Achievements and learnings of researching intelligent lighting solutions in living labs at the TU/e Intelligent Lighting Institute.
SYNOPSIS

Since its establishment in 2009 the Intelligent Lighting Institute of Eindhoven University of Technology has been conducting research with users in living labs. This publication provides an overview of the various Living Light Labs, our achievements and the key learnings we gained over the years. These learnings cover requirements on the technical infrastructure, organisation of processes around living labs and embedding of responsibilities in the organisation, as well as involving users in research while respecting their privacy.

This publication is launched at the opening of our newest living lab in the Atlas Building: an indoor living lab at an unprecedented scale. We hope our learnings inspire many people to join us in researching intelligent lighting ‘in the wild’.

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

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PREFACE

“To build and apply scientific knowledge for the design of intelligent lighting solutions that create value beyond pure illumination.” On this mission the Intelligent Lighting Institute (ILI) was founded in 2009. In the past 10 years ILI’s lighting research has produced unique know-how and a technological head start for the lighting industry in the Brainport Region and beyond.

Lab facilities are crucial for experimental research, and definitely so for lighting research. In well controlled lab environments one can study the impact of light on humans. In such environments all settings of sensors, connectivity devices and light sources can be accurately and reproducibly controlled. This allows the researcher to create well controlled interventions and measure their impact on e.g., human perception, cognition, performance or behavior. Related experimental results are generally used to formulate or validate hypotheses on how a lighting system’s behavior might affect humans.

Such controlled lab experiments, however, have limited ecological validity, as a lab with invited participants is an oversimplification of the real world. In a naturalistic context, illumination is influenced by daylight variations and/or by (unwanted) reflections at walls or furniture. The interaction of humans with the lighting system is less controlled and often less conscientious. As such, the impact light may have on humans may be less pronounced or even completely different in ‘the wild’ than in the lab. It is thus paramount to also quantify the impact of intelligent lighting solutions in real contexts, where the lighting actually matters. In addition, controlled lab experiments do not allow to follow the effect of light on humans for periods of weeks, months or even years. They also do not allow to co-create intelligent lighting solutions with users and stakeholders. That is why ILI is proud to present its Living Light Labs: facilities in real-world environments that allow next level ways of experimenting.

Since its start in 2009, ILI has invested in multiple Living labs for different environmental contexts. The most recent example is the renovated Atlas building. It is the biggest indoor living lab of Europe that will be officially opened on March 21st, 2019. Experimenting in these labs has given us experience on the do’s and don’ts, and has provided insightful results for different stakeholders, from single users to groups of users and municipalities. This document gives you an overview of our various living labs over the last 10 years, and is meant to share our knowledge and insights with the outside world. We hope you enjoy reading it.

Ingrid Heynderickx, Scientific Director Intelligent Lighting Institute
In 2008 discussions started at the Eindhoven University of Technology (TU/e) to establish a Lighting Institute for interdisciplinary research into intelligent lighting solutions. The ambition was to rethink the way we work and interact with both natural and manmade lighting in the environments we have created, and create the technology to match and even surpass the naturalness and beneficial qualities of daylight, and to extensively enhance our modes of interacting with this technology. This resulted in the project ‘i-lighting the world’, with 6 PhD students and budget to create facilities to demonstrate and test prototypes in experimental research with users. The first Living Light Labs were created.

In 2009 the ‘i-lighting the world’ project was transformed into a research institute building on collaboration with companies, connecting creative and technological competences to develop and research innovative solutions, and work with the city of Eindhoven in public testing environments to create the first intelligent city of light. The result was the official launch of the Intelligent Lighting Institute (ILI) at TU/e. Conducting research with users in real-life test beds was an integral part of the ILI strategy from its early days.

### LIVING LIGHT LABS

| Generating insights | Study the impact of natural use of light on human beings |
| Developing solutions | Create and validate solutions that provide benefits to people |
| Real-life test beds | Human centric research & application design with direct involvement of stakeholders |

**10 YEARS LIVING LIGHT LABS**

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Since 2009 various facilities have been set up and used for research and educational purposes. As with all innovative approaches, it was not always easy. Doing research ‘in the wild’ is inherently difficult as there are many influences that cannot be controlled.

The scientific body of knowledge on living labs is vast. Various definitions are proposed, such as:

A Living Lab is a user-centric innovation milieu built on every-day practice and research, with an approach that facilitates user influence in open and distributed innovation processes engaging all relevant partners in real-life contexts, aiming to create sustainable values.

In practice the label ‘living lab’ is used for a variety of initiatives. A recent publication by the Rathenau Institute distinguishes four basic types of experiments that differ in two dimensions: the type of environment and the level of co-creation. Living labs are characterized by a broad and ‘inclusive’ collaboration between knowledge institutes, companies, professionals, societal organisations and citizens. Moreover, the experiment takes place in the real-life setting of the users, e.g. a neighbourhood. In living labs, the participants search together for solutions for complex issues. The living light labs that we created in the past 10 years all fit into this category, as well as the definition above. However, we do feel that there is still a distinction between labs in the scope for which they were created:

- **FIELD TRIALS**: environments for conducting experiments for one project together with project partners
- **LIVING LABS**: environments for conducting a continuous series of experiments across different projects, and an evolving ecosystem of project partners

In this publication both are included, because we also learned from the field trials and used these learnings in later projects.

Over the years we have gained valuable experience with doing research in living labs, as well as with the challenges to maintain living lab infrastructures. We have created living labs on our own campus, both indoor as well as outdoor. We also collaborated with living labs of our research partners, e.g. in the city of Eindhoven and Amsterdam. We joined the European Network of Living Labs (ENoLL) together with the city of Eindhoven in the 8th wave in 2014, to be able to learn from other living labs as well.

This publication aims to provide an overview of the living light labs that were active in the first 10 years of ILI’s existence. It provides a summary of the living lab infrastructure and its function in research and education. It also shows our academic achievements and learnings. In this way we aim to share our experience and contribute to living lab research.

The publication is launched at the official opening of Atlas, the new main building of the university. The building offers a unique environment for research, with its large scale, its focus on sustainability, its place in the TU/e community, and its intelligent lighting infrastructure. Atlas hosts our newest, and to date most sophisticated living lab at an unprecedented scale. In this living lab we implement the learnings of the last 10 years and our aim is to make this a true best practice in living lab research: where we do groundbreaking research while respecting the privacy of the residents. This requires redefining the processes of planning and conducting research as well as data gathering and management.

In the coming years we will gain further experience with researching ‘in the wild’. If you are interested, please follow our progress through our bi-annual ILI Magazine.

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ILI started with Living Light Labs on its own campus in 2009. Since then various living labs have been up and running on various locations.

This overview shows when living labs started and when they were discontinued. The blue bars indicate the living labs at TU/e’s own campus, the dark green bars indicate living labs at a location of one of our research partners.

Three living labs (Hoekenrodeplein, Atlas and Jouw Licht op 040) already had extensive preparation activities before the opening of the premises and start of the actual living lab research. These preparation periods are indicated by the lighter coloured bars.

**OVERVIEW OF ALL LIVING LIGHT LABS**

ILI started with Living Light Labs on its own campus in 2009. Since then various living labs have been up and running on various locations. This overview shows when living labs started and when they were discontinued. The blue bars indicate the living labs at TU/e’s own campus, the dark green bars indicate living labs at a location of one of our research partners.

Three living labs (Hoekenrodeplein, Atlas and Jouw Licht op 040) already had extensive preparation activities before the opening of the premises and start of the actual living lab research. These preparation periods are indicated by the lighter coloured bars.
Living lab research at ILI started with a Breakout Room in our own main building to research how lighting influences people’s state-of-mind and develop adequate and user-friendly interfaces that allow people to communicate with the lighting system and deal with the complexity of its opportunities.
Purpose

In office buildings with an open-plan architecture, there are often particular areas designated as breakout areas. Office employees can use breakout areas to have informal meetings, receive guests, have small brainstorm, make a phone call, read a book or simply to relax for a moment. Lighting is an important element in breakout areas, which enables and supports people in their activities. Lighting may enhance productivity, but in breakout-context lighting can also be an important atmospheric influence, and influence peoples’ state of mind. The Breakout Room was ILI’s first living lab and was opened in 2009.

Infrastructure

The space contains furniture in two seating areas. One is made up of two comfortable chairs for individual retreat such as reading, reflection, or relaxation. The other area has benches for small group meetings such as student-supervisor meetings, reception of guests, small brainstorms or a coffee break. The lighting in the room consists of coloured ambient lighting (wall washing) as well as functional (warm-) white lighting (down-lighting). Coloured lighting on the walls is provided by three sets of Digital Multiplex (DMX) controlled RGB led fixtures. Halogen lamps in various fixtures that are both floor- and ceiling based provide the white lighting. Outside the area is a 60x60cm 12x12 RGB LED panel that can be used to display abstract information about the current usage of the space.

Apart from the lighting infrastructure, the area contains several sensors that can be used by the system to provide smart behaviour. Each area has a ceiling-based motion sensor (Passive Infra-Red or PIR), and the general sound pressure level in the room is measured, as well as the incoming daylight. In total, the area contains 10 wirelessly controllable nodes for lighting control, sensing or both.
Research

Our aim is to develop adequate and user-friendly interfaces that allow people to communicate with the lighting system and deal with the complexity of its opportunities. In addition, a breakout area that is ‘smart’ also needs to learn and adapt its behaviour to varying needs and users. Challenges are therefore in the development of machine learning algorithms, which allows the system to learn from the information that is gathered from the area. The Breakout Room is an ideal context for our research on interaction with lighting systems in real-life conditions.

Education

The context and the infrastructure of the Breakout Room has been used by many student design projects for developing and testing their design in the area of smart and social lighting.

Learnings

The breakout room was situated within the office premises of the Intelligent Lighting Institute. The technical infrastructure was relatively simple, and researchers had direct access to the system. Because of its limited scale the required procedures were relatively simple.

The breakout room was dismantled in 2013 when the building was cleared for a major renovation.

Academic results


Conducting research here was relatively simple because of easy access to the technical infrastructure, limited scale and location in our own office.
Adaptive urban lighting provides a solution for reducing energy consumption and light pollution by having the lighting adapt to the activity on the street. Such systems may operate autonomously based on sensor data, or through input from road users (i.e., light-on-demand), and provide lighting only where and when people need it. The ENSURE project studied the technical implementations of autonomous smart lighting systems and its requirements from a user perspective. One question addressed in ENSURE is how adaptive lighting systems should respond to the detection of a street user. This involves, for example, where on the streets the light levels will be raised: In a pedestrian’s immediate environment, or only in the direction in which they are heading? Behavioural tests conducted within ENSURE provided empirical answers to such questions.

ENSURE was a fairly short project (2 years) and towards its end it was decided to set up a more extensive project to study outdoor lighting aspects. This new project, ISLES 2014, was executed in the period Jan 2011 - Feb 2014. During this project, De Zaale was used for developing and testing sensors for adaptive lighting solutions until it was dismantled in 2014.

**Purpose**

The living lab De Zaale was the first outdoor living lab of the Intelligent Lighting Institute. In the context of the “kenniswerkersregeling” (the Dutch government response to the economic downturn) the project ENSURE started as a collaboration between Philips Research, Philips Lighting and the TU/e. ENSURE established an outdoor testbed in ‘de Zaale’ at the university premises to research adaptive urban lighting solutions and their effects on energy savings and pedestrians’ perceptions of safety and comfort. The research in the living lab started in 2009.

**Infrastructure**

The Zaale is one of the main roads on the TU/e campus, and is used by cars, cyclists and pedestrians alike. The adaptive lighting infrastructure of De Zaale spanned about 330 meters, and contained:

- 12 Philips CitySoul BGP431 GRN88 led luminaires (8820 lm max, 4000k) placed next to the existing luminaires.
- Intensity of each luminaire individually controllable through Philips Starsense powerline communication.
- Large range of illuminance levels: Eh 0.5 – 15.5 lx on street level
- 2 sensor boxes: Plug and play sensors & data storage through glass fibre

**Partners**

Philips Research, Philips Lighting, and ViNotion.

**Research**

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De Zaale was used by students in several honours and Human Technology Interaction courses and graduation projects.

Learnings

As ILI’s first on-campus living lab, we faced a lot of challenges. The university appeared not to be ready for living labs, and TU/e facilities management had to become accustomed to experiments and experimental infrastructure to be installed on the campus. The university considered De Zaale as a temporary trial, to be removed after the research had finished, and did not share our vision of De Zaale to become a more persisting living lab in support of all kind of related research in the future. Upholding the living labs in times of inactivity, for example, when no research funding was available for support, proved difficult. The learnings of De Zaale were used in discussions with all stakeholders to identify improvement opportunities. This resulted in campus facility management adopting the living lab approach and offering support from various services.

Academic results


We underestimated the challenges of keeping a living lab running when research funding stops, and it is not embedded in regular processes.
**Purpose**

Potentiaal was the home-base of the department of Electrical Engineering. In 2010 a living lab was set up to explore energy aware buildings using activity and context knowledge:

- To achieve energy savings at whole building level
- Technical architecture allowing retrofitting and scalable solutions for existing buildings

GreenBuildings is a European project consisting of universities and industrial partners that has developed a holistic, activity-aware framework for saving energy and enhancing occupant comfort in commercial buildings. The framework utilizes already installed and novel sensors to recognize occupant activities, behaviour, and context in office environments affecting energy consumption and comfort.

Building-wide distributed context information is processed and used to support system control in existing BMS and to manage office appliances.

**Infrastructure**

The living-lab installation in the Potentiaal building at TU Eindhoven campus comprises of three shared offices, one private office, a pantry area with a kitchenette, coffee machine and tables, as well as a meeting room. Various sensor installations allow recognition of dynamic usage patterns in the occupants’ behaviours, which, in consequence, provide excellent opportunities to minimize energy consumption.

The living-lab installation comprises the following sensors:

- Passive Infrared (PIR) sensors for motion detection and counting number of people
- Ultrasound ranger (USR) in order to measure distances and detect presence
- Microphones to recognize office activities
- Light, temperature, humidity, CO2 sensors for detection of environmental conditions
- Magnetic contact switches to recognize use of windows and doors
- Plug-in power meters to measure consumption of appliances

In order to allow acting towards reduced energy consumption, the installation is completed by the following actuators:

- Light switches to activate and dim lights
- Plug-in power meters to be able to activate and deactivate appliances
- Blinds motor/controller for controlling angle and height of window blinds
- Portable air conditioner to control and adjust temperature, humidity and CO2 level
Partners
Philips Lighting, FS-@, Advantic, Groningen University, Sapienza University, ITI, Cini

Research
Research in the Potentiaal living lab focuses on:

- Activity and context inference: activity recognition and improvement of user comfort
- System architecture for a large number of sensors, distributed processing units to integrate activity and contextual information to estimate energy saving options

Results from studies that we conducted in the living-lab installation at the Potentiaal building indicate that a dynamic control can indeed lead to substantially reduced energy consumption. The findings confirm the relevance of building energy management based on activity sensing: dynamic information on user activities provides a valuable source for building control in general and building energy management systems in particular.

A ubiquitous embedded systems framework for energy-aware buildings using activity and context knowledge was developed. The project also revealed further research questions that could be addressed in further research:

- Can we automatically optimize energy consumption of by means of user feedback, e.g., via controller input or window usage?
- Is it possible to learn dynamic usage patterns of occupants based on characteristic developments of their energy consumption to optimize energy-saving efforts?
- Can feedback to office occupants change their behaviour in order to reduce the overall energy needs?

Learnings

The Potentiaal living lab provided insight into requirements for future installations, such as the option to integrate working prototypes with state-of-the-art Building Management Systems.

The Potentiaal living lab was dismantled in 2013 when the building was renovated and transformed into student housing.

Academic results


Infrastructure

The project was divided into two phases. In the first phase an experimental set-up was created in the Design Huis during GLOW in 2010. A series of dark corridors were created, where the different lighting scenes could be experienced by the public. On a touch screen they were asked for their experience.

In the second phase prototypes of the adaptive lighting system were installed on-site with dimmable led with amber and white led’s and a mobile control application.

Four lighting scenes were designed and tested:

a. Early evening: white light, with 5 lux, to enable commuters to safely cycle home
b. Late evening: dimmed yellowish light, 3,5 lux, to provide good visibility for the occasional cyclist or athlete and less disturbance for flora and fauna
c. Night: cool white light, less than 1 lux, to mimic moon light, save energy but still provide an aesthetically pleasing atmosphere.
d. Morning: cool bright light, 7 lux, to increase alertness of cyclists

In September 2012 the prototypes were used to analyse how residents and stakeholders perceived safety and atmosphere of the four scenes.

Partners

Municipality of Eindhoven, Lux Lab and Indal (now Signify).

Purpose

The project Zilverackers aims create a safe and pleasant environment in an ecological zone. An innovative lighting concept was developed that uses a stakeholder approach to ensure different lighting settings (varying in colour and intensity) at different times accommodate the different stakeholders. Before implementing the solution, a field trial was used to explore how people perceive safety and whether they accept the new lighting solution that features different (dimmed) scenarios over the course of the evening and night.

Scenes for different times of the night

Prototypes installed for the tests with stakeholders (The Lux Lab)
The project focused on two aspects:

- Developing methodologies to assess intelligent lighting solutions with multiple stakeholders
- Conducting field experiments to gain insight in the appreciation of stakeholders for different scenes.

To understand the appreciation of residents and other stakeholders for different lighting scenes it proved to be very valuable to be able to experience the scenes at the site itself with prototypes. As light is intangible, it is very difficult for people to imagine the difference between light levels and colours.

In this project we combined perception questions with visibility capability measurements, to gain insight into the relation between visibility and appreciation of scenes. This proved to be very helpful in discussions with the municipality and police department on the results of the analysis.

**Education**

Master students from Industrial Design designed tangible tools for stakeholder analysis.

PhD students from Industrial Design were involved in creating an interactive tool for assessing the perception of safety and atmosphere of different settings.

User System Interaction PDEng students designed and conducted an experiment with prototypes in the field.

**Research**

**Learnings**

A temporary setting with prototypes on-site is not easy to realise in public space but proved to be very valuable for the interaction with citizens. Smooth working systems, in this case with a control application to switch between different lighting scenes made the research process very smooth.

**Academic results**

Purpose

In cooperation with the Eindhoven municipality, the ISLES 2014 project consortium installed a living lab in the residential area of Achtse Barrier. The living lab was used to collect information about the performance of adaptive street lighting in respect to energy savings, accuracy of detecting road users, and effects on safety and safety perceptions. The research in the living lab started in 2011.

Infrastructure

An adaptive lighting system was installed in two different areas in the Achtse Barrier: On a section of the main connection road, and in various residential streets (see Figure 12).

- On the main road 18 dual-luminaire poles were retrofitted with 36 Philips Iridium LED luminaires. Near the entrances of the retrofitted area, four passive infrared (PIR) sensors were attached to monitor the activity on this road.
- On the smaller streets and some connecting bicycle and pedestrian paths, a total of 45 poles were retrofitted with Philips UrbanStar LED luminaires. On 42 of these 45 poles, a PIR sensor was installed to monitor the nearby activity.
- Four cabinets were installed to collect ground-truth information using video cameras and to monitor the technical performance of the system using radio communication sniffers.
- All LED luminaires and PIR sensors were provided with a Philips StarSenseRF module, such that the LED luminaires could react to activity detected by the PIR sensors.

Partners

Philips Research, Philips Lighting, NXP, ViNotion, Y’all Solutions, Metatronics and CER.

Research

In the ISLES project, the performance of the adaptive lighting system with respect to energy consumption and safety perceptions was investigated in isolation of any possible effects of the transition to LED lighting. For this purpose the research was conducted in three phases: 1) the existing lighting (i.e., baseline), 2) LED lighting, and 3) adaptive LED lighting.

Based on research conducted in living lab De Zaale during the ENSURE project, and on additional research conducted within a VR simulation of the Achtse Barrier, an algorithm was designed for the activation of the LED luminaires in the residential area based on activity detection.

Energy consumption in different scenarios
The effects of the transition to LED and the adaptive dynamics on lighting quality and safety perceptions were investigated for the residential area. For this purpose, surveys were distributed three times amongst all inhabitants in the experimental area, and in a comparable control neighbourhood: once in each phase of the research. In addition, multimethod (diaries, interviews, focus groups) qualitative research was conducted to uncover how residents experienced, thought about, and were affected by the adaptive lighting system installed in their neighbourhood. Recommendations for future generations of such systems could be formulated on the basis of this data.

To determine the estimated energy savings of the dynamic street lighting system, a simulator was constructed that used the collected activity data to evaluate how different parameters of the algorithm affect the energy consumption of individual luminaires in the area.

**Education**

Master students from Industrial Design designed Quantitative and qualitative student research projects at Human Technology Interaction.

**Learnings**

The project provided valuable insights in collaborating with companies and municipality in real residential areas and in involving citizens in research in their own living environments. These learnings were carried along to new living labs.

Despite the desire to keep the living lab running, there were no immediate resources to conduct studies in the near future, so the living lab was discontinued at the finalization of the ISLES project in 2014.

**Academic results**


Purpose

The purpose of the living lab is to enable research in context, and by this gain a deeper understanding of the needs of people living with dementia, as well as other stakeholders such as caregivers, family members etc. In this living lab solutions that support people with dementia in their daily life are developed with them in co-creation. The aim is to find better solutions to allow people to stay at home longer as the condition progresses over time while maintaining a higher quality of life. The initiation of the living lab was funded by Interreg IVB NWE under the Innovate Dementia project. After the project finished (2015) the living lab research continues in collaboration between the mental health provider (GGzE) and TU/e.

Infrastructure

The focus of the living lab is catering for the perspective of people living with dementia at home, therefore the living lab Innovate Dementia is mostly an organizational structure rather than a physical place. In this “distributed” Living Lab - where research takes place at the homes of the participants - the involvement of various stakeholders is crucial. Each stakeholder has a specific role: identifying the needs of people living with dementia (GGzE in the lead), developing and evaluating innovative solutions (TU/e in the lead), dissemination and involvement of companies (Brainport in the lead) and community building (City in the lead). Fundamental to the infrastructure is a community of people living with dementia and their carers (the Innovate Dementia panel) who were dedicated to the Living Lab and could be consulted and recruited.

Research

One of the interesting projects conducted in the Innovate Dementia Living Lab was done in collaboration with Vitaallicht: Vitaallicht produces a luminaire with bright bluish light to support the day-night rhythm of its users. The company added a dynamic pattern so it adjusts depending on the time of day. A study was conducted with eleven people with dementia and their caregivers, at their homes, to grasp their experience of such luminaire at home and how they would use it in their daily lives. Each user was given a small “probe” kit with a recorder, a camera and a notebook to log their day-to-day experiences.

Based on the results of the study the company could improve their product offering for this specific target group. In ‘Design for Dementia’ these insights, among other cases, were used to formulate design guidelines to help others to design technology and services for people living with dementia that are more human-centred, and allow for direct interaction with technology by those with dementia. Following this work several new research tracks have been started, and an expertise centre for Dementia & Technology has been set up, as part of the Human & Technology centre. Two PhD candidates are continuing this line of work.

Partners

Mental health provider GGz Eindhoven, Brainport Development, City of Eindhoven, and several companies such as Vitaallicht (now Sparckel).

INNOVATE DEMENTIA

Visual overview of Living Lab process

ILI LIVING LIGHT LABS
Since the start of the Innovate Dementia Living Lab in 2012 a continuous flow of students projects have been focusing on this topic within Industrial Design. Input from students contributed both need finding and designed solutions.

Learnings

In this ‘distributed’ living lab we gained several insights. First, ethics are very important and complex when dealing with vulnerable groups such as people with dementia, as they can often not consent to research themselves. For this we partnered with GGzE, and currently collaborate with University of Tilburg. We introduced a “conversation” consent which is not only used at the beginning of the project, but throughout the study at every research-participant encounter. A living lab proves to be ideal to facilitate design-driven projects, and even in the case of dementia, can facilitate a ‘design with’ perspective rather than ‘design for’. All the involved stakeholders such as companies, care organisations, cities and universities are needed for successful design and implementation of solutions in complex contexts such as dementia.

Academic results


Working with vulnerable people in this living lab resulted in new ways of working regarding informed consent.
THE MARKET HALL

The Market Hall living lab enables research on intelligent lighting solutions from a technical as well as human centric perspective.
The Market Hall living light lab is situated in the roofed area in front of the Metaforum on the TU/e campus. This area acts as a main transition hub for staff and students, and houses many smaller and larger activities (e.g., Momentum, Christmas market, Hajraa festival). The infrastructure was realized in two phases in 2012 (v1) and 2015 (v2), and both systems co-exist to date:

### The 2012 infrastructure:
- Adaptable warm and cool ceiling luminaires with RENA Leonardo LED modules covering 62.5 by 75 m in a 20 by 24 grid. This lighting installation is part of the permanent building infrastructure. Controlled by an Artnet DMX controller

### The 2015 infrastructure:
- 32 Philips CK Powercore RGB LED and 32 Philips CK Powercore iWhite LED spots arranged in an 4 x 8 grid covering 12.5 by 25 m. Controlled by a Pharos DMX controller
- 3 Axis P1357-E network cameras pointing downwards equipped with wide angle Theia lenses to deliver a wide view with minimal distortion
- 12 Microsoft Xbox 360 kinects arranged in a 3 x 4 matrix using innovative algorithms for pedestrian tracking developed by the Crowd Flow group at TU/e
- Dedicated NAS for data storage
- Dual platform software architecture: A core platform designed around the open source OpenRemote software, and an experimental platform for user-written control software.

### Partners
Philips Lighting, OpenRemote, Living Projects, ViNotion, DITTS, Axis, Studio Lucifer, Wolfpack, Studio Philip Ross, Sorama.

### Research
The Market Hall has supported research on 3D depth cameras and crowd flow algorithms for people tracking. It has supported research on the application of lighting for crowd management, for example by testing whether dynamic lighting can affect crowd speeds. This resulted in the INFLUX installation, and large scale crowd management experiment at the Market Hall during Eindhoven’s lighting festival GLOW in 2016. The hardware and software setup developed for INFLUX were later used for the 2017 GLOW installation and crowd management experiment MOVING LIGHT in the city centre.

It has supported research on social urban lighting, aimed at creating socially pleasant night time spaces, or to enhance community sense or social capital amongst residents. Research in this domain has focussed on the
effects of lighting on interpersonal distancing, perceptions of the sociality of space, or on creating playful interactive lighting scenarios. For the 2019 TU/e Christmas market, for example, an interactive light experience was created for the ice skating ring using Market Hall luminaires and 3D depth sensors. Current research on social lighting uses the Market Hall living light lab as testing grounds for applications that grant residents more control, and thus a shared responsibility over the lighting in their neighbourhood.

A final example of research supported by the Market Hall is the development of IoT-based approaches to light control, for example by assigning virtual IP-addresses to each individual DMX luminaire.

Education

USE secret life of light projects, Bachelor’s course Physics of light and lighting design, Honour program projects, Bachelor and master thesis projects in Software Engineering, Psychology & Technology, and Human-Technology Interaction, and multidisciplinary Bachelor thesis projects at TU/e Innovation Space.

Learnings

From the 2012 installation (v1), we learned that setting up a successful living lab takes more than installing technology. It requires a consideration of the needs of all stakeholders (including users of a space) and a shared goal towards improving a certain space—which was missing or not yet identified in the Market Hall. It also requires an understanding of the needs of researchers with respect to what technology to install, and of their skill level in using these. These and other lessons, were applied to the 2015 infrastructure. Since then we learned about the difficulties of maintaining a living lab and the effort required for building an eco-system that includes users, researchers and industry. We learned that a solid front-end development environment is strongly required in order to allow researchers and other users to benefit from and built upon earlier software developments.

Academic results


A solid front-end development environment is required to benefit from and built upon earlier software developments.
Purpose

The Green Strip is a crucial part of the Campus 2020 Master Plan to revitalise the TU/e campus into a science park. The aim is to create a pleasant and inviting atmosphere and strengthen the innovative image. TU/e Facility Management initiated contact with lighting designers Har Hollands and Rombout Frieling to create an accompanying lighting master plan, which included adaptive lighting for the Green Strip using specially designed lighting poles, and turning the old chimney into a light beacon. The systems are designed to enable different scenes to show what is happening on campus.

Infrastructure

The special lighting pole: LanTUern can spread light into all directions. It contains the same RENA Leonardo LED modules as used in the Market Hall, and can be controlled with the same ArtNet DMX controller. The atmosphere can be regulated through warm and cold white light. The Green Strip was realised in 2012.

AnTUenna: The chimney of the former boiler room has been covered with a grid of led-lights on the chimney, that serves as a display. It has become a dynamic beacon for the nightly TU/e campus and the city. AnTUenna was realised in 2017.

Partners

Har Hollands, Rombout Frieling.
Research

Research at Human-Technology interaction has used the adaptive lighting on the Green Strip for research on pedestrian safety perceptions and on exploring novel ways of measuring such perceptions in more objective ways than the typical self-reports, for example through the distance people maintain between themselves and a stranger on the street. This research has demonstrated the potential of such a metric by demonstrating that interpersonal distancing is affected by safety-related environmental factors.

AnTUenna: Computer Science students developed advanced control software for AnTUenna, enabling real-time data visualization on the chimney. We conducted an analysis among different stakeholders in and around the TU/e campus and found directions for applications that could be of value to the TU/e and Eindhoven community.

Education

The Green Strip hosted USE secret life of light projects. AnTUenna served as platform for two courses:

- The Software Engineering Project, a group graduation project for Computer Science Bachelor students;
- The Honours Students Light Force track for the university’s top bachelor students.

Learnings

The AnTUenna proved to be a fruitful platform for education. The step from educational prototypes to robust everyday applications is a large step. Student software needs to be adopted and adapted by university staff to become maintainable. This requires effort and budget, that need to be taken into account in case everyday application is a goal.

Academic results

Research

TU/e used the living lab of Strijp-S to do some initial studies on how residents can collaboratively control smart public lighting (for example) with a mobile interface. The research in the S-mart Strijp-S project focused on:

- Stimulation of an innovative ecosystem on Strijp-S and the factors for success and failure in the development of solutions based on data and lighting technology.
- Development of smart city solutions based on the needs of residents, visitors and companies on Strijp-S. For example whether residents could be given more control over the lighting in their neighbourhood and the possible benefit of sensor data in supporting neighbourhood watch teams in their duties.
- Data-infrastructure and -governance to support the development of innovative applications and safeguard commercial and public values at the same time.
- Valorisation mechanisms for smart city applications.

Purpose

The purpose of the living lab Strip-S is to improve quality of life of residents and visitors; to create more social, comfortable and sustainable ways of living. Strip-S offers a dynamic environment to create, develop, demonstrate and replicate innovative products and services.

In the NWO-funded project ‘S-mart Strijp-S’ TU/e conducted research into the development of an innovation ecosystem for the creation of smart city solutions based on open data.

Infrastructure

The smart city infrastructure in Strijp-S consists of three layers:

- The ‘cloud layer’ houses all data and online traffic. Analysis, communication and content development all take place in this layer.
- Next is the ‘liveable layer’: the tangible part of the city. The streets, the lights etc. Part of this layer are the RGB street lights, camera’s and sensors.
- Finally, there is the ‘infrastructure layer’: roads, railways, pipes and optical fibre cables.

The interaction between these layers makes the city smart. The layers communicate with each other and work together, thus creating crossovers and integrations. The result is a more efficient and sustainable city with opportunities for innovative business models.

Partners

Park Strijp-S Beheer BV, City of Eindhoven, TNO, VolkerWessels, Sorama, and various companies and start-ups residing on Strijp-S.
Education

The flexible lighting infrastructure at Strijp-S was used to explore new opportunities with lighting as part of the masterclass of OPENLIGHT, the creative lab of ILI. Students designed the IRIS installation that was part of GLOW in 2013, using the RGB Led lighting to demonstrate that colours only exist in our minds.

In the S-mart Strijp-S project bachelor and master students of Innovation Management, Psychology & Technology, and Computer Science conducted their graduation projects. Student teams of the Certificate Technology Entrepreneurship and Marketing analysed the business potential of smart lighting applications.

Learnings

The lighting infrastructure of Strijp-S and its connection to broadband glass-fibre opens up new opportunities for smart lighting solutions. However, in this project we learned that a good interface to design lighting scenario’s is a prerequisite for success. If this process is too cumbersome, only few people will take the effort to use the system.

A second learning is the importance of the composition of the innovation ecosystem to stimulate open innovation. When commercial parties drive the ecosystem, other companies hesitate to invest in creating applications, as it is not clear if they can capture the value of their investments.

A technical infrastructure, although an essential element, alone is not sufficient for a living lab to thrive. Some shared goals towards what is to be achieved in the area is important.
Infrastructure

The infrastructure on Stratumseind consists of:

- Philips tunable (warm/cool) white and RGB luminaires that can be controlled individually to create dynamic lighting scenarios.
- A wide range of sensors, such as cameras with people count algorithms and 3D sound cameras.
- An open source software platform to connect the lighting, sensors and other data sources (e.g. weather info and social media monitoring).
- A base camp: a room where the data of all sources is collected and monitored.

Partners

The De-escalate partners are: Eindhoven municipality, Philips Lighting, Polyground, DITSS, Politie Brabant Zuid Oost, RTR-NL, Het Lux Lab and Open Remote. Many other companies joined the Stratumseind ecosystem later on: a.o. VNotion, Coosto, Omines, Atos.

Research

The NWO Click-NL funded De-escalate project used the Stratumseind living lab to conduct research on the possible role of lighting in reducing aggression on Stratumseind. For this purpose, specially designed luminaires were installed on Stratumseind that housed tunable white and RGB led modules. Research aimed to explore the role of the environment, of which lighting is a part, on the development of aggression. This led to the identification of changes in ‘atmosphere’—defined as an attribute of the social-physical context that affects the behaviour of groups and individuals by emerging from and feeding into ongoing social interactions—as an important factor in the development of aggression. The second aim of the project was to explore whether lighting, as part of the physical environment, could be used to positively affect atmosphere and hence aggression. Results indicated that atmosphere is amenable to change, for example through colour temperature of the street lighting.

Purpose

Stratumseind is a popular pub street in the centre of Eindhoven, where incidents and aggression happen. It became one of the first living labs that were the result of the vision and roadmap on urban lighting Eindhoven 2030 that was made by TU/e for the municipality of Eindhoven in 2012. The purpose of this living lab is twofold. The aim of the municipality is to improve liveability, safety and economical sustainability of the area. The aim of TU/e is to research the impact of dynamic lighting.

The Stratumseind living lab is also interesting as it employs an open and collaborative innovation approach with a wide range of companies and organisations.

Integrated sensor system and lighting scenes
The innovation ecosystem on Stratumseind has also been a topic of research. Research projects aim at understanding the process of developing new business in such a setting where value is added for multiple stakeholders, but business models are not clear yet.

**Education**

USE secret life of light projects, USE technology entrepreneurship projects, Psychology & Technology Bachelor thesis projects.

**Learnings**

Stratumseind most likely is one of the best functioning living light labs to date. It is successful, in part, because stakeholders have the shared goal of improving the livability, safety and economical sustainability of the area; and technological infrastructure is first most installed to meet these shared goals. Second, it proves to be an essential asset to have a person who is committed to the project and can spend time and effort to resolve issues that may provide data that in the future could be used for psychological research. Another lesson learned is that the university, as academic partner, should not own or be responsible for any part of the technical infrastructure of off-campus living labs. This was the case for the lighting installation during the De-escalate project, and led to continuous maintenance issues.

**Academic results**


The smart lighting system consists of a set of LED spotlights that enable different light scenes by adjusting the light levels for the individual light sources. The system uses camera’s and mac-address tracking to count the people on the square and monitor their locations. In this way the system can adapt the light scenes to the use of the square, for instance commuting during the morning and evening rush hour, or leisure activities at weekend evenings. It can adapt by dimming the light when there is nobody around, or by lighting up the areas in which people are present to create a pleasant atmosphere. During events the system provides and inviting light scene to attract people to come or to stay longer. When it is very busy the system can be geared up to a higher light level, enabling surveillance of the crowd for security reasons. The adaptive lighting provides the service to create the right ambiance for any moment.

Partners

City of Amsterdam, Philips Lighting, Cisco, Alliander, KPN.

Research

The research during the field trial focused on:

- Identification of the needs of users of the square: residents, commuters, bar and restaurant owners, emergency services etc.
- Validation of the lighting scenarios through analysing the data provided by the system.
- Analysing business model options for smart lighting services.
Education

Bachelor students of the USE module ‘Business aspects of intelligent lighting’ analysed the business models of the different parties in the ecosystem.

Bachelor students of Human Technology Interaction analysed the value of smart lighting for their final project.

Learnings

The initial vision for smart lighting at Hoekenrodeplein was ambitious. However, due to the lack of an integrator role, the contribution of the project partners did not deliver a fully functional system. Due to technical incompatibilities, a mismatch in interests and the absence of a clear locus of control the project ended in an impasse. The lighting system functions, but it is not as interactive as it should be. The system does not provide the right data to analyse the effect of the different lighting scenarios.

Academic results


The integrator role is essential to create a fully functional system using hard- and software of different project partners.
Purpose

Research in laboratories allows excellent experimental control, but the physical circumstances and the tasks studied there are highly artificial and quite remote from real-world experience. Moreover, most of this research is performed with students. But of course, students are only a very limited representation of the wide variety of people out there. In our collaboration with GGZE, we get to gain insight in the light’s potential for real people, and in areas where light could really make a difference.

Infrastructure

Perhaps the term ‘Living Lab’ does not fully apply here - at least not in the sense of a fixed infrastructure at one specific location. But GGZE has repeatedly opened their doors for technology-enabled field studies in their care facilities. Starting in the High & Intensive Care (HIC) Unit, where Philips Lighting and GGZE realized facilities to prevent having to place clients in separation rooms, light installations were temporarily implemented and evaluated in the GGZE crisis center, psychosis units and forensic hospital Woenselse Poort. Installations included interactive contact walls and light coves for immersive and pleasant light scenarios in the HIC, dynamic lighting in the group living room, dawn-dusk lighting in clients bedrooms, and personalized dynamic light scenarios in clients’ rooms implemented through Philips Hue lighting.

Partners

GGZE - Geestelijke gezondheidszorg voor mensen in Eindhoven en omgeving; Several projects also in collaboration with Philips Lighting - now Signify. Parts of the work - in particular the work at Woenselse Poort - was funded by NWO Creative Industries (De-escalate project).

Research

People are affected by their environment more than we often realize. Environmental cues may influence our emotions, cognition, and perceptions of others, and, through this, our behaviour. Most of the research performed in this context has centered on preventing or defusing stress, and improving wellbeing. This includes efforts to lower arousal and create more sociable and approach-oriented atmospheres via the visual pathway, as well as efforts to promote a good circadian rhythm (e.g., via dawn/dusk simulation) via the non-visual pathway.

Education

Beyond PhD students and clinical psychologist in training, several MSc students Human Technology Interaction have been involved in, or even running studies at GGZE as their thesis work.

Learnings

Working with vulnerable people is challenging - none of the standard protocols and instruments from the lab work, privacy, respect and beneficence are should be very salient and explicitly discussed between all partners - but also very rewarding. If ever one can make a positive impact, it is here.

Academic results


The original 11 fluorescent-tube based recessed luminaires have been replaced with a connected lighting system. The lighting system uses a customised version of Zigbee through XBee radios for wireless communication. Each of the 22 LED luminaires is fitted with an XBee radio and has integrated logic and sensing (motion, light level, and temperature). The light output can vary in intensity (0 - 3800 lm) and colour temperature (1700 - 8000 K). This artificial lighting system is the only light source in the workspace, apart from little daylight from north-facing window.

Partners

TU/e Industrial Design, Signify, Zumtubel, Johnson Controls

Research

Interface characteristics play a major role in interacting with light. The experience of light, the user acceptance and the actual use can be enhanced by making the interface more engaging. Another important aspect the shared nature of lighting systems: multiple people can interact at the same time, and new interactions can change the (carefully) selected light settings of others.

Education

The experience with connected lighting system has inspired many students to design interfaces and related services for interactive lighting systems.
Learnings

This living lab was situated near the office premises of the Intelligent Lighting Institute. The technical infrastructure was advanced but fully accessible for the researchers. Investigating new emerging technologies as interacting with connected lighting in a real life context is challenging. In between controlled experiments and real offices, this living lab provided us the opportunities to explore the challenges of interacting with light and discover the needs and requirements of designing for such systems in an easy to reconfigure and easy to observe environment.

Academic results


Prior to going to real offices with new emerging technologies it is important to gain experience in an easy to reconfigure and observe setting.
The final design has been validated by a pilot installation in the office of the GGD Brabant-Zuidoost in the “Witte Dame” (White Lady) building in Eindhoven. This building is a former Philips factory built in 1930 in which light bulbs were made. Renovated by the City of Eindhoven it is now a national industrial monument and in daily use as offices. In the last quarter of 2017 400 luminaires, with a mix of manufacturers, has been installed for a 5-month trial period starting January 2018.

Partners

The project brings together a strong collaboration of the leading lighting companies Zumtobel, Tridonic, and Philips Lighting and the major players in IoT technology ARM and NXP, and Imtech. Consortium partners Johnson Controls and Dynniq represent the installer and the end user. Academic knowledge on system architecture, integration and user interaction is added by ILI-TU/e and TNO-ESI.

Purpose

The Horizon 2020 project “OpenAIS” aims at developing a standard for inclusion of office lighting into IoT: connect the luminaires in buildings directly to the Internet, putting the promises of the Internet of Things concept at the heart of lighting system architectures. This enables a transition to an open and service oriented lighting system. The vision of the OpenAIS project is to create an open ecosystem of suppliers of interoperable components and a market for apps and services that exploit the lighting system to add value beyond the lighting function and allow easy adaptability to cater for the diversity of people and demands. Added value can be related to more efficient use of the building, reduction of energy consumption, and increased comfort and wellbeing.

Research

The inclusion of IoT in office lighting allows people to have personal lighting control at their workplace. To design lighting control interfaces that fit people’s everyday living, we need a better understanding of how people experience lighting interaction in the real world. This living lab allowed us to execute field studies concerning the user experience of the introduction of connected lighting and two control interfaces: a smartphone app for personal lighting control in the office, and tablets with dedicated control for meeting rooms. Based on the results, we are able to formulate design considerations for interface characteristics, shared control, and hybrid control, i.e. the integrating between autonomous control and user involvement.
Learnings

The implementation of a new generation of connected lighting in a real office space is the final stage in a research exploration from lab to field. The context of this living lab is a real office with real, everyday employees. The technical infrastructure was very advanced, while the researchers and developers were still highly involved, being able to monitor and observe the circumstances, interactions and experiences.

Making this infrastructure possible requires a high effort of many stakeholders, including commercial suppliers, installation companies, and paying customers. After a field study of 5 months, reported in academic papers and project deliverables, the living lab was terminated, while the lighting infrastructure remained in the building to be used on everyday base.

Academic results


Making a living lab infrastructure for a real office requires a high effort of many stakeholders.
JOUW LICHT OP 040

Purpose

In 2012 the municipality decided to co-create a vision and a roadmap for urban lighting towards 2030. A procurement process followed where the goal is to create city-wide living labs aimed at the increase quality of life in the cities. After a public tender the project was awarded in 2014 to the consortium of Philips Lighting and Heijmans, who will implement five living labs. The ‘Jouw Licht op 040’ project will realise these living labs that will host continuous innovation in co-creation with citizens, local stakeholders, knowledge institutes, SME’s and creative companies. TU/e is involved in the processes to identify the needs and opportunities, to (co-)create ideas and solutions to meet these needs and the validation of the implemented processes solutions.

The five living labs of ‘Jouw Licht op 040’

Infrastructure

The Jouw Licht op 040 project starts in each living lab with the implementation of ‘connected’ LED lighting. The lights are connected to the Interact City software that enables scene management and schedules as well as the opportunity to add sensors for e.g. energy, presence of movement detection. It also enables data analytics and the development of smart city applications.

The idea in the project is that the basic infrastructure of connected lighting is implemented upfront in the living labs. In a co-creation process the needs are identified and specific solutions are developed which may lead to extension of the system with dedicated sensors or software.

Partners

Heijmans, Signify (previously Philips Lighting), municipality of Eindhoven, various other companies, a.o. Sorama, ViNotion, Omines, and Fontys University of Applied Sciences.

5 Living Labs: 2 trace’s 3 residential areas

5 Living Labs:
2 trace’s
3 residential areas

Information

Interact City Interfaces

Open data interfaces
Asset & Control Link API
Connected lighting assets
City dashboard/Data analytics
Smart City applications
The connected lighting infrastructure
M2M connectivity
Interact Ready sensors
Interact Ready luminaires
Asset link API
Connected lighting

Learnings so far include:

- Using a commercially available infrastructure has the big advantage of a robust and reliable basic infrastructure, which is especially important for living labs in public space. The disadvantage is that adaptations take more time, because they need to go through strict procedures before being rolled out.

- Having a smaller scale test set-up available for students to work with in developing ideas and solutions proves to be very helpful. It enables the students to work with real life equipment, but at the same time do this in a more controlled environment that allows more experimentation.

- The living labs for continuous innovation also enable research in innovation management and business development. This creates added value for the project partners beyond technical innovation: business innovation and business processes can be researched as well and lead to valuable.

Research

The Jouw Licht op 040 project and its living labs enable various research projects at TU/e:

- Development of methodologies for co-creation with citizens and other stakeholders (e.g. [X]-Changing Perspectives)
- Analysing the impact of the co-creation process and specific lighting solutions on social capital (various students)
- Co-creation approaches in technical innovation (e.g. in the SCALINGS project)
- Creating and capturing value in collaborative innovation of urban lighting solutions (e.g. PhD research co-funded by Philips Lighting and Heijmans)

Education

Many students from the ‘certificate program intelligent lighting’ and ‘entrepreneurship in action’ were involved in courses that used the cases of the different living labs. Also, a number of master students from various departments did their graduation project in the context of the living labs. ILI also supported a lighting design project at Fontys.

In 2018 an intelligent lighting program was set up within the TU/e Innovation Space, and a series of student projects was initiated connected to the project, including the innovation Space Bachelor End Project.

Learnings

At the time of this publication three living labs have started in the city of Eindhoven: Woenselse Heide West, De Ring and Gijzenrooi.

Academic Results


Examples of sessions with residents and stakeholders

Using robust, scalable and upgradable products in a backbone, allows experimenting with new applications in public lighting without the risk of a ‘black out’.
The Atlas Living Lab is our newest and most sophisticated living lab, in which 10 years of experience with living labs accumulated in a flexible infrastructure and accompanying processes to conduct groundbreaking research while respecting the privacy and comfort of the residents.
An Atlas Living Lab server that extracts research data from the system and that runs research applications.

The Atlas Research Database. This database stores research data from the Atlas Living Lab.

The possibility to extend the infrastructure with new sensors and actuators.

Partners

Unica Building Services, Signify, TU/e facility services, TU/e Information Management Systems, and many project partners.

Research

The first projects are due before summer 2019. The following list gives an impression of the topics and projects that are in preparation:

- Applying technology to promote vitality, well-being and prevention of disease and dysfunction. The TKI projects DYNKA and PerDYNKA investigate how the interaction between dynamic light and temperature scenarios can offer a pleasant and comfortable environment while reducing energy use significantly.
- The ‘Burnout prevention: good lighting and circadian alignment’ first tier project will explore burnout-related complaints in relation to light exposure and circadian entrainment among office employees. Subsequently it will assess the effectiveness of a light intervention. Insights signal potential risks for burnout at an early stage and advance the development of lighting solutions to reduce burnout-related complaints.
- Realising robust and effective artificial intelligence for indoor lighting applications. This topic is treated in the Oplight project of TU/e.
- Study and influence environmentally relevant behaviour to attain energy saving, treated in the OPZuid Sustainable Building project.
- Efficient facility management applications based on real-time insight in building usage patterns, treated in the OPZuid Sustainable Building project.
- Meaningful user interactions with intelligent lighting, treated in the TU/e Innovation Space Master project.

Education

In 2017, the TU/e Innovation Space launched, a community and facility that supports interdisciplinary hands-on education, engineering design and entrepreneurship. It’s a place where students learn to deal with complex societal and industrial challenges, create prototypes and develop innovations in collaboration with researchers, businesses and each other.

The Atlas Living Lab offers an unique research and test facility for student projects related to the ‘Office of the Future’. At the time of publication of this document, two student teams - one bachelor team and a master team - started their projects to develop solutions that aim to improve working, studying or visiting in the Atlas building and beyond.

Infrastructure

The Atlas Living Lab infrastructure spans the 4th to 11th floor of the Atlas Building, excluding the toilets, technical spaces and emergency stairs. This infrastructure is based on Signify’s Connected Office lighting system. It consists of the following elements:

- An IP based network infrastructure.
- Dimmable LED luminaires that are IP addressable.
- Sensors embedded in the luminaires, measuring occupancy and luminaire performance.
- Control software that allows monitoring of luminaires and sensors and control of dim levels of individual luminaires. The Connected Office system is also connected to the building’s climate system.
- For our living lab use, the software’s Application Programming Interface (API) is available to read out sensors and control the luminaires with our research applications.

Purpose

Research and development of intelligent technologies and services for health, wellbeing and sustainability is an integral part of the TU/e and European research agenda. To tackle the challenges in these fields, researchers increasingly look into intelligent and networked technologies that are embedded in our built environment. The long-term patterns of use and the effects on people, for example on health, wellbeing, social interaction and energy use, can best be researched in the real, live world. The Atlas building offers a unique environment for such research, with its large scale, its focus on sustainability, its place in the TU/e community, and its intelligent lighting infrastructure.

ATLAS LIVING LAB

- Study and influence environmentally relevant behaviour to attain energy saving, treated in the OPZuid Sustainable Building project.
- Efficient facility management applications based on real-time insight in building usage patterns, treated in the OPZuid Sustainable Building project.
- Meaningful user interactions with intelligent lighting, treated in the TU/e Innovation Space Master project.

In 2017, the TU/e Innovation Space launched, a community and facility that supports interdisciplinary hands-on education, engineering design and entrepreneurship. It’s a place where students learn to deal with complex societal and industrial challenges, create prototypes and develop innovations in collaboration with researchers, businesses and each other.

The Atlas Living Lab offers an unique research and test facility for student projects related to the ‘Office of the Future’. At the time of publication of this document, two student teams - one bachelor team and a master team - started their projects to develop solutions that aim to improve working, studying or visiting in the Atlas building and beyond.
Learnings

At time of publication of this document, we are finalizing the preparations for use of the Atlas Living Lab. But the 5-year long preparation process has already delivered valuable learnings.

Integrating a Living Lab of this scale in a building requires early involvement. We came on board not long after the TU/e started preparing the full renovation of this building, even before the architect started. In this way, the large intelligent infrastructure could become part of the renovation vision, serving both the TU/e’s living lab goal and sustainability goal (BREEAM Outstanding).

Creating such a Living Lab is as much an organisational challenge as it is a technical challenge. There are many parties involved with different responsibilities using the same infrastructure. Facility management needs to be sure they can maintain the system, also when experiments are conducted. Suppliers need clarity about changes in the system that might influence their contractual obligations. And all the while, the university needs to offer a safe and workable environment for staff and students. Creating coordination processes between the parties helps, and so does a shared information point. A process like this requires every party to go beyond the boundaries of their own discipline. Some of these things can be arranged in contracts, but the essential ingredients are mutual trust and the will to make something special happen.

The interests of everyday building users come first. Their acceptance of a living lab in their environment requires dialogue. We carefully created a first draft of a Data Use Policy, making sure we stayed within boundaries of the GDPR and scientific codes of conduct. When we presented that draft to different resident groups, we learned that they still had worries about their privacy. We changed our policy to suit their wishes. For example, we added to the policy an experiment-free zone in the vicinity of every experiment as an extra opt-out possibility. The dialogue with the residents took longer than expected (14 months), but was crucial for the acceptance of the Atlas Living Lab by the community that works and studies in it. And next to this acceptance, we are already continuously receiving project requests, indicating that the Atlas Living Lab offers relevant research opportunities.

When this publication appears, we are still in the pilot phase, doing trials of the research processes we developed. So these lessons learned are not final, but just the beginning. Please go to www.tue.nl/altaslivinglab for the latest updates.
CONCLUSIONS

10 years of conducting research in living light labs have provided us with important insights. We have taken those learnings along in newer projects, and especially in living labs on our campus: Market Hall and Atlas Living Lab. The image shows how living labs have been inspiring other living labs.

We conclude this publication with a recap of the main learnings and that can also be read as recommendations for other living labs. We emphasize four key success factors:

1. A good technical infrastructure
2. Support in the organisation
3. An extended ecosystem
4. Ethics and privacy of users

These four points will be further elaborated in the following paragraphs.

LIVING LABS @ TU/e CAMPUS

1. **A good technical infrastructure**
2. **Support in the organisation**
3. **An extended ecosystem**
4. **Ethics and privacy of users**

These four points will be further elaborated in the following paragraphs.
1. A good technical infrastructure

In our living labs we have found that it is very important to work with high quality hardware and software.

On the one hand this means a clear split between a front-end and back-end. The back-end is a permanent installation that reliably delivers the required functions of the space (e.g. functional lighting or escape route indication). It provides a stable base and is preferably made up of commercially available products, that receive adequate maintenance and new releases. The front-end contains temporary installations and settings of the space (e.g. functional lighting or escape route indication). It provides a stable base and is preferably made up of commercially available products, that receive adequate maintenance and new releases. The front-end enables experimenting with new hard and software and provides a structure to develop new applications (e.g. through GITHUB). The front-end contains temporary installations and settings and can result in unexpected behaviour of the system. It is therefore crucial that the system can be ‘reset’ by a dedicated person (such as a lab coordinator) that keeps the experience and knowledge of what is possible in the living lab (organisation wise, but also technical) and who can provide support to the researches is a crucial asset of a living lab.

It is also important that the living lab is embedded in regular processes in the organisation. To gain support of the services in the organisation, such as facility management or procurement, it is important that the living lab agrees with these organisations on alignment with regular procedures, or creates accepted adaptations that become part of the standing organisation.

2. Support in the organisation

The second prerequisite for an effective and efficient living lab is the availability of a supportive organisation. This means that sufficient resources need to be available (in time and competences) to keep the living lab up and running. In our experience it is inevitable that research staff and students make often only temporary use of the living lab (as most of its use is project based), and new staff and students are not aware of the functionality of the systems and the related processes. To have a dedicated person (such as a lab coordinator) who can provide support to the researches is a crucial asset of a living lab.

This means that sufficient resources need to be available to keep the living lab up and running. In our experience it is inevitable that research staff and students make often only temporary use of the living lab (as most of its use is project based), and new staff and students are not aware of the functionality of the systems and the related processes. To have a dedicated person (such as a lab coordinator) who can provide support to the researches is a crucial asset of a living lab.

3. An extended ecosystem

We also acknowledge the importance of an innovation ecosystem around a living lab. This ecosystem flourishes best when it develops a shared vision and goal for the living lab and the research programs related to it. This goes beyond the technical infrastructure (which is of course also important for forwards and backwards capability), but also deals with agreements on the potential revenue models for the partners in the projects.

A well-developed ecosystem makes collaboration between the partners and with relevant stakeholders easier, as people can also make use of each other’s network and competences.

Involvement of stakeholders ensures the inclusion of various perspectives in the design and evaluation of new solutions. The living lab can especially support the process of eliciting these perspectives and developing a solution that all relevant stakeholders support.

4. Ethics and privacy of users

Last, but not least it is important to address ethical dilemmas and ensure the privacy of the users in the living lab.

This means that an approval process needs to be set up for experiments and research projects, where an ethical committee is checking the burden of the research on the residents of the living lab, ensures that data collection is kept to the minimum by only collecting data that is required for the research, and that data is stored and used in a way that privacy is guaranteed. At TU/e we are now working with data stewards that guard the process.

The living lab should also make use of the technical possibilities to ensure ‘privacy by design’. E.g., when using camera images to count people it is not necessary to keep the raw camera images but run the counting algorithm in the camera itself and only store the number of people counted. In this way, the identification of individuals becomes impossible, and privacy of people is guaranteed.
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