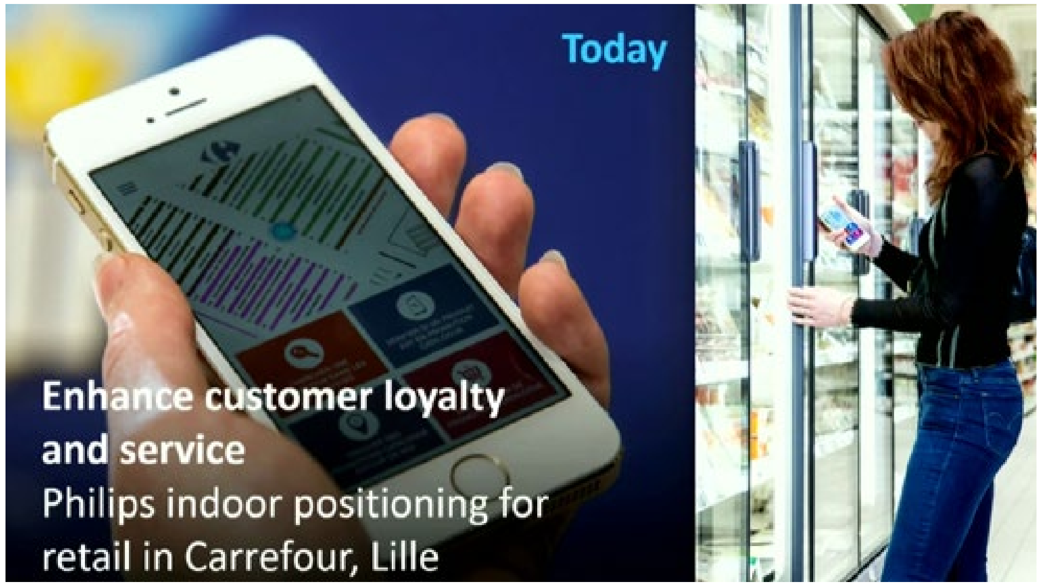
CityTouch lighting management in Jakarta, Indonesia

Visions that are closer than you think

In all of these examples, Philips Lighting is embracing the concept of 'light beyond illumination' – and the concepts are not far-fetched by any means. For instance, where digital lighting is concerned, the company has already launched *SmartPole* technology with built-in 4G/LTE network capabilities, with scope to upgrade to 5G, and is also establishing audio sensor networks across Los Angeles to support noise abatement and even gunfire detection. Further, Philips Lighting recently announced a large-scale *CityTouch* lighting management system rollout in Jakarta, Indonesia, involving some 90,000 street lights.

In terms of enabling drones to function underground, Philips visible light communications (VLC) systems have already been deployed at a 'Drone Café' at TU Eindhoven. Meanwhile, Philips indoor positioning technology has been introduced at a Carrefour hypermarket in Lille, France – helping consumers find their way via efficient LED lighting that communicates with their smartphones. Finally, Philips has installed connected office lighting at Torre Europa in Madrid, Spain, giving employees individual control over their light, no matter where they are in the building.

The 'urban farm' vision is also closer to reality than some may believe – and there is certainly a need for action. Currently, for example, a lettuce in the United States travels an average of 2,500 kilometers before reaching the consumer's plate. This impacts the food's freshness and quality, requires the use of herbicides, consumes more water and creates an excessive carbon footprint. However, a company called *GrowUp* has already been farming fish, herbs and salads in London using aquaculture and hydroponics – showing that the technical possibilities for urban agriculture already exist.



Indoor positioning technology at Carrefour in France

GrowUp urban agriculture in London

Kees van der Klauw and his team believe that by 2030, the value of the data provided by urban lighting systems could actually exceed the value of the illumination these systems provide. As light sources decrease in price, their value increases hugely because of the information they share. Urban planners and governments should therefore seek to capitalize on this potential by opting for intelligent solutions, as opposed to 'dumb' conventional street lighting. There is a clear vision for more human-centric, more relevant urban lighting as a key enabler for smart cities – taking the role of light beyond illumination.

ILIAD Advances in Illumination Optics

Wilbert IJzerman

Wilbert IJzerman is Manager of Technology Innovation at Philips Lighting. Since 2014, he has also been Professor of Illumination Optics at the Eindhoven University of Technology. He joined Philips Research after his PhD in Applied Mathematics at the Twente University of Technology. In 2008 he moved from Philips Research to Philips Lighting, first as a venture manager, and later taking on different management roles within Advanced Development. His research interest has always been in illumination optics.

Bringing light to customers

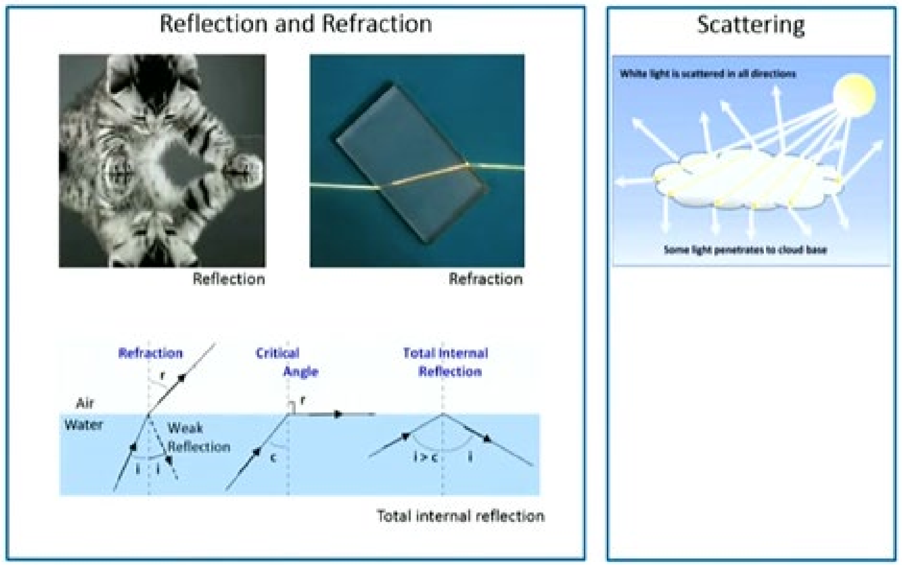
Illumination optics is at the core of lighting. At the TU/e and Philips, this field of research looks at how to deliver light to customers. Six PhD students and three members of staff study the impact of various materials and physical phenomena on light sources, with a view to creating innovative, efficient solutions.

The issue with LEDs as sources, for example, is that the light is extremely bright, and travels in all directions. Ensuring the eye is not dazzled by this high intensity takes optical elements, placed over the LEDs, to control the distribution of light. As a field of study, illumination optics is all about finding the right materials and solutions to combine with a light source to reach the desired effect.

Physical phenomena of light

L use these phenomena (through lenses, reflectors and diffusers) to control the flow of light.

For example, LEDs are typically hidden behind diffusers of varying strengths or hiding powers. Too little hiding power and the intensity of the LED can be dazzling, but too much reflects a great deal of light which is inefficient. A key area of research in illumination optics is optimizing and balancing throughput with hiding power to achieve the ideal, efficient solution that meets application requirements.



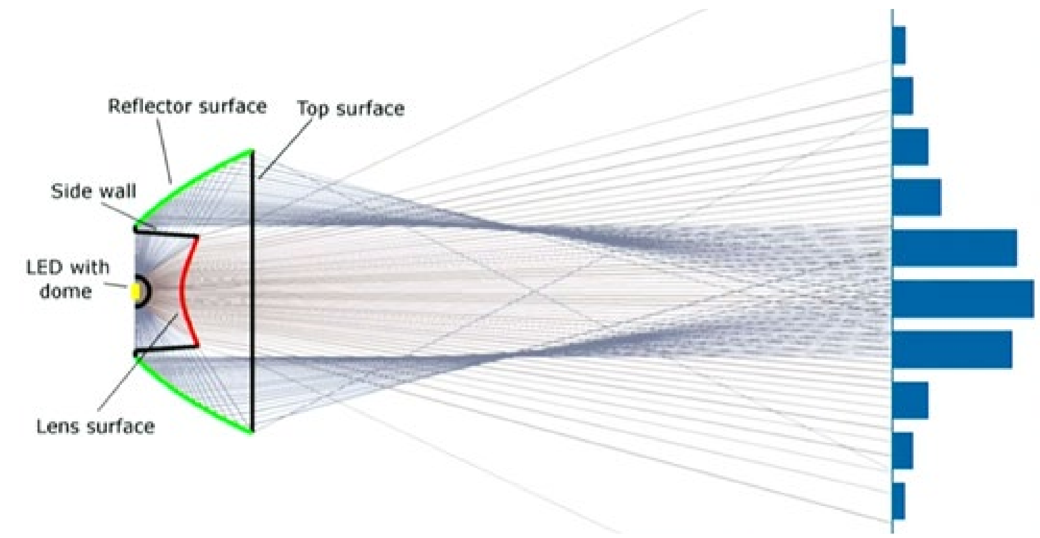
Illumination optics is about the control of physical phenomena

An age-old problem

Finding the right materials to combine with light sources has long fascinated scientists. As an established field of study, illumination optics dates back over a century. In the past, because of the heat generated by incandescent bulbs, the materials used were mostly glass or metal. However, since LEDs do not emit heat, today's options include plastics, which provide much greater freedom of form, and a wider scope for creativity.

In addition, due the availability of computational power, we can now calculate predicted outcomes much more easily without the need to physically create hardware solutions and perform experiments. This saves time and money in the development phase and provides more insight into how materials are likely to behave.

In 2008, the Illumination Optics program was involved in creating LED car headlights that used multiple LEDs to control the beam of light automatically so as to provide adequate illumination without dazzling oncoming drivers.[1]



Monte Carlo ray tracing: shoot rays randomly from source to target; calculate intensity by counting the arriving rays

Tracing the rays

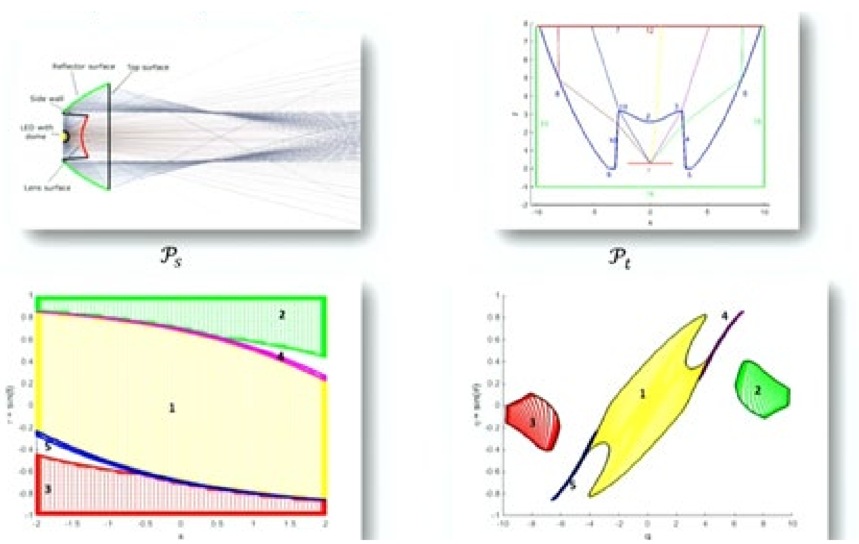
One example of how to apply this computational power is in calculating the effects of a lighting fixture. Traditionally this has used the Monte Carlo simulation. This calculates resulting light intensity patterns by tracing rays from a source to their target. For example, by tracing the rays emitted from an LED source and counting how many arrive at a defined area of the target you get insight into the light distribution.

The Monte Carlo ray tracing model is established and successful, but since the selection of rays is effectively random, it lacks accuracy. There are many examples of applications where certain features were overlooked because of flaws in the Monte Carlo simulation. However, to reduce errors by a factor of 10, you would need to increase the number of rays by a factor of 100 – which can make the entire process slow and inefficient.

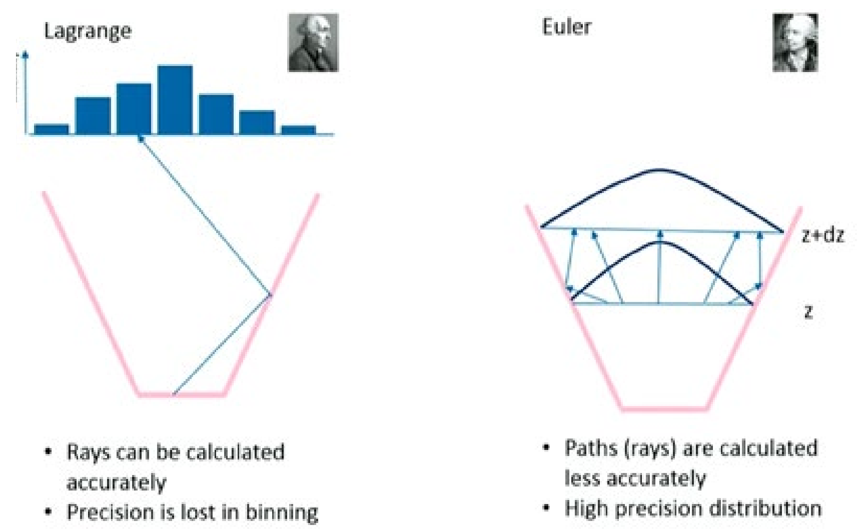
Overcoming the issues

The team at TU/e has been working on a number of ways to overcome challenges arising from the Monte Carlo method: phase-space ray tracing, the Eulerian approach, and inverse optical problem.
In phase-space ray tracing the emphasis shifts to detecting the boundaries where the rays shift from one arrival region on the target to another. This method also correctly calculates light intensity, but now increasing the accuracy by a factor of 10, takes 10 times as many rays, rather than 100 with the Monte Carlo method. However, because calculating the boundaries is more intensive than tracing rays, the team is currently

1 Automotive examples courtesy Philips Lighting



Comparison of Monte Carlo ray tracing (on the left) with Phase-Space ray tracing.



Lagrange (ray tracing) compared with Euler (energy transport)

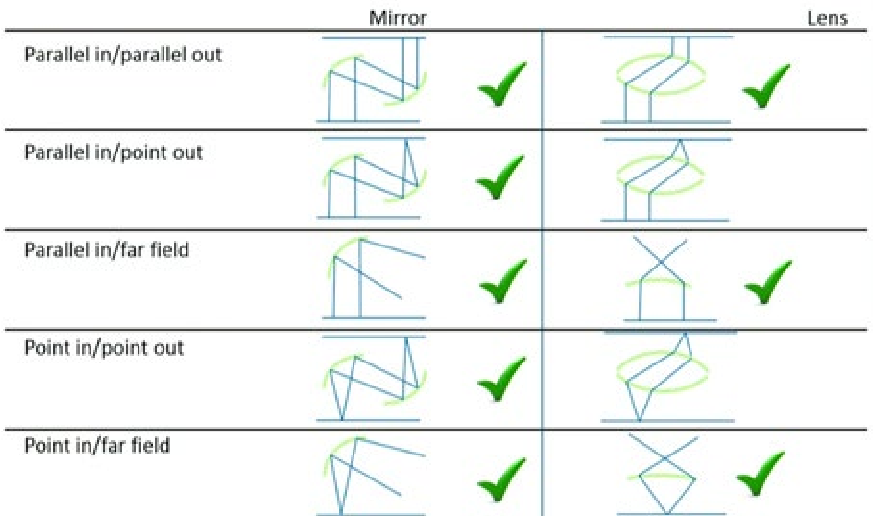
looking into just how much gain phase-space calculations can deliver, and how to further optimize the results.

The Eulerian approach follows how energy flows from the source to the target – using a fluid dynamics type of approach. While this loses the accuracy of rays, it gains precision in modelling the distribution of energy at the target. The challenge here is developing the 4-dimensional models which involve two angle and two position coordinates.

Transferring energy

Rather than simulating how rays or energy move from the source to the target, the inverse method defines the source and target distributions and works on finding the mirror or lens geometries suitable for achieving the desired results. This can be compared to constructing a sand castle: you have to decide whether to transfer your next spade of sand to the right or the left. Similarly, for the inverse optical problem, rays must be transferred correctly by one system or another. The mathematics behind this problem, referred to as the mass transport problem, has been known for over 200 years. But it is only in the last 10 years that physicists, including those at TU/e, have discovered how to solve this problem.

In fact, there is no unique solution. Concave or convex solutions have been calculated, but there may be many more. Optical designers are working to develop the quadratic cost functions of different optical components as a way of exploring other possible solutions.



Even for the archetypal optical systems where the cost functions are understood, the necessary quadratic models still need more extensive exploration.

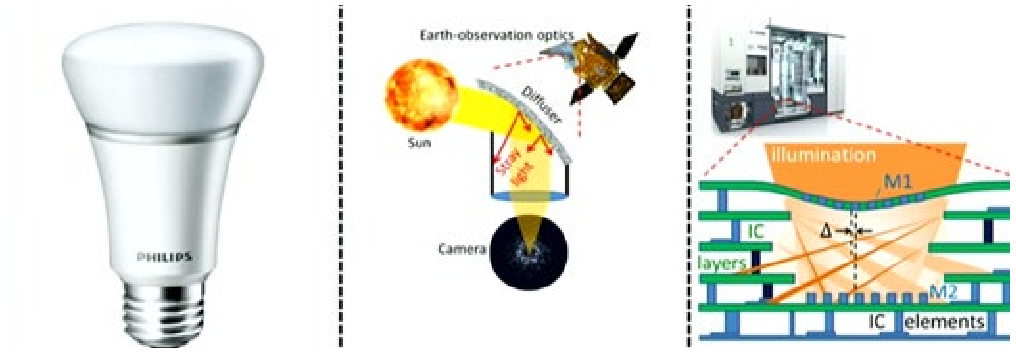
Scattering of light

Another area where the researchers at the TU/e are working toward a fuller understanding is study how scattering phenomena affect illumination optics. This is throwing up unexpected effects. In one experiment, they scattered laser light off a single, tiny dust particle while a rotating detector measured the scattered light. They quickly realized the results were different every time. It transpired that the particle was losing mass, reducing in size by two nanometers a minute. This is an unexpected phenomenon they first need to understand, before they continue with the scatter properties experiment.

At the same time, the Illumination Optics program is also working on growing particles with different geometries to create controlled diffusion effects.

Characterizing free-form components

A further, recurring and important challenge for the team is how to characterize free-form components. There are many techniques, each with its own advantages and disadvantages. For one scanning tool they are looking at the possibility of using plasma “bullets”, that is, fast moving discharges. Plasma bullets always follow the same trajectory, which is highly interesting though as yet unexplained. A likely explanation is that ions or electrons in the path influence the bullet’s direction. Confirming this needs detailed information on the complex, non-linear field surrounding the plasma bullet. Understanding this field would make it possible to both control the bullet reliably and to interpret how the plasma interacts with the surface under investigation, to characterize it as an optical component.



Examples of free-form scattering optics

Other challenges here regard the design of effective diffusors. While much of the understanding of scattering is at the nanometer scale, for flat objects with finite boundaries, understanding free-form scattering optics is about larger components, and the different geometries and effects that happen at the millimeter scale. Combining these dimensions is another characterization challenge being tackled. The problem is so complex that even for something as commonplace as a light-bulb, there are only a few designers qualified and experienced enough to do the work. But there are related issues that could benefit from a generally applicable understanding. These range from designing satellite systems to cope with the variations in light (and heat) intensities in space, and in the design of lighting elements on integrated circuits.

The future of illumination optics

Philips and the TU/e continue to work on illumination optics and creating innovative lighting solutions. Key areas of research include improving the alternatives to the Monte Carlo model, extending two dimensional experiments to three dimensional settings, and bringing the theory to life through practical applications. One thing however remains constant: it is a highly valuable and interesting field of work.

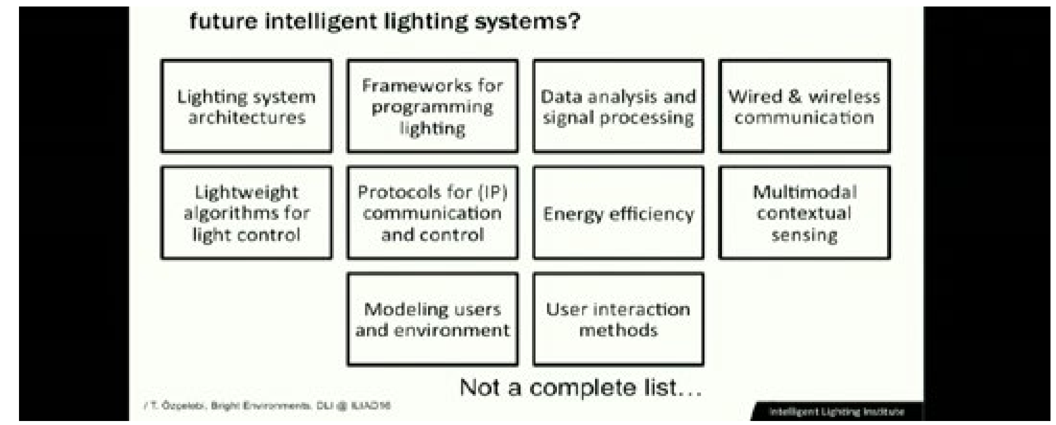
Digital lighting in the IoT era

Tanir Özçelebi
TU/e Intelligent Lighting Institute

Tanir Özçelebi received his PhD in 2006 from the Koç University in Istanbul, Turkey, and then joined the Eindhoven University of Technology (TU/e), first as a post-doctoral student, and since 2008 as an assistant professor. Since 2013, he has managed the Intelligent Lighting Institute (ILI) program on Bright Environments.

The Internet of Things (IoT) will have a crucial role to play in the future of digital lighting. The vision is for intelligent systems that can communicate seamlessly with users and their surroundings while delivering high energy efficiency. To this end, Tanir Özçelebi and his colleagues at the ILI are developing and testing concepts that could underpin the smart lighting systems of tomorrow.

ILI is currently engaged in three research programs: Sound Lighting, Bright Environments and Light by Design. Özçelebi leads the Bright Environments program, which is exploring control and sensing aspects of both indoor and outdoor lighting systems. This program is complemented by Digital Lighting Infrastructures (DLI), a Lighting Flagship research program led jointly by Philips and TU/e.



Key aspects of the Digital Lighting Infrastructures (DLI) research program

The Bright Environments team is researching several key areas that are paving the way for intelligent lighting systems. These include underlying architectures; frameworks for lighting applications, data analysis and signal processing; wired and wireless communication protocols; and adapting control protocols, such as Internet Protocols (IP) for the lighting domain. Additional focus areas include energy efficiency, multimodal contextual sensing, the ability to model users and their environments, lightweight algorithms for light control, and deepening the understanding of user interactions.

The team foresee a future where digital lighting infrastructure is IoT-capable: in other words, where lighting end-points can collect, share and use vast amounts of data from their environments, though their connections to the IP domain. To realize this vision it will be necessary to address the specific challenges of lighting.

Ongoing projects

TU/e and Philips are currently collaborating on numerous projects around the globe. One of the most significant is *OpenAIS*, a European Union Horizon 2020 initiative. The mission is to create a platform for smart lighting systems that can be programmed by third-party application developers. The project's deliverables include an open system architecture for IoT-capable intelligent lighting infrastructures.

Meanwhile, the Delphi4LED project – also part of Horizon 2020 – aims to create multi-domain LED-based design and simulation tools for the solidstate lighting industry. Its scope includes research into modeling better LED modulation techniques for visual light communication.

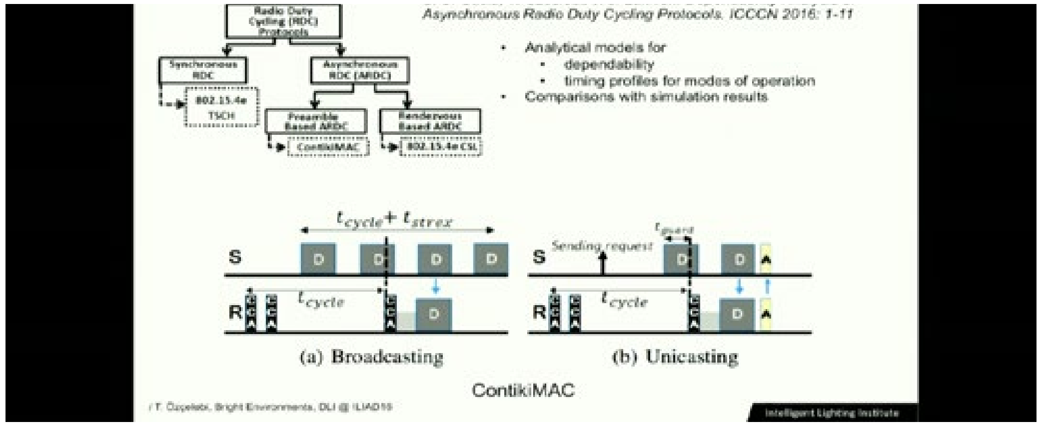
Further, an ARTEMIS project known as DEWI (Dependable Embedded Wireless Infrastructure) focuses on interoperability between embedded devices in smart spaces, including research into modeling wireless communication environments.

The OptiLight project is exploring mathematical optimizations for human-centric lighting – providing deeper insights into how humans experience light, and developing quantified models and optimization algorithms that can implement these theories in real-world systems.

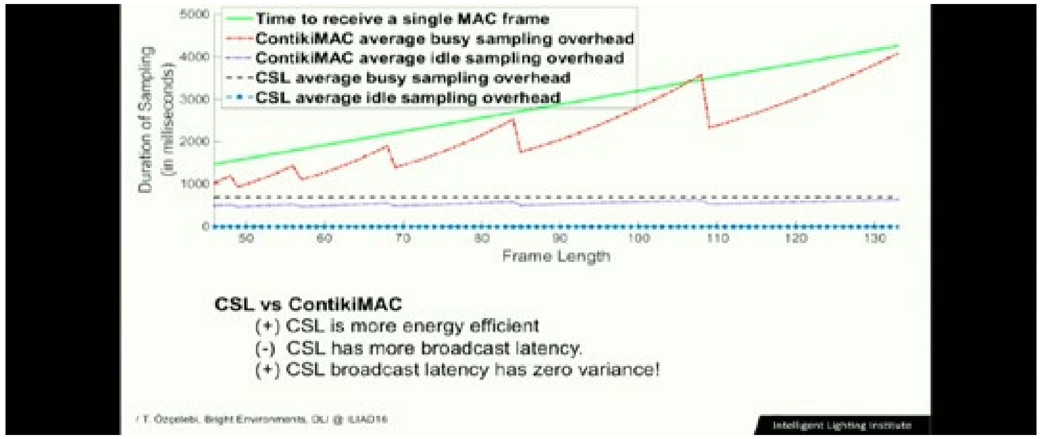
Research highlights

Özçelebi and his colleagues can look back on numerous significant successes in their research – not least with regard to energy efficiency. To enable users to retain control of their light around the clock, the lighting systems of the future will need to be able to communicate all the time, even when nobody is around. One option would be to leave the system's embedded radio on to listen for commands from the network – but this uses additional energy, without adding any appreciable efficiency.

With these points in mind, the team analyzed energy-efficient communication protocols, such as Asynchronous Radio Duty Cycling (ARDC). This would allow the lighting end points to 'sleep' for periods, but with activity at certain frequencies causing them to 'wake up' and check for messages.



Analysis of ARDC protocols as part of the *OpenAIS* initiative



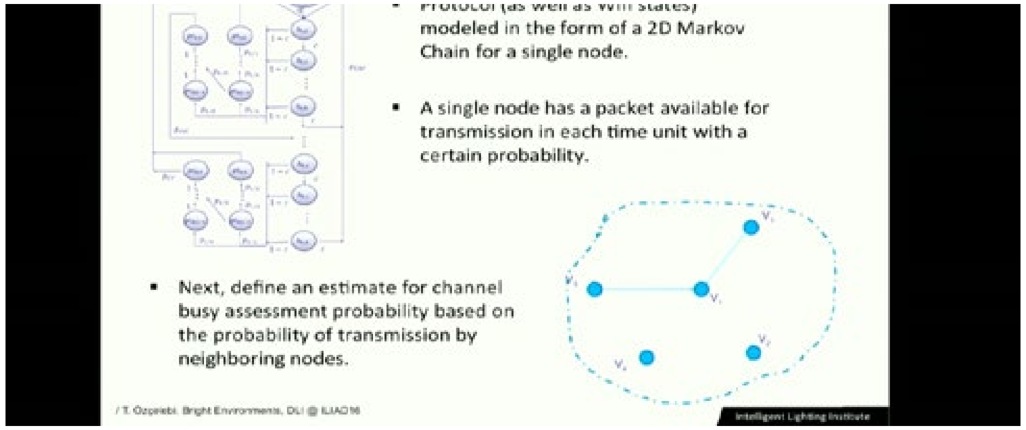
Graphical representation of findings from ARDC protocol analysis

The team compared ContikiMAC and Client Server Link (CSL) protocols, and found that CSL is more energy-efficient, and that its broadcast latency – though higher overall – has zero variance. So for example, when a user's lighting application demands highly synchronized switching of lights, CSL would be the best choice, whereas ContikiMAC would be preferable for applications that need lower broadcast latency.
Such findings allow system designers to tune parameters and select suitable protocols for specific applications.

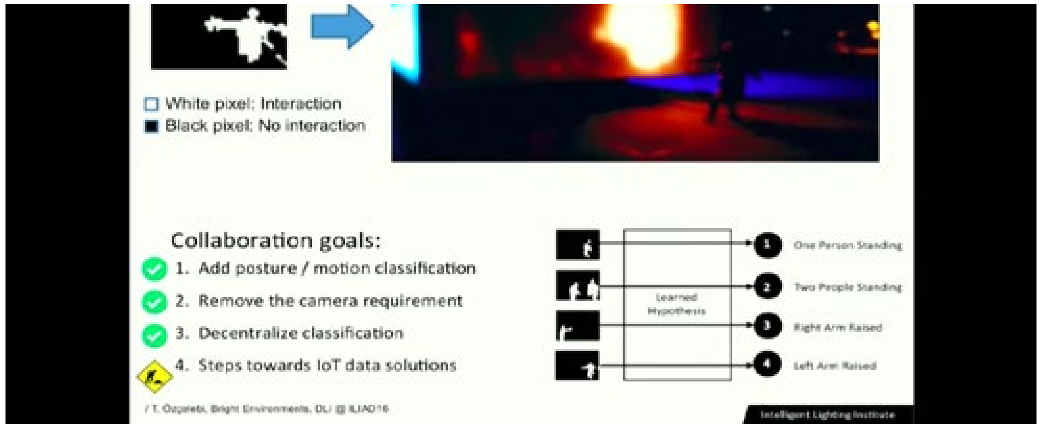
Elsewhere, the Bright Environments team sought to address the need for IoT-based lighting infrastructures to co-exist with legacy systems. To understand how this may work in practice, the team evaluated the performance of a ZigBee network under Wi-Fi interference. The two technologies operate in the same radio band. Potential issues include reductions in link reliability, as well as inefficient use of the radio spectrum, with ZigBee currently experiencing the more significant negative impacts of the two.

Using a node model, the team found that as they increased the size of the network from 8 to 128 nodes, the success rate dropped for end-to-end packet transmission. But when as they increased the clear channel rate, the success rate increased too.

The team has also explored ways of dealing with data efficiently, bearing in mind that not all data can be processed in the cloud. This is especially true for applications that need real-time information processing. To this end, the Bright Environments program teamed up with Philips on the Philips Natural Elements project. This interactive light sculpture uses

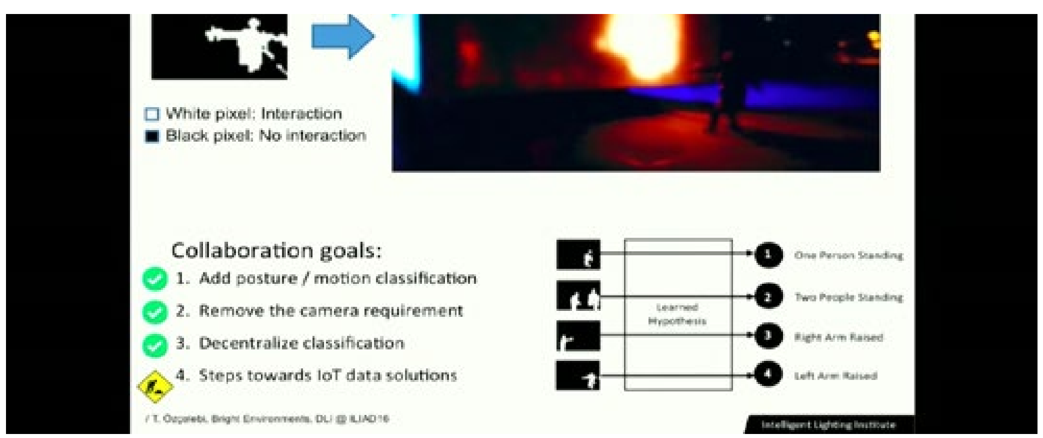


The node model used to investigate the performance of a ZigBee network under Wi-Fi interference



Graphical representation of findings from node model analysis mathematical models to learn and emulate natural light effects. The screen responds to human interactions with visual effects, such as fire, water or wind.

The project team wanted to see if data collected from users could be analyzed to enable better interaction – adding posture and motion classification, removing the need for a camera to monitor user movements, and decentralizing the classification process. In other words, they pushed parts of computation to the pixels where values are detected. They achieved these goals – with notable success in decentralizing classification – and the team is now exploring how to apply these successes in other IoT-based data solutions.

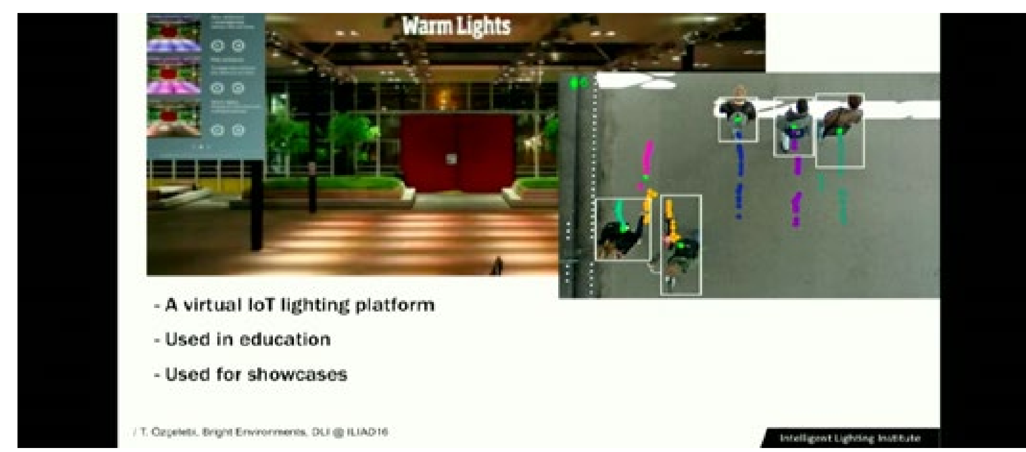


Goals of the Philips Natural Elements project

Living labs and pilots

The team are engaged in several pilots and real-world experiments, to see how research concepts may work in real-world applications. The *TU/e Markthal* living lab, for instance, has evolved into a virtual IoT lighting platform, following successful student projects. The lab is used for education and to showcase the project team's work.

A further living lab can be found in the *TU/e Laplace building*. The lighting system in this open-plan office has 22 ZigBee-addressable luminaires, each equipped with integrated motion and light-level sensors, and local intelligence. Each luminaire can be dimmed and tuned to different color temperatures. In late 2016, this lab played host to a three-month study involving over 25 participants to investigate three interface types that vary the lighting in an open office.



TU/e Markthal living lab

The *TU/e Atlas Building* will also be home to a living lab when renovations are completed in 2018. This lab will create the opportunity to study systems where IPv6 is used to communicate with every luminaire and sensor, plus an API that supports intelligent lighting applications.

Further, as part of the *OpenAIS* project, an IoT pilot study is planned at the Witte Dame building in Eindhoven. Özçelebi's team will contribute to application development as a project partner.

Looking to the future

Students at TU/e have completed a number of successful IoT and lighting-related projects. These include localizing lighting fixtures using wireless statistics such as RSSI measurements, gateway design for interoperation of IoT lighting and legacy networks – such as between ZigBee- and IP-based networks – and control deployment in an open office.

Moreover, a recently-launched IoT course is enabling over 100 masters students to design and implement IoT lighting concepts on Raspberry Pi systems, re-using many of the concepts generated in collaboration with partners, such as Philips and NXP Semiconductors, as part of the *OpenAIS* project.

In summary, the Bright Environments team are collaborating with numerous partners to help shape the future of intelligent lighting systems, with a continuous stream of significant projects being implemented in many forms – from student-level developments to national and European initiatives. This collaboration benefits all parties by increasing knowledge, yielding results and enhancing competitiveness in the lighting domain.

Light for Health and Wellbeing

Sjoerd Mentink and Yvonne de Kort

Sjoerd (Philips Lighting) and Yvonne (TU/e) are the topic owners for the health & wellbeing program in the Flagship Lighting – an ambitious strategic collaborative program between TU/e and Philips.

Sjoerd Mentink obtained his PhD in Physics from the University of Leiden in 1994. He spent two subsequent years in Toronto as a postdoc in the areas of condensed matter physics and neutron scattering before joining Philips in 1996. After 10 years in particle microscopy instrumentation and applications and 3 years of technology strategy and planning, Sjoerd became Innovation Program Manager Applications. In Philips Lighting Research his work focuses on the interaction of light with products, plants and people, omnichannel user experience, human behavior, scenarios of the future and new business creation.

Yvonne de Kort is full professor in the Human-Technology Interaction group, and manager of the Sound Lighting research program of ILI. She is an expert in environmental psychology, and in social and biological psychology with regard to light and lighting. Her research focuses on the effects of light and natural views on human functioning. This encompasses both image-forming and non-image forming pathways of light, on mood and wellbeing, vitality, attention and performance, health and social behavior.

Where physics meets psychology

Sjoerd Mentink and Yvonne de Kort come from very different scientific disciplines – physics and environmental psychology. But their academic interests converge in a shared vision to create meaningful lighting solutions that promote safety, health and wellbeing for people. A key starting point is understanding the impact of light on human behavior – something both Mentink and de Kort are investigating within their own fields of study.

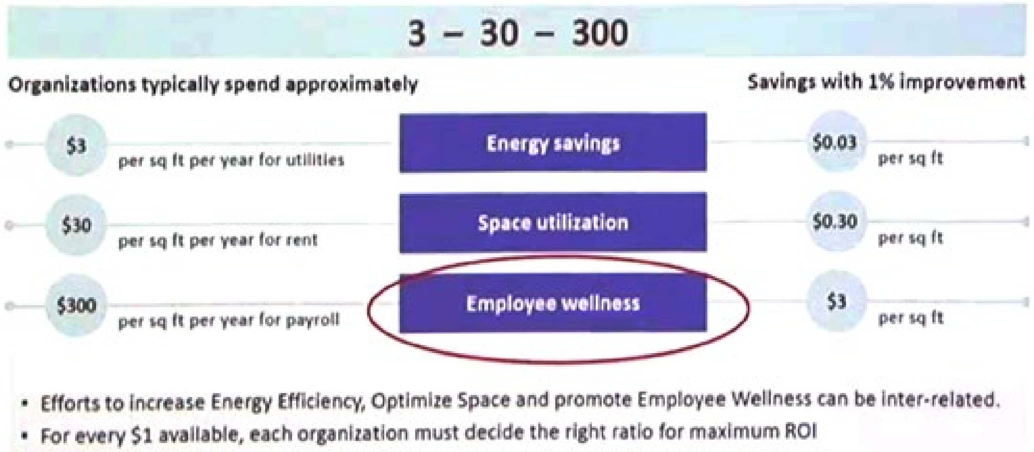
Having conducted a great deal of research, including observing subjects in sleep laboratories and other controlled environments, Mentink and his colleagues are now starting to create real-world platforms. These intend to bring the theory to life, by piloting solutions that begin on a small scale but are designed to scale up to eventually cover entire cities.

Meaningful lighting 24/7

Human-centric lighting is relevant to everyone in some capacity or setting and at a particular moment in time. Against this background, Philips recently launched its second generation of tunable lighting solutions for use in offices, healthcare environments, and the home. These solutions have been created based on extensive research into color intensity and temperature, and how altering these parameters can impact on humans. The light alarm clock, which has been available for around 10 years, is a prime example of how light can be used innovatively to help people start their days, even when there is no natural light available. The latest solutions take this concept even further and ask how lighting can accompany us throughout the day as we move around our homes, offices, and cities. Manufacturers are beginning to recognize the potential and the value of light in terms of enriching our lives, and have been bringing new innovations to market. Philips' vision goes beyond engineering new technologies and developing new light bulbs; it is about adding value and improving health and wellbeing.

Optimizing energy, space and welness

To date, the primary focus of the Intelligent Lighting Institute's Sound Lighting Program has been on indoor applications. External large-scale platforms, such as cities, where lighting systems can be tested in real-world conditions were only scarcely available, with the exception of Stratumseind 2.0 – the most popular nightlife street in Eindhoven, housing over 50 bars and cafes. However, this is set to change. Both Philips and TU/e are working on bringing their solutions to a larger stage and using light to optimize safety, health, user experience and resources. For businesses, the potential cost gains from deploying light to optimize



Taking the next steps in Human Centric Lighting: A joint roadmap for light in health and wellbeing space and resources are much higher than those achievable through energy savings alone. For example, per one square foot, per year, organizations typically spend approximately $3 for energy, $30 for rent, and $300 for payroll. When people fall ill, they cost their employer an average of 2000 euros a year. Incorporating solutions that create attractive, pleasant environments conducive to health and wellbeing is a key economic factor. Though capturing this value remains a major challenge.

Mental health is playing an increasing role in healthcare, in particular in light of the ageing population. This creates additional pressures for care providers. Some of these pressures can be alleviated through intelligent lighting concepts that promote good health by having a positive influence on people's emotions and actions. In the future, living and working spaces will be designed with this in mind. For the time being, several innovative new solutions are hitting the market and moving years of research into the open.

Lighting and the crowd

A key focus of research is the power of light to manage and influence crowds. Lighting has long been used to capture the imagination and draw people to places such as stadiums; impressive light shows often accompany music or sporting events, for example. But while it is important for stadium owners to entertain visitors, their primary concern remains safety. The PSV stadium in Eindhoven holds 50,000 people, which is a huge liability for owners.

Researchers at TU/E have been investigating how innovative lighting concepts can address some of the associated challenges, for example by

Safety is the top priority: high insurance cost and liabilities in case of adverse events

positively influencing the crowd's frame of mind in a way that makes them less likely to panic in an emergency. All stadiums need an evacuation plan. But how can targeted use of light help direct and guide large numbers of people? The main obstacle to answering this question is that it is very difficult to simulate crowd situations. The types of experiment performed in the lab, the home or office settings are not feasible for large groups. Sophisticated models are often used to simulate evacuation scenarios but these rarely take lighting into account.

To be able to predict how people will react in these situations and establish which solutions will be most successful, we need insight into human behavior and the impact of light of thoughts and actions. And that is something that Yvonne de Kort and her teams are studying.

An exciting field

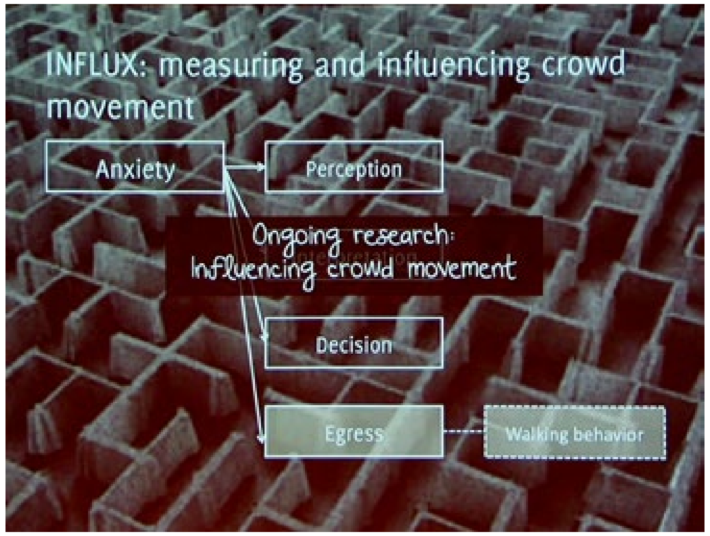
It is a relatively new area of research and there is still a great deal of work to be done, but de Kort and Mentink, their colleagues and research students are currently setting out a vision which will ultimately help to create intelligent lighting solutions. To do this, they have been looking at people's responses to light and darkness and have identified how factors such as entrapment, confinement and anxiety play key roles.

Already de-escalation projects are being rolled out that use light scenarios to defuse aggressive or potentially aggressive events in mental healthcare environments and in Eindhoven's nightlife hotspot Stratumseind. Implementing programs like this requires an understanding of moods, how they can be manipulated, and how external triggers may affect them.

Learned behaviors and previous experiences play an important part in our interpretation of events. For example, in tests people associate black with negative thoughts and feelings and white with more positive emotions. When shown the same two images in a lighter and a darker version, people assessed the figures in the lighter version as friendly while attributing negative traits to the same figures in the darker version.

Adding a layer of complexity

However, when you perform similar tests in dynamic environments, for example to study behavior during an emergency, the outcome is not so clear cut. Moreover, the very nature of these situations makes them give rise to panic and anxiety. When it comes to emergency evacuation of a stadium, for instance, challenges include unfamiliar surroundings, reduced spatial orientation, and in some cases the influence of substances such as alcohol or drugs. A loss of overview creates a loss of feeling in control, which in turn leads to panic. To even begin creating lighting solutions that may aid evacuation, researchers need to first gain a deeper understanding of the human mind.



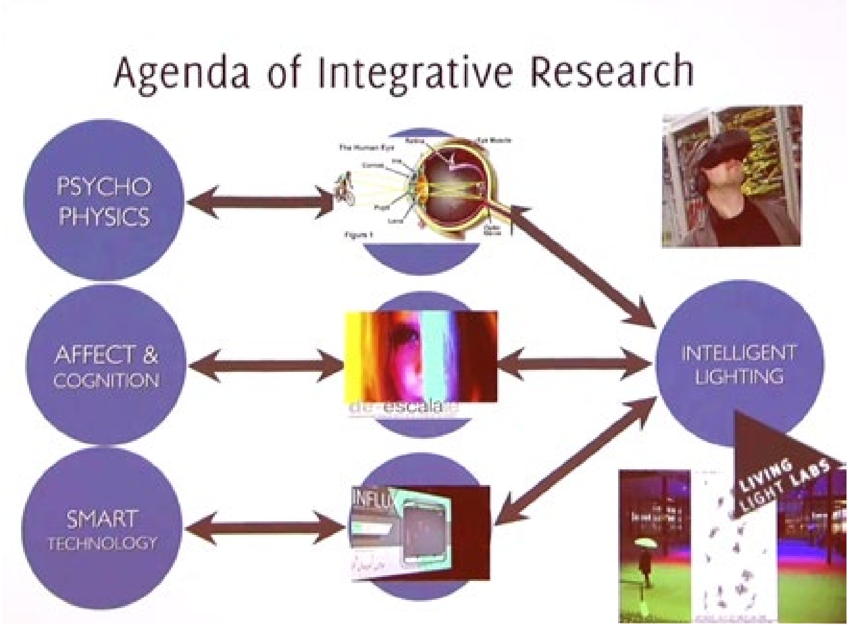
Descalation means understanding and manipulating the atmosphere of the crowd: including visual performance and cue utilization under stress, and how this influences crowd movement

Descalation means understanding and manipulating the atmosphere of the crowd: including visual performance and cue utilization under stress, and how this influences crowd movement

Faced with an emergency, stadium visitors need to make rapid decisions. Researchers know that these decisions are based on individual perception of the scene and of the available options. But where panic and mass movements of people are involved, all responses are influenced by anxiety. Simulating anxiety in a lab or gaming setting to predict how people will react is extremely difficult. De Kort and her team have observed that people weigh up their surroundings and then use certain cues from their environment, including lights, to give something a safe or non-safe label. Under pressure and the influence of anxiety, people no longer have the clarity to assess all the options: decisions are made much faster and based on fewer criteria. Future lighting designers will need to take this type of human behavior into account, for example, by using light to make the safest escape route from the stadium appealing and immediately obvious, so that visitors notice it and make the decision to use it.

The power of light

When it comes to managing crowds of people, many factors are at play, such as the speed and direction in which they move. Is it possible to use light to influence how fast someone is moving? At Eindhoven's GLOW light festival in November 2016, ILI presented an interactive Closed Science installation, the biggest experiment the group has been involved in to date. The installation invited people to move around freely as their speed and direction were tracked. Unbeknown to participants, the lights were subtly altered at certain intervals in an attempt to influence behavior and gauge reactions in real time. The system tracked interpersonal distances, speed and direction to measure how responses changed when more people entered the installation. The number of people involved in a situation is highly relevant since humans are social beings who look to their peers for guidance. In an emergency evacuation, for example, this could be a critical factor.

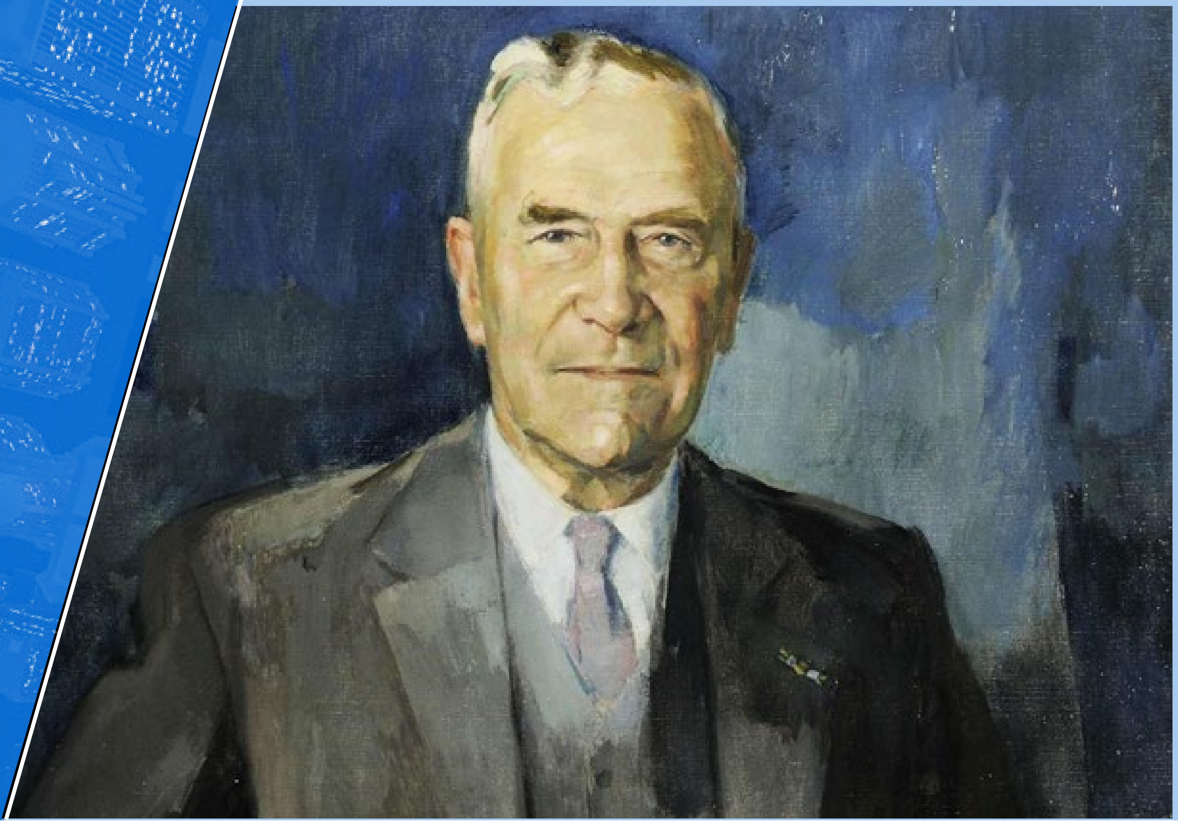


The agenda for integrative research

In addition to this experiment, De Kort and her fellow researchers continue to study how people respond in lab settings, virtual reality scenarios, simulations and in the real world. Based on their findings, they hope to pave the way for effective lighting concepts that fulfill the demands of today and tomorrow and promote safety, health and wellbeing.

History of the Holst Memorial Lecture and Award

The Holst Memorial Lecture is held each year at the University of Technology in Eindhoven (TU/e), the Netherlands, with support from Philips Research. The theme reflects an important contribution to the development of research and technology, in line with the idea advocated by Dr. Gilles Holst concerning the development of applied sciences, particularly mathematics and the natural sciences, for the benefit of industry on the one side and their implications for society on the other.



The Holst Lecture is given by an eminent scientist in a selected field of research. Candidates for the lecture and the associated Award are selected by a committee consisting of representatives of both Royal Philips Electronics and the University, under the chairmanship of the Rector Magnificus of the TU/e and the CEO of Philips Research.

The audience is made up of university staff and students, representatives from industry, and other guests with a general interest in science and technology. To honour the guest speaker, a symposium with invited speakers precedes the Memorial Lecture.

After the Lecture, the Rector Magnificus presents the Guest Speaker with the Holst Memorial Lecture Award, a medal designed by Dutch sculptor Jos Reniers.

Gilles Holst (1886-1968)

As an academic, Gilles Holst is best known for the essential part he played at the University of Leiden, the Netherlands, in the discovery of superconductivity by Nobel Laureate H. Kamerlingh Onnes.

However, Holst is first and foremost remembered as the founding director of the famous 'Nat Lab', the Philips Physics Laboratory in Eindhoven, where he worked between 1914 and 1946. Gilles Holst was also chairman of two committees that were instrumental in establishing the University of Technology in Eindhoven in 1956.

List of Holst Memorial Lecture Award Recipients

The first Holst Memorial Lecture was given in 1977 to commemorate the 21st anniversary of the founding of University of Technology. Since then the speakers have included:

1977 **Dr. Alexander King,** Director OECD, Paris, 'The role of the engineer and the engineering sciences in future society'.

1978 **Prof. Dr. Cristopher Freeman,** University of Sussex, Brighton, UK, 'Technology and employment: long waves in technical change and economic development'.

1979 **Prof. Dr. Carl Friedrich Von Weizsäcker,** Max Planck Institute, Starnberg, Germany, 'Langfristige Energiepolitik als Beispiel technischer Zukunftplanung'.

1980 **Prof. Kevin Lynch,** MIT, Cambridge, USA, 'What is a good city? General theory of good city form; a new try at an old subject'.

1981 **Prof. Dr. Hendrik B. Casimir,** Philips N.V., Eindhoven, the Netherlands, 'Gilles Holst, pionier van het industrieel onderzoek in Nederland'.

1982 **Dr. Michiyuki Uenohara,** Nippon Electric Co, Kawasaki, Japan, 'The Japanese social system for technological development; its merits and demerits'.

1983 **Prof. Dr. Joseph Weizenbaum,** MIT, Cambridge, USA, 'The place of the computer in our world'.

1984 **Prof. John M. Ziman,** F.R.S., Imperial College London, UK, 'Doing my own work: the individual in collectivized science'.

1985 **Prof. Ilya Prigogine,** Nobel Laureate, The Solvay Institute, Brussels, Belgium, 'Exploring complexity from the intemporal world of dynamics to the temporal world of entropy'.

1986 **Prof. Sir Hermann Bondi,** F.R.S., Churchill College, Cambridge UK, 'The application of satellites in connection with the environment'.

1987 **Prof. Dr. Dick Swaab,** Dutch Institute for Brain Research, Amsterdam, the Netherlands, 'De klok in onze hersens'.

1988 **Prof. Dr. Abraham Pais,** Rockefeller University, New York, USA, 'Einstein's influence (the impact of Einstein's relativity theory)'.

1989 **Sir John Maddox,** Nature Magazine, London, UK, 'How true is the promise of science?'.

1990 **Prof. Dr. Cornelis M. Braams,** FOM-Institute Plasma Physics, Nieuwegein, the Netherlands, 'Kernfusie in historisch perspectief'.

1991 **Prof. Dr. Philippe G. de Gennes,** Nobel Laureate, ESPCI, Paris, France, 'Bubbles, foams and other fragile objects'.

1992 **Dr. Arno A. Penzias,** Nobel Laureate, AT&T Bell Laboratories, Holmdel, USA, 'The future of knowledge intensive industries'.

1993 **Prof. Dr. Henk C. van de Hulst,** University of Leiden, the Netherlands, 'Het astronomisch spectrum'.

1994 **Prof. Dr. Donald P. Greenberg,** Cornell University, Ithaca, New York, USA, 'Imaging and the electronic age'.

1995 **Prof. Dr. Hubert Curien,** Université Pierre et Marie Curie, Paris, France, 'Big instruments and big programmes for research; where is the limit?'.

1996 **Prof. Dr. Serguei P. Kapitza,** Russian Academy of Sciences, Moscow, Russia, 'World population growth and technology'.

1997 **Prof. Dr. Nicholas Negroponte,** MIT, Cambridge, USA, 'Why Europe is so unwired'.

1998 **Prof. Dr. Alan J. Heeger,** Nobel Laureate, University of California, Santa Barbara, USA, '20 years of research into conducting and semiconducting polymers; is it worth the effort?'.

1999 **Prof. Dr. H. Koenraad Hemker,** University of Maastricht, the Netherlands, 'Een bloedstollende geschiedenis'.

2000 **Dr. Rod C. Alferness,** Lucent Technologies, Holmdel, USA, 'Optical networks, enabler of the communication revolution'.

2001 **Dr. John L. Hennessy,** Stanford University, Stanford, USA, 'Directions and challenges in microprocessor architecture'.

2002 **Dr. Harold G. Craighead,** Cornell University, Ithaca, USA, 'Nanostructures for mechanical and biological applications'.

2003 **Dr. Sanjiv Sam Gambhir,** Stanford University, Stanford USA, 'Imaging diseases with molecular detectives'.

2004 **Sir Richard Friend,** FRS, University of Cambridge, UK, 'Plastic Electronics: new science, new technology, new products and new markets'

2005 **Dr. J. Craig Venter,** the Venter Institute, Rockville MD USA, 'From the Human Genome to Environmental Metagenomics'

2006 **Prof. Dr. Peter Carmeliet,** KU Leuven en VIB, Belgium, 'The neurovascular link of A. Vesalius revisited'

2007 **Prof. Dr. Henk van der Vorst,** RU Utrecht, the Netherlands, 'Men and Computers: an Upward Spiral'

2008 **Prof. Dr. Shuji Nakamura,** University of California Santa Barbara USA, 'Current and Future Status of Sold State Lighting'

2009 **Prof. Dr. Rutger A. van Santen,** Royal Academy of Arts and Sciences professor at TU/e, 'Energy, Catalysis and Society'

2010 **Dr. Denis Le Bihan,** Neurospin, Gif-Sur-Yvette, France 'Water: from Brownian Motion to the Mind'

2011 **Prof. Donald E. Ingber MD, PhD,** The Wyss Institute, Harvard University, USA. 'From Cellular Mechotransduction to Biologically Inspired Engineering'

2012 **Russel Foster, Bsc, PhD,** FRS, The Nuffield Laboratory of Ophtalmology, Oxford University, UK, "Light and the Rhythm of Life'

2013 **Cherry A. Murray, PhD,** Dean Harvard School of Engineering and Applied Sciences, 'Engineering for All'

2014 **Dr. ir. Robert Cailliau,** Former staff member CERN, 'The Web Adventure'

2015 **Prof. dr. Bastiaan R. Bloem, MD, PhD,** Radboud University Medical Center, Nijmegen, the Netherlands 'Healthcare Networks need Innovative Technology'

2016 **Andrew B. Watson PhD,** NASA Ames Research Center, Moffet Field, California, USA. 'The Windows of Visibility'

Imprint

Holst Committee

Candidates for the Holst Memorial Lecture 2016 were selected by the Holst Committee under the joint chairmanship of Frank Baaijens, Rector Magnificus Technische Universiteit Eindhoven (TU/e) and Kees van der Klauw, Senior Vice President, Philips Lighting.
Secretary to the Committee: Joep Huiskamp (TU/e).

Members of the Scientific Organizing Committee 2016

Sjoerd Mentink (Philips Lighting Research),
Marc de Samber (Philips Lighting Research),
Ingrid Heynderickx (TU/e),
Jean-Paul Linnartz (TU/e),
Johan Lukkien (TU/e),
Secretary to the Committee: Joep Huiskamp (TU/e).

The Organizing Committee 2016 was assisted by the TU/e Conferences Team.

Publication and distribution

The editors wish to thank Beau Watson, Leo Marcelis, Filip jan Depauw, Zary Segall, Kent Larson, Ingrid Heynderickx, Kees van der Klauw, Wilbert IJzerman, Tanir Özçelebi, Sjoerd Mentink and Yvonne de Kort for their kind cooperation.
This edition was edited by Joep Huiskamp (TU/e).
Text: David Hegarty, KPUNKT Technology Marketing
Graphic Design: Luc de Bruijn, KPUNKT Technology Marketing
Project Coordination: Linda van Gend, KPUNKT Technology Marketing

Illustrations

Illustrations have been published with the permission of the speakers.

On the 17th of November, 2016, Eindhoven University of Technology hosted the Holst Memorial Lecture and Symposium, with the support from Philips Lighting Research. This cooperation is fitting for an event commemorating Gilles Holst. He both founded the Philips Physics Laboratory in Eindhoven, which later became Philips Research, and was instrumental in founding the Eindhoven University of Technology.

www.tue.nl/holst