Design of User Experience Evaluation (UXE) Toolbox for Smart Urban Lighting Solutions

DESIGN OF THE UXE

(User eXperience Evaluation)

TOOLBOX

for Smart Urban Lighting Solutions

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DESIGN OF THE USER EXPERIENCE EVALUATION (UXE) TOOLBOX

FOR SMART URBAN LIGHTING SOLUTIONS

By

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A dissertation submitted in partial fulfillment of the requirements for the degree of

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The design described in this thesis has been carried out in accordance with the TU/e Code of Scientific Conduct

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Abstract

North West Europe (NWE) faces a great challenge to cut 80% of greenhouse gas emissions by 2050. To reach this target by 2050, energy efficiency is one of the main instruments defined in the Climate and Energy Roadmap of NWE (Notenboom, 2012). Energy efficiency in cities is one of the biggest challenges for the municipalities that have been struggling recently. According to European Commission (2013), standard public lighting is one of the largest consumption items for municipalities, covering up to 60% of total electricity consumption. Thus, most of the municipalities have been seeking lighting solutions for public spaces considering the environmental, economic, and social impact of lighting.

As pointed out by Den Ouden and colleagues (2012), new lighting technologies have been creating a revolution in the lighting industry and urban lighting has been benefiting from this innovation. With the possibilities that LED offers and the integration of smart sensors, new solutions for urban lighting are emerging to reduce energy use by dimming down the streetlights at the right time and place, which is recognized as smart urban lighting. For instance, smart lighting systems can manipulate lighting parameters such as light level that react to external input such as the presence of a pedestrian or cyclist. For this reason, the Smart-Space Project aims to facilitate the uptake of smart urban lighting in small and mid-size municipalities to reduce energy use and CO_2 emission while ensuring safety and livability throughout NWE.

The Smart-Space Project brings together end-users (cities/citizens) and innovation stakeholders (research institutes, SMEs, enterprises) from the Netherlands, Belgium, France, and Ireland to develop an interoperable smart lighting platform. One of the main goals of the Smart-Space Project is to demonstrate the impact of smart lighting on energy consumption and CO_2 reduction while enhancing the safety and livability of public spaces at four pilot cities (Smart Space Project). Thus, the social impact of the project needs to be investigated through the evaluation and monitoring of user experience (UX) at four pilot sites. However, there is not a validated UX evaluation method to be used for smart urban lighting yet.

The goal of this PDEng project is to design a toolbox to support municipalities in the evaluation and monitoring of citizen's perspective. This toolbox is entitled the User eXperience Evaluation (UXE) Toolbox. The UXE Toolbox presents 25 tools in five categories (i.e., self-report technique, measuring body signals, information and communication technologies, statistics of official documents, and site observations) to measure 23 sub-parameters under seven parameters (i.e., acceptance, visual performance, visual comfort, perceived safety, attractiveness, liveliness, and safety) in three dimensions (i.e., attitude, perception, and behavior). It provides an excel-based tool, guidelines, and demo cases. Guidelines help municipalities to find relevant parameters and choose suitable tools. Demo cases show how the guidelines work over the use cases co-created within the Smart Space Project.

A set of methods and tools addresses the different purposes of measurement (i.e., obtaining public opinion, receiving feedback to improve the lighting design, and monitoring the impact of the smart lighting implementation), goals of implementation (i.e., A- increasing road safety for all, B-enhancing leisure activities and C-enhancing nightlife & security), and interaction levels (i.e., 1-active, 2-active, 3-reactive, 4-interactive, 5-intelligent). Thus, the UXE toolbox offers case-specific methods and tools in line with the needs of municipalities. The UXE Toolbox designed based upon eight use-cases in four cities within the Smart Space Project, however, is not only available for the four pilot cities but also for other municipalities that are willing to adopt smart urban lighting.

Reading Guide

This thesis has been written to document the design process of the UXE Toolbox. Municipalities that are interested in the UXE Toolbox are recommended to read especially Chapter 3 and Chapter 4 . Readers who are interested in the theoretical background and underlying design aspects are invited to read Chapter 2 in particular.

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Chapter 1 Introduction

Urban lighting has become an important issue for cities in terms of public safety, livability, and sustainability. Research shows that lighting has many benefits for the safety and livability of cities. These benefits are the prevention of road accidents (Fotios & Gibbons, 2018; Rea et al., 2009; Uttley et al., 2017; Wanvik, 2009), reduced -fear of- crime (Painter, 1996; Welsh & Farrington, 2008), greater sense of safety (Boyce et al., 2000; Fotios et al., 2019; Haans & de Kort, 2012), active use of outdoor facilities after dark (Fotios et al., 2019; Fotios et al., 2017; Pedersen & Johansson, 2018; Rahm et al., 2020), and enhancement of urban spaces (Giordano, 2018; Nasar & Bokharaei, 2017a). Besides these benefits, there are also some concerns related to the negative environmental impact of lighting. Excessive and/or inappropriate use of light leads to energy waste, carbon emission, and light pollution in cities. Conventional street lighting, which is switched on from dusk to dawn, is not energy efficient and detrimental considering these concerns. Fortunately, new lighting solutions combining light-emitting diodes (LED), sensors, and information and communication technologies (ICT) can improve the benefits of light at night while minimizing the negative impact on the environment (Boyce, 2019).

1.1. Smart Urban Lighting

Smart urban lighting is an umbrella term that covers public outdoor lighting (e.g. street lighting), private lighting (e.g. car park and façade lighting), and indoor lighting (e.g. shop windows) affecting the outdoor spaces (Valkenburg & den Ouden, 2021). Smart lighting is an innovation backed up by the dissemination of LED lighting technology, and the developments of ICT. LED offers better controllable and higher quality light with higher energy efficiency by saving up to 60% of lighting energy than conventional lighting infrastructure using metal halide and high-pressure sodium lamps (European Commission, 2013). ICT enables an integrated system by combining hardware (lighting, sensors, actuators) and software (control, data management, algorithm). These technologies make human-centric design possible by facilitating adaptive lighting in line with the actual needs. For instance, smart lighting systems can manipulate lighting parameters such as light levels that react to external input such as the presence of a pedestrian or cyclists.

Smart lighting has a great potential to increase the efficiency and sustainability in cities since it can provide a sufficient amount of light only when and where it is needed due to the installation of LEDs and, the automatization of the control system with embedded sensors. Therefore, smart urban lighting can contribute to energy efficiency, cost-saving, decrease in CO_2 emission, and light pollution. What is more, smart lighting can improve the well-being of citizens by increasing the safety, comfort, and attractiveness of public spaces which eventually motivates people to spend more time outside, adopt an active lifestyle and interact with other people.

1.2. The Smart Space Project

The Smart Space project is an Interreg North-West Europe (NWE) project aiming to facilitate the uptake of smart lighting in small/mid-size municipalities to increase energy efficiency and reduce CO2 emissions. The uptake of smart lighting highly depends on its social and economic benefits and its acceptance which are being investigated by this project. Thus, the Smart Space project brings end-users (municipalities and citizens), knowledge institutes, and technology partners together to create meaningful smart lighting solutions addressing the needs of citizens and to develop technical solutions which then facilitate pilot sites to monitor the impact of smart lighting. 11 partners are collaborating in 9 work packages (WP) to achieve the goals of the project. The objectives of the project are:

- To develop an interoperable smart lighting platform adjustable to the specific needs of different municipalities
- To demonstrate the impact of smart lighting on energy consumption and CO_2 emission, while enhancing public space safety and livability at four pilot municipalities
- To increase awareness of smart lighting technologies and their potential
- To develop a transition roadmap with procurement standards, implementation guidelines, and policy recommendations to the EU
- To establish the sustainable SMART-SPACE knowledge center.

1.2.1. Joint Monitoring and Evaluation

"If you can't measure it, you can't improve it"
Peter Drucker

Smart urban lighting solutions aim to minimize CO_2 emissions based on energy use while providing good quality lighting for citizens in line with their needs. In Smart Space Project, there are three key activities to achieve these goals: (1) the design of smart lighting applications regarding citizens' needs, (2) the implementation of smart lighting in pilot sites, and (3) and the evaluation of implementation in pilot sites considering energy consumption, light quality, and citizens' perspective. Joint monitoring and evaluation is one of the work packages defined in the Smart Space Project and the current PDEng project is part of this work package. In the joint monitoring and evaluation work package (WP T2), Katholieke Universiteit Leuven (KUL), as the WP leader, carries out assessments of light quality, Université de Picardie Jules Verdes (UPJV) deals with the calculation of the energy use and CO_2 emissions and Technology University of Eindhoven (TU/e), with this PDEng project, is responsible for the assessment of citizen's perspective.

1.2.2. Co-creation of Smart Lighting Solutions

In four pilot cities (Middelburg (NL), Oostende (B), Sint-Niklaas (B), and Tipperary (IE), eight deep-dive workshops were held with the participation of citizens to explore site-specific opportunities and problems. After the deep-dive workshops, the needs were identified, and they became the starting point of the ***use case***[1] workshops. ***Use case*** workshops were held with the participation of the pilot cities and each ***use case*** was depicted via a storyboard (Figure 1-1) illustrating the interactive use of smart lighting systems and related constraints and requirements.

Co-created ***lighting scenes***, addressing site-specific needs, were grouped under three ***clusters in terms of anticipated use***. These ***clusters*** are (A) improving safety for all road users, (B) enhancing leisure experiences, and (C) increasing security at nightlife. ***Cluster*** A envisages smart lighting solutions to provide good quality lighting for traffic safety while minimizing energy use. It addresses all kinds of road users such as pedestrians, cyclists, and drivers of motor vehicles (i.e., car, bus, truck, two-wheeled vehicles). The main activities defined in this cluster are passing by, cycling, driving, and commuting. People need to find their way and detect any road hazards to be able to feel safe and comfortable while traveling. ***Cluster*** B covers all kinds of leisure activities in public spaces such as shopping, doing sports, strolling around,

[1]) Please check Expansion Box 1 for the definitions of key concepts written ***italic*** in the text.

sitting in the park, or visiting events. This ***cluster*** addresses the need for attractive public spaces enabling different activities. Lighting design can create a matching atmosphere with the situation and contribute to the formation of the place. ***Cluster*** C proposes the use of smart lighting to increase security in nightlife areas. The main need is to de-escalate aggressive ***behavior*** in entertainment areas where pubs, restaurants, concert halls, and clubs co-exist. In these areas, municipalities aim to support police or camera surveillance to provide security. Lighting can support this surveillance by applying uniform lighting preventing hard shadows and creating sufficient light for face recognition (Valkenburg & den Ouden, 2019).

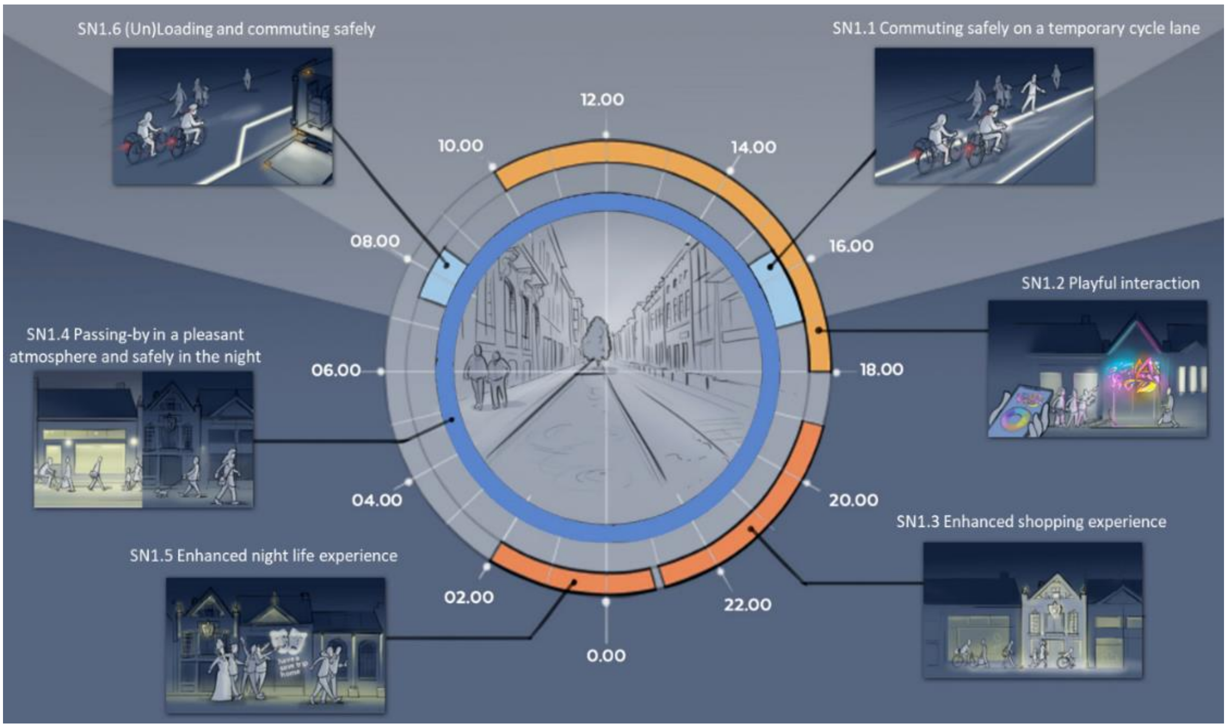

Figure 1-1: The Storyboard depicting the use case consisting of lighting scenes SN1: Stationsstraat Sint-Niklaas" Atmosphere and light experience in shopping street"
(Valkenburg, den Ouden, & Rietjens, 2019)

1.2.3.System Requirements of Smart Urban Lighting System

The system requirements framework for smart urban lighting is a five by four matrix of ***interaction levels*** and smart lighting ***system elements.*** Rows of the framework show five ***interaction levels*** from 1- Static to 5- Intelligent and columns indicate ***system elements*** such as lighting, controls, data management, and infrastructure as shown in *Figure 1-2*. Level 1, the basic level, is termed as static lighting with a single predefined *lighting scene* which could be turned on and off by control software. Level 2 is active lighting which provides multiple predefined *lighting scene*s and works based on a fixed timetable. Level 3 is reactive lighting and true to its name, it reacts in real-time to a single trigger (i.e., presence of people, obstacle, or other light sources) with multiple predefined *lighting scene*s. With reaching level 4, it gets smarter and becomes interactive with local adaptation to real-time input such as changing light level triggered by the presence, direction, and speed of occupants. At Level 5 as the ultimate level of interaction defined, intelligent lighting uses self-learning algorithms to optimize system performance (Valkenburg & den Ouden, 2019).

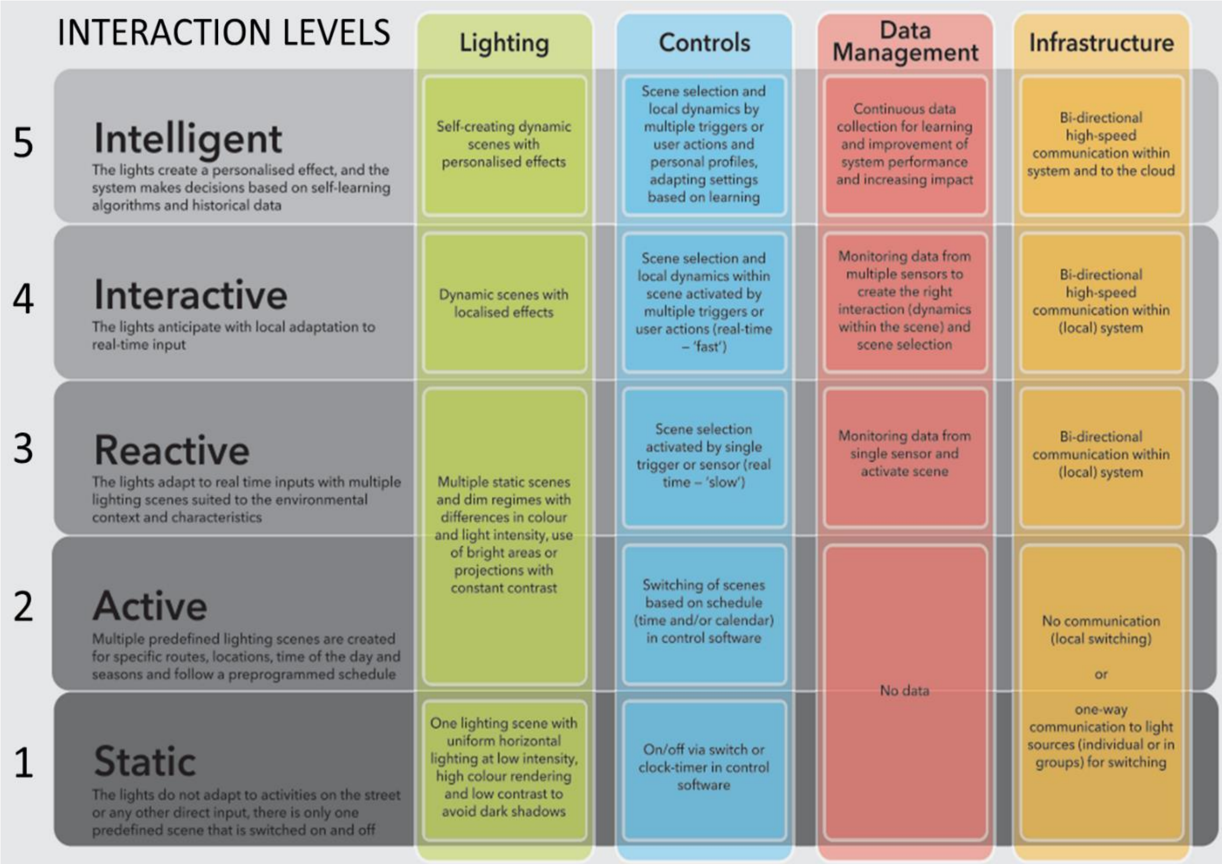

Figure 1-2: Interaction levels and requirements for Smart Lighting System (Valkenburg & den Ouden, 2021)

1.3. Problem Definition

Although smart lighting looks very promising considering the envisaged energy efficiency, environmental, and social benefits, investment costs seem to be an obstacle for municipalities. Moreover, they have some concerns related to the social acceptance of smart urban lighting. If smart lighting provides social benefits besides energy efficiency and maintenance cost, it will be a driving force for municipalities to adopt smart lighting. Thus, municipalities need to become aware of the social impacts of this change.

The main question related to the evaluation of citizens' perspective is what the social impacts of smart urban lighting would be. To what extend citizens would accept and appreciate smart urban lighting and what kind of social benefits can be achieved by applying smart urban lighting. To answer these questions, the interaction between citizens and the smart lighting system needs to be understood for different situations which could be encountered in urban areas at night. Research has shown that acceptance of reduced street lighting can be achieved if the feeling of safety is not threatened (Boomsma & Steg, 2014). Not only the feeling of safety but also overall experience in a lit environment affect citizen's *attitude* towards smart lighting. The *user experience* studies are crucial to assess social acceptance, to reveal the societal impacts, and to improve the smart lighting system further. Unfortunately, there is currently no sufficient knowledge on how to measure *user experience* with smart urban lighting. Thus, the design challenge of this PDEng project is to design a *toolbox* for small and medium-sized municipalities to evaluate *user experience* with smart lighting solutions.

Concepts & Definitions

Expansion Box 1

Attitude: *Attitude*s are learned predispositions towards aspects of our environment (Krech et al., 1963). They influence our likes and dislikes-how we appreciate our environment and how we use and abuse it (Cassidy, 1997). This study refers to citizens' opinions about smart urban lighting such as acceptance and appreciation.

Behavior: Bergner (2011) defines *behavior* as any observable overt movement of the organism generally taken to include verbal *behavior* as well as physical movements. In this study, *behavior* refers to only physical movements and their results taking place in urban areas. Such as walking, cycling, spending time outdoors, violation of speed limit, traffic accidents, committing a crime, etc.

Clusters of anticipated use: Three clusters were determined via the analysis of many potential ***use cases*** and ***lighting scene***s for the use of smart lighting. These clusters are: (A) improving safety for all road users, (B) enhancing leisure experiences, and (C) increasing security for nightlife.

Interaction level: It represents the smartness of the urban lighting system and defines the system requirements for the ***system elements***. There are 5 ***interaction level***s from static to intelligent, where static is a basic functional lighting level and intelligent with the highest level of smartness.

Lighting scene: It is a light setting defining properties of light (i.e., amount, color, direction) and ***interaction level*** (i.e., timing, triggers, data collection) designed for a specific time and/or location-based on identified needs.

Parameter: It describes the purpose of the measurement and puts a limit on it by identifying the scope by sub-***parameter***s and their attributes. For instance, if user pattern is a ***parameter***, then one of its sub-***parameter***s can be the use pattern of pedestrians. The sub-***parameter*** can be defined by determining attributes such as the number of pedestrians, the direction of pedestrians, the speed of pedestrians, etc.

Perception: It refers to the collection and organization of visual sensations through higher-order brain activities that shape the meaningful interpretations of the environment. In this study, it refers to visibility, visual (dis)comfort, perceived safety, attractiveness.

System elements*:* It refers to elements creating a smart lighting system. There are four elements defined: lighting (public lighting & special elements), controls (sensors & software), data management (system data & platform service) and infrastructure (energy & connectivity).

Tool: It is an instrument, technique, or device to evaluate *UX* with smart urban lighting.

Use case: It is the description of potential ***lighting scene***s. In the Smart Space Project, ***use case*** workshops provided an overview of the area with different types of use and users over the flow of a day and night and the seasons of a year. Based on that, ***use case***s consisting of different ***lighting scene***s were developed for each pilot site.

User Experience (UX): *UX* is defined as a person's ***perception*** and response resulting from the use or ***anticipated use*** of a product, system, or service. The definition of ISO includes users' emotions, beliefs, physical and psychological responses, (ISO, 2010). In this study, *UX* refers to the ***attitude***, ***perception,*** and behavior of citizens in urban areas illuminated with a smart lighting system.

User Experience Evaluation (UXE): It refers to a collection of methods consisting of parameters and tools to measure citizens' ***attitudes*** about smart urban lighting, how they perceive specific lighting scene(s), and behave in it.

UXE Toolbox: It is a facilitator excel-based tool containing the list of ***parameter***s, ***tool***s, and methods together with guidelines to measure ***user experience*** with smart lighting systems based on their ***attitude***, ***perception,*** and behavior.

1.4. Aim and Scope of the PDEng Project

This PDEng project aims to design a ***toolbox*** consisting of a set of validated ***tools*** to measure ***user experience*** with smart lighting solutions in urban areas. These smart lighting solutions are dealt with under three themes based on developed ***use cases*** and ***lighting scenes***.

A. How to measure ***user experience*** with smart lighting solutions aiming to increase road safety?
    i. How do road users experience their lit environment? What would be their opinion and how would they perceive and behave in it?
    ii. What are the ***parameters*** and ***tool***s to measure road safety? How to apply these ***tool***s?

B. How to measure ***user experience*** with smart lighting scenes aiming to enhance leisure activities?
    i. How do citizens experience smart urban lighting during leisure activities (i.e., shopping, doing sports, strolling around, sitting in the park, etc.)? What would be their opinion and how would they perceive and behave in it?

ii. What are the relevant ***parameter**s* and appropriate ***tool**s* to measure this experience? How to apply these ***tool**s*?

C. How to measure ***user experience*** with smart lighting solutions aiming to increase nightlife security?

i. How do citizens experience smart urban lighting for nightlife? What would be their opinion and how would they perceive and behave in it?

ii. What are the ***parameter**s* and ***tool**s* to measure nightlife experience? How to apply these ***tool**s*?

This PDEng project is a two-fold process; (1) analysis of the output of Smart Space Project (i.e., ***use case**s*, common needs, and requirements) in the light of outdoor lighting, urban studies, and environmental psychology literature to define the relevant ***parameter**s* and ***tool**s*, and (2) design of *UXE Toolbox* together with its guideline and demo booklet for small and medium-size municipalities. The *toolbox* aims to cover smart lighting solutions clustered into three ***anticipated use**s* through a wide array of ***tool**s* measuring various ***parameter**s*. The guidelines aim to define a customized *User Experience Evaluation (UXE) method* regarding the purpose of the *UX* research, the ***anticipated use*** of the smart lighting implementation, and the ***interaction level***(smartness) of the solution. Thus, the deliverables are (1) the project report explaining the UXE Toolbox and guidelines about how to choose the relevant parameters and tools for a specific case, (2) an excel-based *UXE Toolbox*, and (3) a demo videos showing the use of the interface.

1.5. Design Process

The double diamond design method (British Design Council, 2015) was used to develop the *UXE Toolbox (*Figure 1-3). This method consists of two diamonds (analysis and design) and four phases (discover, define, develop, and deliver). In this study, these phases were conducted in an iterative way to stay aligned with the dynamics of the Smart Space project and to maximize lessons learned from the innovation process.

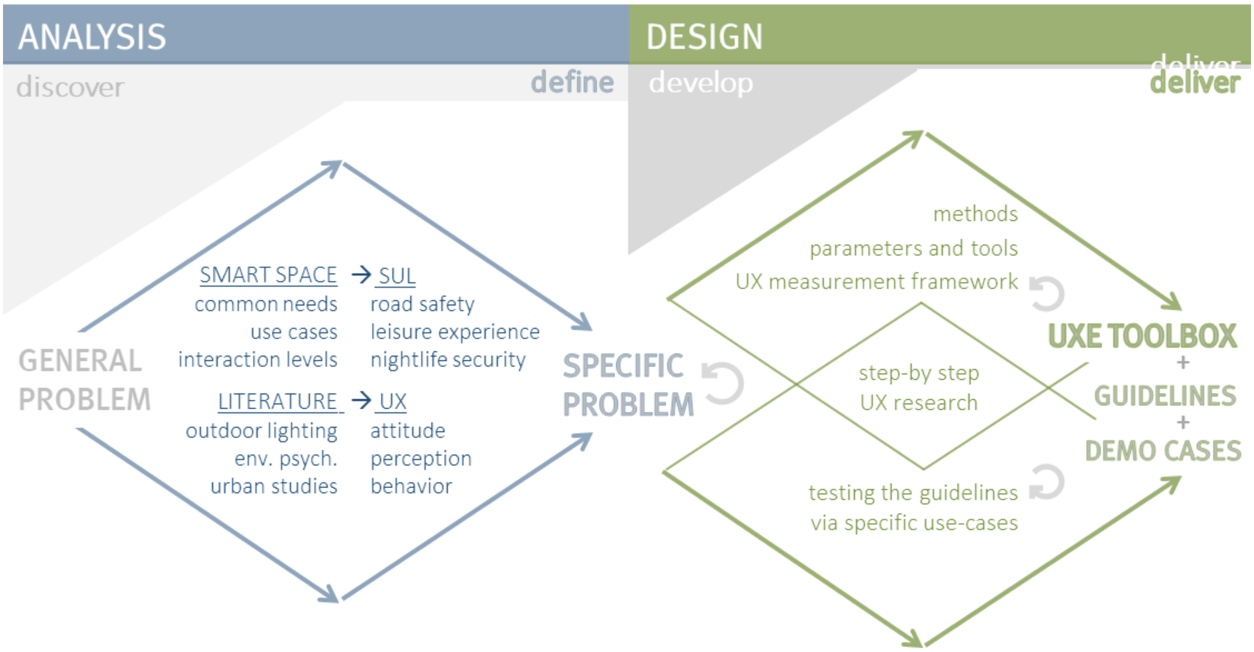

Figure 1-3: Double Diamond Design Model for the PDEng Design Project
(abbreviations; SUL=Smart Urban Lighting, UX=User Experience), env. psych.=environmental psychology)

The first diamond shows the analysis phase consisting of research and its synthesis, while the second diamond shows the design phase containing ideation, creation, demonstration, and delivery. Both analysis and design are conducted with diverging and converging processes. The first diamond starts with a general problem statement derived from the Smart Space Project. The general problem is the lack of knowledge about the acceptance of smart lighting and its effect on citizens. It continues to discover the problem further via literature research in the field of outdoor lighting, urban studies, and environmental psychology. This first diamond ends with the definition of the specific problem which is small and mid-sized municipalities' need for validated methods to measure ***user experience*** with smart urban lighting. The specific problem sets functional design specifications shaped through three ***anticipated uses*** of smart urban lighting and three dimensions of *UX*. In the design phase, the upper diamond presents the develop and deliver phases of the ***UXE toolbox*** consisting of a *UX* measurement framework and a list of ***parameters, methods,*** and ***tool***s for ***user experience*** referring to ***attitude***, ***perception,*** and ***behavior*** in the context of smart urban lighting covering road safety, leisure experience, and nightlife security. The bottom diamond represents the demonstration of the ***toolbox*** through selected ***lighting scene***s. The intersection of design diamonds is the development of the guidelines that are used both in the UXE Toolbox and demo cases explaining how to evaluate *UX* step-by-step using the *UXE Toolbox*. As a result, the deliverables of this project are (1) the project report, (2) the *UXE Toolbox* (an excel workbook) together with guidelines, and (3) demo cases (video records).

1.6. Report Outline

This report consists of five chapters as summarized below.

Chapter 1 introduced smart urban lighting regarding its social aspects. It starts with the explanation of smart urban lighting and its potential to enhance the benefits and minimize the negative impacts of urban lighting. It continues with the Smart Space Project by providing the analysis of relevant activities (i.e., co-creation of *use case*s, defining common needs and system requirements, joint monitoring and evaluation) as the basis of the discover phase of the first diamond (Figure 1-3). Then, the general problem and the design challenge are defined together with the aim and scope of the deliverables.

Chapter 2 corresponds to the converging process of the first diamond of design model (Figure 1-3) to characterize and measure the relation between people and the lit urban areas are the main concern of this chapter. It starts with a literature review focusing on user ***experience*** with urban lighting in the field of outdoor lighting, environmental psychology, and urban studies. It continues researching existing ***methods*** and ***tool***s to be used to measure ***user experience*** with light. Based on the literature review, this chapter concludes with the functional requirements derived from the literature covering three dimensions of ***user experience*** (***attitude***, ***perception,*** and ***behavior***) and analysis of the Smart Space Project (i.e., Eight use-cases consisting of 31 lighting scenes in three clusters of anticipated use and five interaction levels)

Chapter 3 explains the components of the UXE Toolbox (measurement methods, timeframes, parameters and sub-parameters, tools, and guidelines) within the defined UX measurement framework. The guidelines are presented in this chapter for conducting UX research through decision tables and checklists. Guidelines help municipalities find the most suitable methods and tools in line with their needs and requirements of their smart lighting case. This chapter explains the designs of the UXE Toolbox that falls into the upper diamond of the design phase (Figure 1-3).

Chapter 4 provides the preview of the excel-based UXE Toolbox by following the guidelines for three lighting scenes designed for two pilot cities (i.e., Sint-Niklaas and Middelburg). The UXE Toolbox is demonstrated with the help of three lighting scenes, called demo cases, each representing one of the three clusters and smart-ready or smart lighting solutions. These demo cases test the usability of the guidelines and open new windows into the excel-based UXE Toolbox. This chapter addresses the design of the decision-making process and user interface of the UXE Toolbox through the demo cases referring to the develop and deliver phases of the lower diamond in the design model (Figure 1-3).

Chapter 5 summarizes the main outcomes of the design project in light of the functional requirements. In conclusion, the functional requirements are revisited to assess to what extend the UXE Toolbox meets the functional requirements. Regarding this, follow-up studies are discussed to tackle shortcomings and take the UXE Toolbox a step further.

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Chapter 2 Characterizing and Measuring UX with Urban Lighting

In this chapter, urban lighting is considered as a fundamental factor affecting spatial experiences after dark. This chapter aims to understand the relation between the citizens and the urban lighting through lighting studies, urban studies, and environmental psychology literature. First, the literature on urban lighting is introduced considering its main purposes on a human scale (i.e., improving road safety, enhancing leisure activities, increasing security for nightlife). Secondly, the experience of the lit environment is dealt with considering its physiological and psychological aspects. Thirdly, this chapter brings the existing methods and tools together to determine the main criteria and functional requirements to measure user experience with urban lighting. These methods and tools are categorized into two main groups: (1) person-centered measurements which collect data from people either by asking them or tracking the physical and physiological changes and (2) place-centered measurements which collect data from public spaces through observations (performed by a researcher) and monitoring (through use of archival data or/and ICTs). Based on the analyses presented so far (Chapter 1 Chapter 2), the functional design requirements are defined as the initial stage of the design process.

2.1. Purpose of Urban Lighting

2.1.1. Improving Road Safety

According to the report of the European Transport Safety Council (ETSC), 9500 people were killed on urban roads in the EU in 2017 and 70% of those are vulnerable road users: 39% pedestrians, 12% cyclists, and 19% powered-two-wheeler (PTW) riders. The most vulnerable ones among those are children and the elderly. Even though NWE countries have a better overall road safety record compared to many other EU countries, their citizens still find road safety as a problem and as a barrier against cycling and walking (ETSC, 2019). Some of the countermeasures could be the presence of road markings and bike traffic lights, traffic calming measures, efficient road lighting, and separated pike paths and sidewalks to create safe cycling and pedestrian environment.

Road Safety and Risk Factors:

Elvik and colleagues (2009) define four main risk factors affecting the rate of traffic accidents. The first factor is the type of road (i.e., urban road, rural road, motorway, main road, collector road, and access road) as the rate of traffic accidents varies greatly between different types of road and different types of the traffic environment. For example, studies show that motorways have the lowest risk of injury accidents of all roads; however, urban roads have a higher rate of injury accidents than the average for public roads (Elvik et al., 2009; European Transport Safety Council, 2019, 2020). The second factor is the design of roads which can be described in terms of the number of lanes, lane width, presence of sidewalks, and bike paths. Road design plays an important role in terms of traffic calming measures to decrease the risk of an accident. The next factor relates to the user, there are several sub-factors determined by the user and their traffic behavior such as age, medical condition, alertness, speed and rule compliance, maintenance of the vehicle, and use of protective gears. The last factor is environmental conditions like darkness, precipitation, and snow- or ice-covered road surfaces. According to an estimation model developed based on the traffic records of Norway (Elvik et al., 2009), the risk of accidents increases in the dark especially for pedestrians and cyclists, and the risk is higher when the roads are wet or covered with snow and ice as shown in Table 2-1. Improvement in lighting would minimize the risk on pedestrians and cyclists and therefore encourage the mobility of pedestrians and cyclists.

Table 2-1: Relative risk of injury accidents in different environmental conditions (Elvik et al., 2009)

Factor	Value of factor	Relative accident rate	Confidence interval
Light conditions	Daylight	1.0	
	Darkness – vehicle accidents	1.0	(0.9; 1.1)
	Darkness – pedestrian accidents	2.1	(1.7; 2.5)
	Darkness – bicycle accidents	1.6	(1.2; 2.0)
Road surface conditions	Dry bare road	1.0	
	Wet bare road	1.3	(1.1–1.8)
	Wet snow	1.5	(1.1–2.0)
	Snow or ice covered road	2.5	(1.5–4.0)

Road Lighting for Pedestrians, Cyclists, and Drivers

The main function of road lighting is to facilitate road traffic at night in a safe and comfortable way for all road users, thus, road lighting is an effective and efficient countermeasure for a safe road trip in the dark (van Bommel, 2015). Regarding road safety, the International Commission on Illumination (CIE, 2010) describes two main purposes of road lighting: (1) to allow all road users, including operators of motor vehicles, motor cycles, pedal cycles, and animal-drawn vehicles to proceed safely; and (2) to allow pedestrians to see hazards, orientate themselves, recognize other pedestrians and give them a sense of security. It is important to understand the specific safety criteria for each road user group (i.e., pedestrians, cyclists and drivers).

Caminada and Van Bommel (1984) suggest three key criteria for the safety of pedestrians. These are detection of obstacles, identification of persons, and pleasant environment. According to the study of Davoudian and Raynham (2012), conducted in residential streets by using an eye-tracking device to record where participants were looking at, the pedestrians spent about 40 - 50 % of the time looking at the pavement ahead but for the rest of the time, their eyes were fixated on objects that attracted attention. This study shows that pedestrians want to be able to move safely over the ground (detect obstacles and hazards), to see where they are (orientate), and to appreciate their surroundings. Moreover, pedestrians want to assess the risk to personal security and to avoid visual discomfort (Boyce, 2014).

Hazard detection and being visible are important for the safety of cyclists likewise pedestrians. Lighting can help cyclists see and avoid potential hazards such as potholes (Fotios, Qasem, Cheal, & Uttley, 2017), and can make cyclists more visible to drivers thereby reducing road traffic collisions involving cyclists (Chen & Shen, 2016). A recent study investigated whether road lighting can reduce the negative impact of darkness on cycling (Uttley, Fotios, & Lovelace, 2020). Its results suggested that in the UK, even only a minimal amount of lighting can promote cycling after-dark, making it an attractive mode of transport year-round.

The main purpose of lighting for motorized traffic is to keep visual performance, visual comfort, and alertness of drivers at a high level. Critical tasks for drivers are the detection of obstacles, the detection of other road users (i.e., pedestrians, cyclists, other motorized vehicles), and the discernment of rapid changes in the visual scene (van Bommel, 2015). Thus, road lighting should illuminate the road surface to provide sufficient contrast to detect any obstacles on the road and conflict areas, where streams of vehicles intersect with each other or with pedestrians and cyclists and residential roads, to ensure visibility of other road users. Apart from these, ensuring the visibility of traffic signs and signals is also very important for road safety (Boyce, 2014).

2.1.2. Enhancing Leisure Activities

As Gehl (2011) points out, cities have always been the meeting place for people. As a gathering place, cities need to focus on the human scale to become lively city which means an attractive, sustainable, safe, and healthy city. According to Gehl (2011), a lively city sends friendly and welcoming signals with the promise of social interaction and invites people to walk, bike, stay, and interact with each other with the help of various outdoor activities (e.g., functional, recreational, and social activities). These activities can be necessary activities (e.g., going to work or school, shopping, waiting for a bus, etc.) which take place under all conditions, optional activities (e.g., walking down the promenade, sitting outdoors to watch around, etc.) which happens if time and place allow, and social activities (e.g., seeing and hearing other people, greetings, conversation, gatherings, playing at the street, etc.) which depend on the presence of other people in city space. The abundance of optional activities in a city prepares a base for social activities which is the key factor of a lively city. Gehl (2010) explains the connection between outdoor activities and the quality of public spaces over these three types of outdoor activities through a diagram shown in Figure 2-1. The quality of the physical environment influences the extent and the character of outdoor activities, for example, when the quality of the physical environment is high, the number of optional activities increases exponentially since people feel like spending time outdoors. Eventually, the rise in optional activities provides a boost to social activities over time.

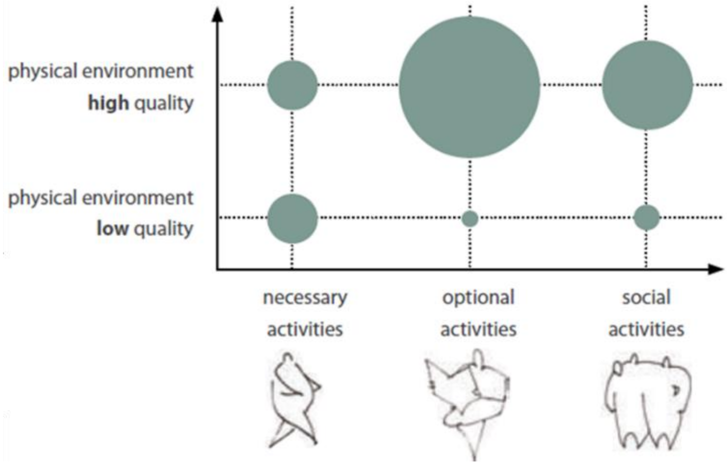

Figure 2-1: Connection between the quality of the physical environment and outdoor activities
(Gehl, 2010)

Urban design has an influential role in the quality of public life and urban lighting is the main factor making the urban design accessible at night. The role of lighting in urban spaces at night has been extending far beyond safety. According to CIE (1995), one of the main purposes of urban lighting is to improve the day and nighttime appearance of the environment. Lighting provides several benefits in cities such as maintaining outdoor activities after dark, attracting people's attention, and enhancing the image of cities (Boyce, 2019b). Moreover, urban lighting can create inviting, relaxing, interesting, and lively atmospheres (Casciani, 2020) which enhance leisure activities and generate place identity, thus increase footfall, dwell time, and diversity of uses in an area (Davoudian, 2019). What is more, Arup's report on lighting (2020) claims that lighting can contribute to ease the pre and post-covid challenges that cities are facing in many ways (e.g. revitalizing city centers by enhancing the attractiveness, making outdoor spaces accessible for social activities, and creating a performance space). Urban lighting enables 24-hour use of cities not only by complying with basic lighting requirements such as providing minimum light level for functional use but also by creating a lively atmosphere which makes a place with the promise of social interaction (Davoudian, 2019).

2.1.3. Increasing Security for Nightlife

Lighting has been used as a countermeasure to reduce or at least limit criminal activity since the fifteenth century (Painter,1999, 2000; Boyce, 2014). Studies show that there is a relation between aggression and environmental characteristics such as the amount of crowd size (Russell, 2006) and outdoor lighting (Welsh & Farrington, 2008). However, it is still unclear whether lighting has a direct effect on the level of crime. For sure, lighting has an indirect effect by increasing visibility since therefore facilitating surveillance and improving perceived safety thus enhancing community confidence and social control (Boyce, 2014). Research shows that especially light and perceived safety at night have a strong and well-established relation (Welsh & Farrington, 2008). Moreover, lighting is essential for the freedom to go out at night, in particular to those vulnerable to or fearful of personal attacks (Keane & Moffitt, 1998). Considering aggression and escalations, light affects various psychological variables that play a prominent role in the onset of aggressive behavior, such as arousal, affect, and sociality (Knez & Kers, 2000).

Painter (1996) investigated the influence of street lighting on crime, fear, and pedestrian street use after dark. She categorized the crime under three groups: (1) violence against the person (robbery, theft, physical and sexual assault), (2) vehicle crime (theft and damage), and (3) threats (verbal harassment, drunken or disorderly behavior). In this study, the street lighting was upgraded in three urban streets. The impact of the street lighting was assessed using attitudinal and behavioral measures, through 'before' and 'after' surveys of pedestrians. The results showed that sensitively deployed street lighting can lead to reductions in crime and fear of crime and increase pedestrian street use after dark. The author stressed out that street lighting can act as a catalyst to bring about changes in social behavior which in turn contribute to a reduction in crime and disorder.

Aggression (e.g., hustle and bustle) is another aspect threatening nightlife security. According to the general aggression model (GAM; Anderson, et al., 1995), aggression results from the environmental (or situational) stimuli and personal factors that influence an individual's internal state (i.e., affect, arousal and cognitions) which influences appraisal and decision- making processes leading to determine subsequent actions (e.g., aggressive behavior)(Kalinauskaitė, Haans, de Kort, & Ijsselsteijn, 2018). In the urban nightlife setting, various environmental factors could trigger escalation such as high population density (Griffit & Veitch, 1971), anonymity due to crowd and darkness (Jorgenson & Dukes, 1976), and people with narrowed attentional and cognitive capacity due to alcohol intoxication (Hirsh, Galinsky, & Zhong, 2011). Contextual cues (e.g., music, fragrance, light) can affect the mood positively, for example, participants exposed to pleasant music reported having a more positive mood (Krahé & Bieneck, 2012). Light is another de-escalating stimulus (De Kort, Ijsselsteijn, Haans, Lakens, & Kalinauskaite, 2014) that has an effect on the levels of arousal (Vogel et al., 2012), affect (Knez, 2001), and self-control (Smolders, de Kort, & Cluitmans, 2012). De-escalate project (Figure 2-2) is one of the most significant examples of the use of dynamic lighting scenarios to improve nightlife security as a part of Stratumseind 2.0 living lab.

Figure 2-2: De-escalate: Defusing escalating behavior via interactive lighting, Stratumseind Eindhoven

2.2. Experiencing the Lit Environment

We need light to be able to see. The vision starts in the eye and it is processed in the brain. The visual system is based on the eye and brain working together for processing the visual stimulus coming from the environment. Thus, how we see and perceive our environment depends on both external factors such as lighting, material, and figure-ground relation and internal factors which is the visual system including sensation and perception of the stimulus (Casciani, 2020). The outcome of the perception is an experience that is also an important input for the visual system by providing continuous feedback and knowledge to the brain. This bi-directional relation enables us to make sense of what we see.

Casciani explains the process of perception with physical factors (external), physiological and psychological factors (internal) as shown in Figure 2-3. According to this path, visual stimuli are processed into sensation, then perception occurs through the collection and organization of visual sensations. In the perception process, higher-order brain activities shape the meaningful interpretations of the perceived environment. The physical factors are interpreted through the intensity of lightness, the spectral distribution emitted or reflected by objects and the surrounding environment, the lighting distribution (lightness and darkness composition), and perceptual constancies (lightness, colors, shape, and size) of perceived objects and environments (Casciani, 2020).

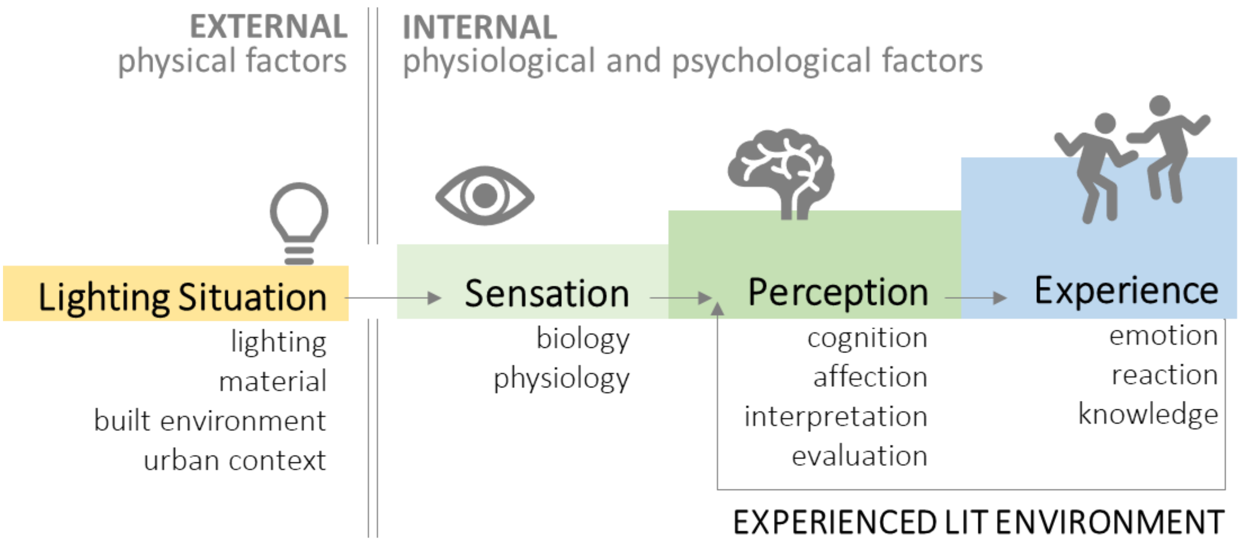

Figure 2-3: The process of perception diagram, adapted from (Casciani, 2020)

According to Boyce (2014), lighting shapes experience by changing the perception of spaces and objects; however, he finds the link between the visual stimuli and the perception of the lit environment weak. Thus, Boyce claims that the perception of the lit environment mostly depends on the state of adaptation of the visual system and the observers' previous knowledge obtained through experience. Having stressed the importance of internal factors, Boyce defines the influence of light on the perception of space at two levels: simple perceptions and high-order perception. Simple perceptions are lightness, brightness, and color appearance while high-order perceptions are formality, spaciousness, and complexity. Simple perceptions show strong links with the lit environment; however, the connection between high-order perceptions and the lit environment is delicate.

2.2.1. Psychological Effects of Light

From the environmental psychology perspective, the psychological effects of light are generally categorized into two major groups which are (1) image-forming (IF) and (2) non-image-forming (NIF) pathways. Both pathways are important to understand how people experience a specific situation though this study only deals with the IF effects of light. Light can influence the overall experience at night through visual system and psychological functioning which consists of behavior and mental processes such as perception, emotion (affect), and motivation (conation). Considering the complex relations between sensation and experience, it is crucial to explore the basic mechanisms behind the IF effects of light in terms of psychological functioning. There are three paths defined to investigate the IF effect of light; (1) visual performance, (2) visual comfort, and (3) visual experience as shown in Figure 2-4 (de Kort & Veitch, 2014) which presents a structure to explore the experience of the lit environment.

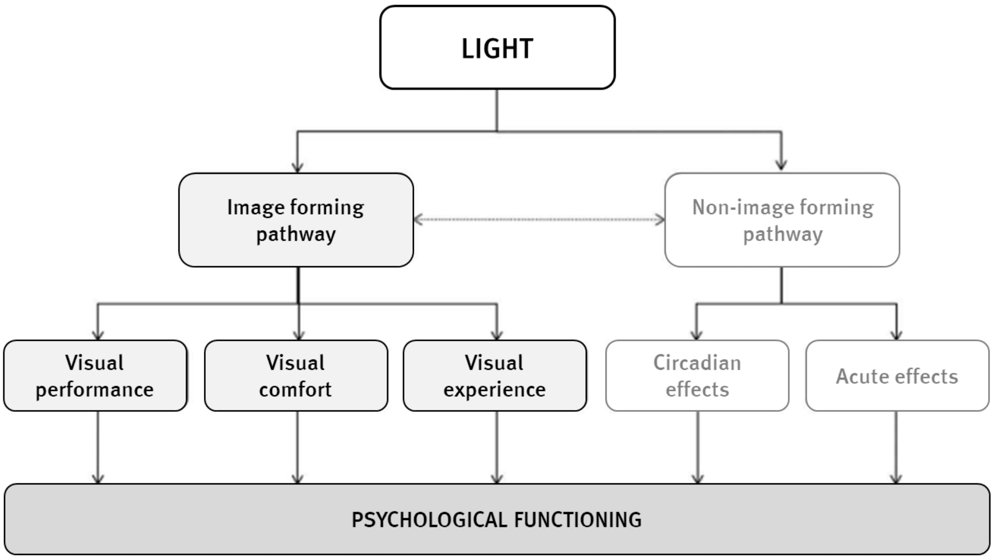

Figure 2-4: Pathways of light relevant to psychological functioning (de Kort & Veitch, 2014)

Visual performance is the first step to be able to see and respond to our surroundings. It is generally defined as the speed and accuracy of performing a visual task (De Kort, 2019). It can be discussed through three mechanisms of the visual system in terms of perception of the lit environment:

(1) The first one is the adaptation which enables the visual system to adjust to the ambient luminance. The human eye can adapt to a wide luminance range- about 10^{-2} to 10^{9} cd/m². Light adaptation is the adjustment of the eye to higher light levels while dark adaptation happens at lower light levels (van Bommel, 2015). The light adaptation happens faster than the dark adaptation. While the bright adaptation typically happens in seconds and eyes fully adapt in 5 minutes; the dark adaptation happens in 10 minutes and full adaptation may take to 40 minutes (Pirenne, 1962).

(2) The second mechanism is contrast sensitivity which is reciprocal for the contrast threshold. The contrast threshold is the lowest amount of contrast required to detect, discriminate, or identify a target (Aparicio et al., 2010). It is an important measure of visual performance, especially when it is dark outside and the contrast between objects and their background is low.

(3) The last mechanism related to visual performance is visual acuity which is the reciprocal value of the smallest object or the smallest detail which can still be perceived.

Visual comfort is a difficult term to define and there is no consensus on its definition. De Kort (2019) points out that visual (dis)comfort is mostly associated with visual performance; however, studies show that visual comfort often correlates with satisfaction with lighting conditions. In the literature, visual comfort is explained as "the absence of visual discomfort" by excluding potential positive and desirable aspects of lighting conditions (Boyce 2014). Most of the studies in the field of visual comfort have focused on visual discomfort. Boyce (2014) considers four main aspects of lighting that can cause visual discomfort. These are glare, lack of uniformity, veiling reflections, and shadows & flickers. Glare is claimed to be one of the main reasons behind the discomfort, and it is defined as "the hindrance to vision by too much light" (Vos, 2003). It can be experienced as ocular pain and muscle strain (Berman et al. 1994) or avoidance behavior (Rea et al. 1985). Vos (1999) suggests eight glare different forms, four of which occur rarely (i.e., flash blindness, paralyzing glare, glare causing retinal damage, and distracting glare). Commonly experienced forms of glare are;

(1) disability glare: the masking effect caused by light scattered in the ocular media which produces a veiling luminance over the field of view

(2) discomfort glare: the distracting or irritating effect of peripheral light sources in the field of view

(3) dazzle (saturation glare): conditions of light overexposure for a long time to which one squints one's eyes, which may even be painful.

(4) adaptation glare: temporary dazzle due to large increase in luminance of the whole visual field such as exiting a tunnel into the sunlight.

Beyond the functional benefits such as way finding and detecting objects and faces, light plays an important role in the relation with the environment by the changing perception of a space. People need to see, not only to perform specific tasks but also to explore and experience their surroundings. Studies show that light influences the appearance of a space by its brightness and luminous distribution (Boyce, 2014). Changing light conditions affects the impression of the space in terms of spaciousness, perceptual clarity, and overall evaluation (Flynn, et al., 1973). Light also has an impact on how people feel and perceive the atmosphere of a space (Vogels, 2008). Light affecting the environmental appreciation may lead to inducing pleasure and/or arousal of the visitor (Kuijsters, Redi, De Ruyter, & Heynderickx, 2015).

2.2.2. Experiencing Urban Lighting

According to the systematic literature review of outdoor lighting conducted by Rahm and Johansson (2016), three overarching themes were stressed out to investigate the relation of people with outdoor lighting. Their overview proposes a theoretical framework connecting human response to outdoor lighting by setting three themes and 12 categories shown in *Figure 2-5*. The first theme "Perception of the Lit Environment" deals with how the lit environment is perceived differently depending on individual factors (i.e., age and eyesight) and properties of light (i.e., amount of light). The categories under this theme are perceived brightness, acuity and contrast, facial recognition, color identification, obstacle detection, and glare. The second theme "Evaluation of the Lit Environment" and the third theme "Behavior in the Lit Environment" concern how people respond to what they see and categorize this response in terms of how they feel and how they behave.

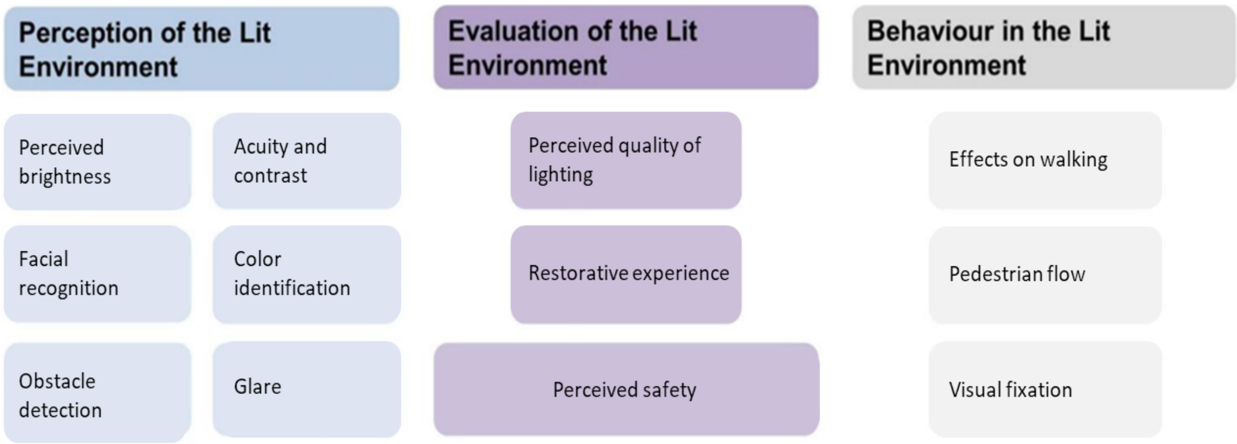

Figure 2-5: An overview of human response to outdoor lighting (Rahm, 2019)

Studies focusing on urban lighting show that light affects environmental appraisal in public squares (Nasar & Bokharaei, 2017b), perceived safety at night (Boyce et al., 2000) via provided prospect, escape, and refuge aspects (Haans & de Kort, 2012), the moods of people (Calvillo Cortés & Falcón Morales, 2016), perceived restorativeness through the fascination with urban streetscape (Nikunen, Puolakka, Rantakallio, Korpela, & Halonen, 2014), aggression in an urban nightlife through atmosphere set by lighting (Kalinauskaitė et al., 2018) and walking preference through perceived safety (Rahm et al., 2020). These studies reveal that light has a significant impact on our attitude, perception, and behavior thus the overall experience of our environment.

2.3. Relevant Methods and Tools to Measure User Experience

The literature research has been conducted with "outdoor lighting", "road lighting" and "user experience" keywords using Google Scholar. 25 studies investigating the effects of lighting on the users out of 43 articles were found relevant in terms of their theme and topic (i.e. themes are attitude, perception, and behavior; topics are acceptance, visual performance, visual comfort, perceived safety, atmosphere, walking and cycling rate, road safety, and security) to measure user experience in a lit environment. Having reviewed these studies, measurement methods were categorized into two groups: (1) person-centered measurements (PEC) and (2) place-centered (PLC) measurements (Figure 2-6). PEC measurements are based on individual experiences and performed via either self-report techniques (e.g., questionnaire, interviews, diaries) or physical and physiological measurements (e.g., visual test and eye-tracking, etc.). On the other hand, PLC measurements collect public data through observation and monitoring from a specific location. Observations are performed by a researcher in the natural environment of the experience and provide periodical data from a specific location such as the number of social interactions. Monitoring is realized by either historical reports (e.g., traffic reports and police reports) or ICT systems (e.g., automated counters and traffic monitoring, etc.) and provides continuous measurements of the targeted activities taking place in urban areas.

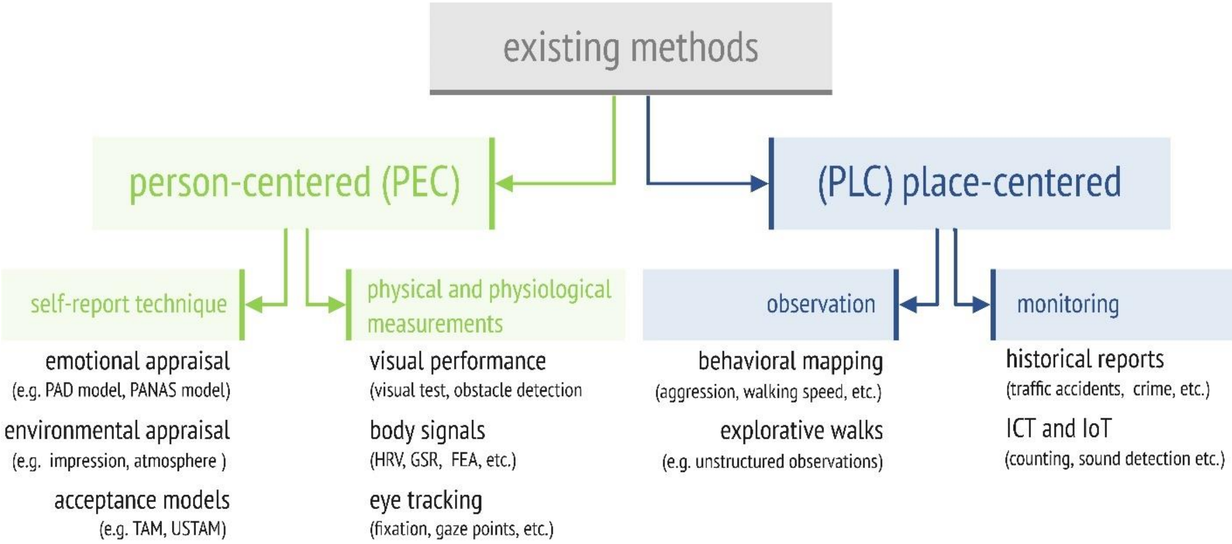

Figure 2-6: Existing methods and tools to measure user experience

2.3.1. Person-centered Measurements

This part focuses on methods and tools to assess the individual evaluation of an environment concerning the presented lighting conditions and characteristics. Research shows that personal appraisal can be measured by asking people or/and through physical and physiological measurements such as eye-tracking, attention tracking, and task and reaction measurements.

Self-report Technique

The majority of the studies reviewed have been using self-report methods based on the direct involvement of participants through surveys and interviews. The questionnaires are based on a variety of semantic differentials (SD) or pairwise comparisons to understand the attitude and perception of users investigating their emotions, lighting impressions, perceived safety and comfort, perceived atmosphere, and user acceptance.

This method explores the feelings or thoughts of the users and gathers their views and opinions based on their self-report. As a result of the literature review, only a few validated models and methods were found to examine how people experience smart public lighting. These models can be grouped into three categories according to their purposes: (1) emotional appraisal models, (2) environmental appraisal models, and (3) technology acceptance models.

Emotional Appraisal Models:

Emotional appraisal models aim to measure how people feel in a specific situation and/or environment. Two validated models were found to be used in lighting studies to assess subjective appraisal based on emotions. The first model is The Pleasure-Arousal-Dominance (PAD) emotion model (Mehrabian & Russell, 1974). It defines three dimensions to quantify self-reported emotional response through semantic differential measures as shown in Figure 2-7. Based on three-dimensional PAD model, a non-verbal assessment technique The Self-Assessment Manikin (SAM) was developed to measure a person's emotional reaction through subjective reports given to a series of pictures (Bradley & Lang, 1994). The second model is The Positive Affect Negative Affect Schedule (PANAS) which could measure changes in feeling and emotion through a rating scale after experiencing a light condition based on positive effects (e.g., excited, inspired, interested) and negative dimensions (e.g., scared, hostile, nervous) as shown in

Figure 2-8 (Watson, Clark, & Tellegen, 1988). These models are suitable for field, lab, or online setups to measure how people feel under specific lighting conditions as long as assessments are momentary since emotions would change instantly depending on the changing stimulus.

Pleasure	
Happy	Unhappy
Pleased	Annoyed
Satisfied	Unsatisfied
Contented	Melancholic
Hopeful	Despairing
Relaxed	Bored
Arousal	
Stimulated	Relaxed
Excited	Calm
Frenzied	Sluggish
Jittery	Dull
Wide awake	Sleepy
Aroused	Unaroused
Dominance	
Controlling	Controlled
Influential	Influenced
In control	Cared for
Important	Awed
Dominant	Submissive
Autonomous	Guided

Figure 2-7: PAD Scale
(Mehrabian & Russell, 1974)

PANAS descriptor	Loading on Positive Affect	Loading on Negative Affect
Enthusiastic	.75	−.12
Interested	.73	−.07
Determined	.70	−.01
Excited	.68	.00
Inspired	.67	−.02
Alert	.63	−.10
Active	.61	−.07
Strong	.60	−.15
Proud	.57	−.10
Attentive	.52	−.05
Scared	.01	.74
Afraid	.01	.70
Upset	−.12	.67
Distressed	−.16	.67
Jittery	.00	.60
Nervous	−.04	.60
Ashamed	−.12	.59
Guilty	−.06	.55
Irritable	−.14	.55
Hostile	−.07	.52

Figure 2-8: The descriptors of PANAS
(Watson et al., 1988)

Environmental Appraisal Models:

Environmental appraisal models aim to measure a subjective impression of an environment. Flynn's studies have been pioneering to assess the effects of light on subjective impressions of a place (Flynn, Hendrick, Spencer, & Martyniuk, 1979; Flynn et al., 1973). These studies investigated the subjective appraisal and response of six lighting configurations in interior settings using a multi-dimensional rating scale. Flynn and colleagues used 34 SD items in their studies, and they investigated the relations between the dimensions according to changing lighting settings with factor analysis and multi-dimensional analysis. As a result of several experiments, Flynn's studies proposed six broad categories of human impressions affected by light. These impressions are perceptual clarity, spaciousness, relaxation and tension, public versus private space, pleasantness, spatial complexity, or liveliness (Flynn, 1988).

Using Flynn's study as a base, Nasar and Bokharaei (2017) have investigated the appraisal of environment together with behavioral intent to demonstrate the effect of lighting modes on impressions of public squares. This study tested the mode of lighting in two simulated. 3D Max was used to creating color slides of 20 squares, which varied three modes of lighting–uniform versus non-uniform, bright versus dim, and overhead versus peripheral tilted down or tilted out Figure 2-9. The participants were asked to assess each color slide of the squares in terms of pleasantness, excitement, restfulness, and behavioral intent. The survey consists of 12 items to be rated via a 7-point scale. Nine of these items are bi-polar environmental descriptors (for pleasantness: ugly-beautiful, unpleasant-pleasant, unappealing-appealing; for excitement: boring-exciting, dull-lively, unstimulating-stimulating; for restfulness: tense-relaxed, upsetting-calming, unsafe-safe) and three of them are the statements for behavioral intent ("I would walk out of my way to visit and spend time in this place", "I would stop at this place if I happened to be passing by", and "I would regularly visit this place").

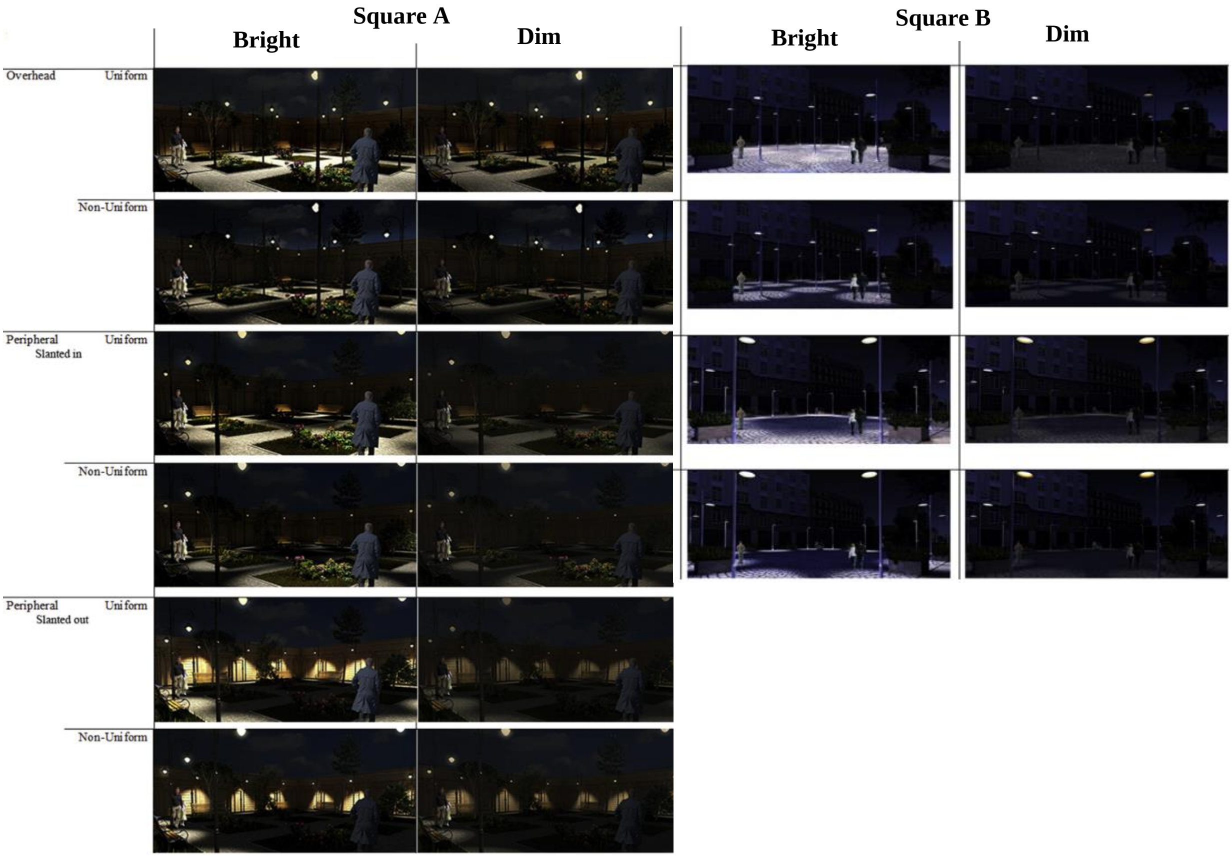

Figure 2-9: 20 color slides of two squares used in the survey (Nasar and Bokharaei, 2017)

Another model examining environmental appraisal is the atmosphere metrics (Vogels, 2008). This model aims to quantify the atmosphere of an environment as experienced by observers. Vogels states that atmosphere is directly related to the environment and how it is experienced. Although atmosphere has the potential to change how people feel, it cannot be measured through mood and emotions because the mood is influenced by many other non-environmental factors. The difference between atmosphere and affective state is stressed out explaining the relation between mood and atmosphere. An atmosphere may or may not change the mood, but mood cannot change the atmosphere. For instance, anyone could feel stressed, and they still could evaluate their environment as relaxing. Thus, the atmosphere seems to be a more stable and efficient concept than the mood of people to determine the effect of the environment on people's experience.

Vogels' research (2008) consists of three sequential studies to develop a new tool to quantify the atmosphere of an environment. In the first study, people were asked to imagine a particular location (e.g., their living room, their favorite shop, the situation at their dentist) and to describe the atmosphere of the environment in their native language Dutch with as many terms as possible. Among the collected lexicon, 38 terms were selected as shown in Table 2-2 and an atmosphere questionnaire was developed based on these selected terms. For each term, participants were asked to rate the applicability of this term concerning the environment they were visiting, on a 5-point scale from 'not applicable at all' to 'very applicable'. The second study tested whether the atmosphere questionnaire can distinguish different atmospheres within different environments. The last study tested the method in four lighting conditions in a fashion shop. The results showed that this method can determine the experienced atmosphere in the same place with the changing lighting settings which implies that the atmosphere factors are reproducible. Using factor analysis, Vogels found that the perceived atmosphere in an environment could be described by four factors: coziness and liveliness, tenseness, and detachment.

Table 2-2: 38 atmosphere terms used in the questionnaire (Vogels, 2008)

Atmosphere term	*Translation*	*Atmosphere term*	*Translation*
afstandelijk	*detached*	levendig	*lively*
beangstigend	*terrifying*	luxueus	*luxurious*
bedompt	*musty*	mysterieus	*mysterious*
bedreigend	*threatening*	ongedwongen	*uninhibited*
behaaglijk	*cozy*	ongemakkelijk	*uncomfortable*
beklemmend	*oppressive*	onrustig	*restless*
deprimerend	*depressed*	ontspannen	*relaxed*
enerverend	*exciting*	persoonlijk	*personal*
formeel	*formal*	omantisch	*romantic*
gastvrij	*hospitable*	ruimtelijk	*spatial*
geborgen	*safe*	rustgevend	*tranquil*
gemoedelijk	*pleasant*	saai	*boring*
gespannen	*tense*	sloom	*lethargic*
gezellig	*pleasant*	stimulerend	*stimulating*
inspirerend	*inspiring*	toegankelijk	*accessible*
intiem	*intimate*	vijandig	*hostile*
kil	*chilly*	vrolijk	*cheerful*
knus	*cozy*	warm	*warm*
koud	*cool*	zakelijk	*business*

Haans & de Kort (2012) investigated the effect of different light distributions on perceived safety through a field study experiment. They conducted two experiments, one with stationary and one with walking participants. Participants assessed the six different experimental conditions in terms of perceived safety and environmental cues prospect, concealment, and escape. As a final step, participants answered a Personal Attributes Questionnaire (PAQ) (Helson, 1979).

The perceived safety is assessed through three statements using a five-point scale, ranging from "disagree" to "agree"

- "I feel uncomfortable with the idea of having to walk into this street"
- "I would walk down this street at a higher pace than I usually walk in"
- "I would rather avoid this street"

The proximate cues were assessed based on the questions below using a five point-scale from "well" to "poor", "easy" to "hard", and "small" to "large".

- Prospect: "How well or poorly can you see what is happening in this street?"
- Concealment: "How easy or hard is it for a potential criminal to find a hiding place in this street?"
- Escape: "How small or large are your chances of escaping from this street in case someone assaults you?"

The results of these experiments show that the participants preferred to have more light in their immediate surroundings, even if this meant a reduction in the illumination of the more distant parts of the road. The researchers hence concluded that illuminating pedestrians' immediate surroundings are more important than illuminating the road that lies ahead.

Outdoor lighting quality is another aspect affecting the use of in urban areas. Johansson and colleagues (2014) have developed an observer-based environmental assessment tool for outdoor lighting in urban areas as a result of empirical studies that compare 10 different conventional and LED outdoor light sources in urban residential areas. The tool, Perceived Outdoor Lighting Quality POLQ), is based on 10 bipolar semantic differential scales which determine Perceived Strength Quality (PSQ) and Perceived Comfort Quality (PCQ). PSQ captures the brightness perception, through the words 'strong', 'light', and 'sparkling', and PCQ captures the extent to which the light is perceived as soft, natural, warm, mild, and shaded. The POLQ is presented as a complementary tool to adapt outdoor lighting to users' needs in practice.

Table 2-3: Confirmatory factor analysis showing the labels of POLQ tool

Item	Distribution		Rotated factor loadings (varimax)	
	M	SD	Perceived strength quality (PSQ)	Perceived comfort quality (PCQ)
Subdued – Brilliant	3.96	1.47	**0.860**	0.068
Strong – Weak	4.32	1.39	**−0.809**	0.109
Dark – Light	3.91	1.65	**0.807**	−0.264
Unfocused – Focused	3.98	1.43	**0.712**	−0.103
Clear – Drab	3.65	1.70	**−0.705**	0.103
Hard – Soft	4.32	1.52	0.183	**−0.820**
Warm – Cool	4.10	1.49	−0.339	**0.722**
Natural – Unnatural	3.91	1.57	−0.417	**0.690**
Glaring – Shaded	5.03	1.50	−0.021	**−0.678**
Mild – Sharp	3.71	1.47	0.406	**0.654**
Eigenvalues			4.01	2.20
% of variance			35.38	26.64
Cronbach's alpha			0.85	0.77

Considering the safety and comfort criteria of urban lighting, eliminating visual discomfort is an important precaution to improve road safety for all road users. However, the visual discomfort of pedestrians and cyclists has not gained as much attention as the visual discomfort of drivers. Recently, Van Hastenberg (2021) examined pedestrian discomfort glare in a shopping street. She conducted a field experiment in Middelburg by asking participants to rate discomfort glare using the De Boer rating scale (1967), as well as to perform a facial expression recognition task and to evaluate their lit environment. Discomfort glare was assessed by the participants through the reversed and the translated version of the De Boer scale (Figure 2-10).

Label	Rating	Label
Just noticeable	1	Niet merkbaar
	2	Tussen 'niet merkbaar' en 'acceptabel'
Satisfactory	3	Acceptabel
	4	Tussen 'acceptabel' en 'net toelaatbaar'
Just acceptable	5	Net toelaatbaar
	6	Tussen 'net toelaatbaar' en 'storend'
Disturbing	7	Storend
	8	Tussen 'storend' en 'ondraaglijk'
Unbearable	9	Ondraaglijk

Figure 2-10: Reversed De Boer Scale and its Dutch version (van Hastenberg, 2021)

The result of this study confirmed that viewing direction has a great influence on discomfort glare, however, there was not any relation found between discomfort glare and the other luminaire variables.

Thus, it can be stated that the height of a light source is a determining factor for discomfort glare in pedestrian areas.

Technology Acceptance Models (TAMs)

The development of information technology acceptance and adoption modeling began with the early adoption of the internet in the 1980s (Davis, 1985). Among numerous theories, the technology acceptance model (TAM) has been the most influential one to explain an individual's acceptance of information systems. The model consists of two main constructs: perceived usefulness and perceived ease of use as shown in Figure 2-11. The first construct is associated with an individual's belief that technology will be useful for improving the performance of daily tasks. This construct can be considered as “perceived usefulness”. Another construct, “perceived ease of use” is associated with an individual's belief that technology will make their daily tasks easier (Venkatesh, Morris, Davis, & Davis, 2003).

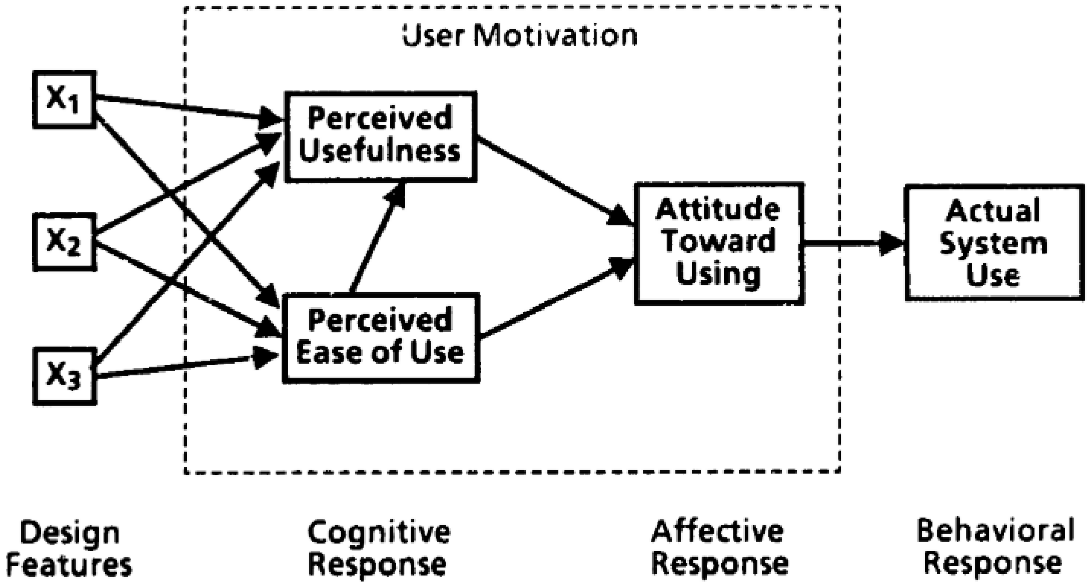

Figure 2-11: The Technology Acceptance Model (TAM, (Davis, 1985))

Hsiao and Yang (2011) obtained three main trends in acceptance modeling in their systematic literature analysis. Sepasgozar and colleagues adapted these trends into three categories to fit them into human-centric smart city research. These categories are 1) Hedonic or psychological approach 2) Social or commercial approach which focuses on how to identify, attract, maintain customers; and 3) Task-related or utilitarian information system approaches (Sepasgozar, Hawken, Sargolzaei, & Foroozanfa, 2019). The first approach considers hedonic and psychological aspects by examining the user’s attitude towards technological applications in daily life. This approach focuses on perceived usefulness and perceived ease of use or playfulness. The second set of models consider social and economic dimensions of technological acceptance. One of the most influential theories in this approach is the social cognitive theory (Bandura, 2001). This theory aims to measure social influences on individual behavior by integrating the concepts of self-efficacy, anxiety, and outcome expectation factors as a result of technological applications (Sepasgozar et al., 2019). The last approach aims to improve commercial and organizational efficiencies with the help of technology such as online services. Urban Services Technology Acceptance Model (USTAM) is the only example found applying technology acceptance theory into the smart city concept. Although smart city innovations have many technological dimensions, technological acceptance modeling has not caught up with the smart cities trend and the integration of technology with cities (Sepasgozar et al., 2019). USTAM presents an empirical model to measure user's perception towards Urban Services Technologies (UST) with twelve constructs such as perceived security, reliability, service quality, and energy saving as shown in *Figure 2-12*.

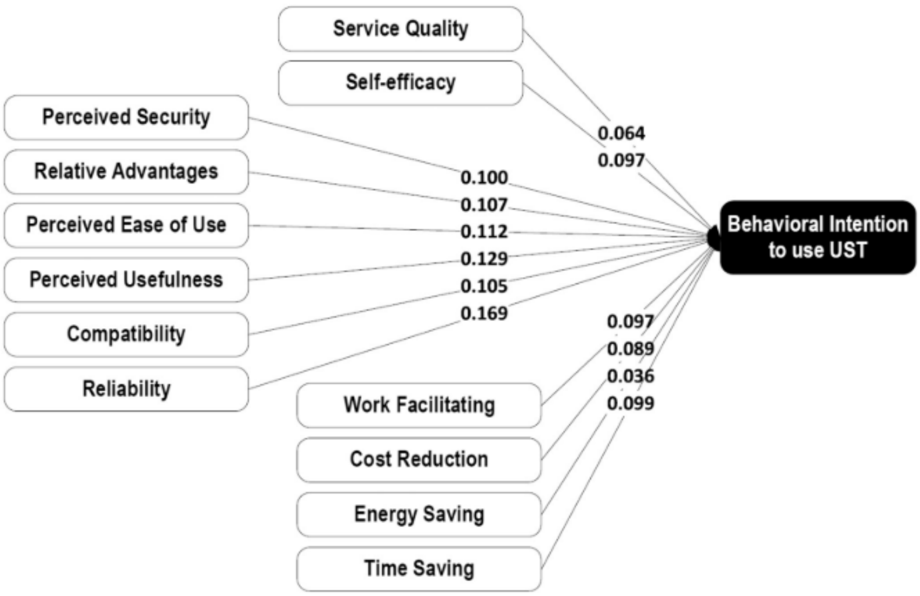

Figure 2-12: The constructs of USTAM (Sepasgozar et al., 2019)

Even if technology acceptance models seem to be useful to investigate the acceptance of smart urban lighting solutions, they do not fit into an assessment of the urban realm since they are specialized for the use of information systems such as websites and mobile applications. The behavior and user preference for a digital interface are expected to be different from than physical environment. Thus, these models do not present a validated method for this study in short term, but they provide valuable insights to understand the adoption of interactive online services such as mobile apps or digital user interfaces within smart urban lighting solutions in the future.

Physical and Physiological Measurements:

The studies using physical and physiological measurements consist of both lab studies and field studies. Most of the reviewed lab studies focus on the visual performance of either pedestrians or cyclists by measuring the obstacle detection or the facial expression recognition time through a response button from fixed distances (Fotios, Mao, Uttley, & Cheal, 2020; Steve Fotios et al., 2017; Uttley, Fotios, & Cheal, 2017; Yang & Fotios, 2015). In another lab study, the effect of dynamic lighting on walking speed and legibility was examined (Pedersen & Johansson, 2018). In this study, walking time of a specific distance was measured with a chronometer and visual acuity and contrast vision were tested with Sloan optotypes.

In the field studies, visibility tests were used as well to measure the visual performance of participants. For example, research, conducted in Zilverackers district (Veldhoven, NL), examined the acceptance of dimmed lighting scenarios by having participants experience different lighting scenarios during the field experiment (i.e., bright white, bright amber, dimmed white, dimmed amber). During the study, the visual performance was measured through Landolt rings for visual acuity, Pelli-Robson for contrast threshold, and color naming test for color identification as shown in *Figure 2-13* (den Ouden & Valkenburg, 2013).

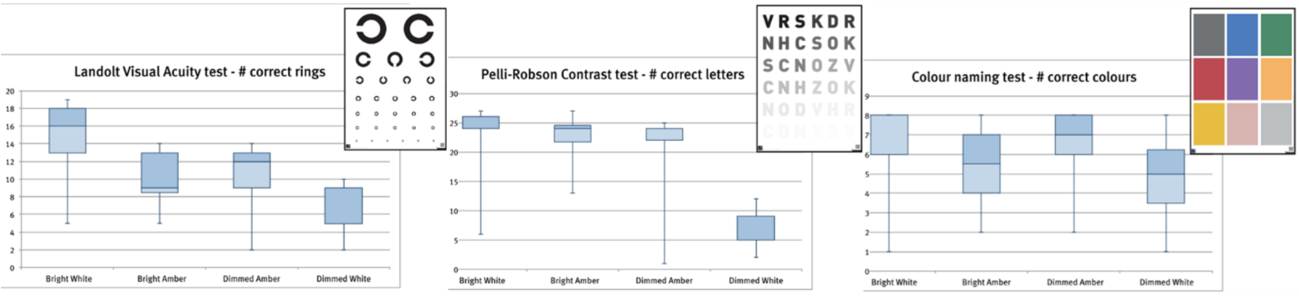

Figure 2-13: Visibility tests used in Zilverackers (den Ouden & Valkenburg, 2013)

Heart rate variability (HRV) was indicated as a physiological indicator to measure stress level (König, Visser, & Hall, 2017). The case study of Licht Poppers Stratumseind investigated the effect of light on the stress level of people in a public space. The momentary stress level of participants was tracked based on HRV measured via pulse oximeter (*Figure 2-14*) for three different light scenes ("control scene", "calm scene" and "stressed scene"); low frequency (LF) power was considered as a measure of the stress branch of the autonomic system and low values of LF power were interpreted as the state of calmness (den Ouden, Valkenburg, & Cluitmans, 2013).

Figure 2-14: Heart rate measurement from fingertip using a pulse oximeter (optic sensor; PPG-photoplethysmography) (Valkenburg & den Ouden, 2021)

Eye trackers are another method used in field studies to explore the variety of visual tasks of pedestrians and cyclists (Davoudian & Raynham, 2012; Fotios, Uttley, & Yang, 2015; Mantuano, Bernardi, & Rupi, 2017). Davoudian et al. (2012) measured the eye movements of 20 participants by an iViewX Head Mounted Eye Tracking device (HED) as shown in *Figure 2-15*. The subjects wearing an eye tracker walked three different residential roads in the daytime and at night. After the completion of the walk, they performed a short interview to get further information about the experience.

Figure 2-15: The head-mounted eye tracker (Davoudian & Raynham, 2012)

Fotios et al. (2015) investigated the critical visual tasks of pedestrians by recording pedestrians' visual fixations when walking outdoors in the daytime and after dark with an eye-tracking system (iView X HED made by SensoMotoric Instruments shown in *Figure 2-16*. They tested the vision of participants by using a Landolt ring acuity test and the Ishihara color perception test before the experiment. During the experiments, besides visual fixations, they measured the attention of participants by asking them to press the respond button when they hear a beep sound. They provided the concurrent dual-task through an Arduino microcontroller with a connected mini-speaker and response button.

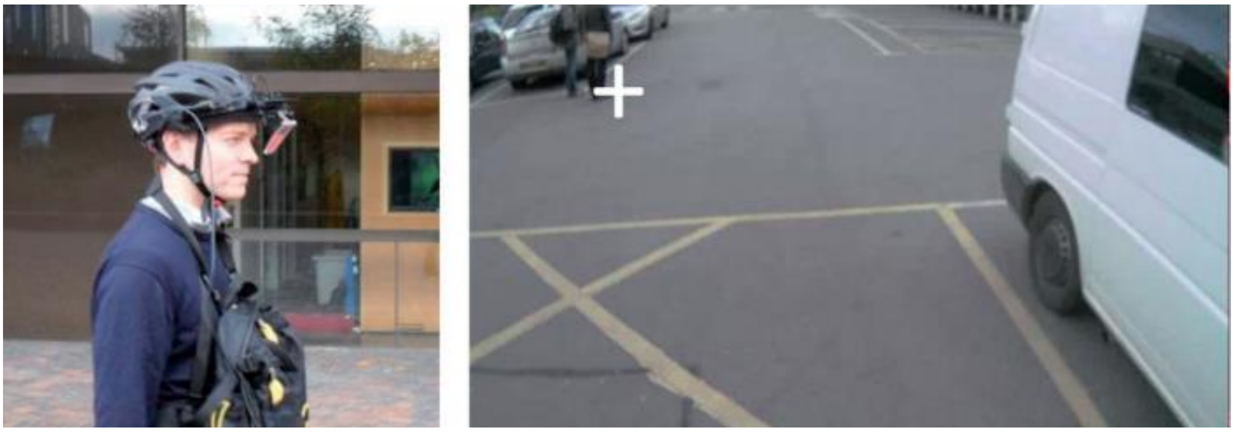

Figure 2-16: iView X HED mobile eye-tracking system (left) and screenshot from a recorded video (right). The white cursor indicates the gaze location (Fotios et al., 2015)

Mantuano et al. (2017) analyzed the actual gaze behaviors of 16 cyclists in the city center of Bologna during the daytime. Participants wearing mobile eye-tracking glasses cycled along a defined route. Eye movements were recorded by using the ASL Mobile Eye-XG system which consists of two digital high-resolution cameras mounted on lightweight glasses (*Figure 2-17*), a portable wireless Data Transmit Unit, and two types of software (i.e., EyeVision and ASL Results Plus GM). They performed a frame-by-frame image analysis with the help of a fixation detection algorithm to calculate the number and duration of fixations across different areas of interest.

Figure 2-17: ASL Mobile Eye XG Glasses on the left, complete equipment on the right (Mantuano et al., 2017)

2.3.2. Place-Centered (PEC) Measurements

Another approach to understand how people respond to their lit environment is to put the environment under a microscope. PLC measurements provide insights about how people behave in specific lighting conditions analyzing use patterns, variety of activities, and outcomes of these activities. Studies show that observations, statistics (using archival public data), and real-time monitoring can provide meaningful information about the use pattern including social behavior(Antal Haans, Kalinauskaite, De Kort, & Ijsselsteijn, 2018), risk of accident (Johansson et al., 2009), risk of crime (Painter, 1996) and mobility during darkness (Fotios et al., 2019; Uttley et al., 2020), in urban areas.

Observation:

Observation is a method performed by researchers to learn about human-environment interactions using any or all of the five senses. It can be used to determine the prevailing use patterns and social behaviors in a lighting condition and compare the use patterns with changing light settings. There are several studies employing the observation method to investigate the impact of public lighting at night.

Kalinauskaite and colleagues (2018) have investigated the ongoing behavioral patterns of the crowd focusing on the repetition of unwanted behaviors such as aggression to reveal the social dynamics on Stratumseind. They performed observations during two full weekends in June and July 2014, on three going-out nights between 10 PM and 5 AM covering in total almost 40 hours of observation and they coded their observations at the end of each night. Their study showed that atmosphere, as an attribute of the socio-physical context, is strongly related to the emergence of aggression and tension in public spaces such as Stratumseind (Kalinauskaitė et al., 2018). Thus, another follow-up structured observation study was conducted for 29 nights (Thursdays, Fridays, and Saturdays) to measure the dynamic atmosphere in Stratumseind. They measured atmosphere with two different methods (Table 2-4) The first method is a structured observation quantifying atmosphere components. The second method is the Crowd Atmosphere Appraisal Questionnaire (CAAQ) based on an observer's evaluation. The observers recorded the dynamic atmosphere under two different lighting conditions (regular street lighting and warmer one), simultaneously but independently. This study showed that street lighting, as an environmental manipulation, has the potential to influence the crowd atmosphere.

Table 2-4: Two methods to measure atmosphere on Stratumseind (Kalinauskaitė, 2018)

Measuring Atmosphere on Stratumseind		
Atmosphere components	Atmosphere appraisals	
busyness of the terraces	aggressive	irritating
lines at the bar entrances or atm	appealing	lively
general busyness of the street	boring	oppressive
drunkenness	cheerful	pleasant
presence of the security	exciting	relaxed
presence of police	fearful	stimulating
noise	festive	tense
amount of glass on the street	happy	tiring
amount of litter on the street	inviting	welcoming

Markvica et al. (2019) used the observation method to compare the effects of three lighting scenarios (conventional lighting (Fluorescent Tube Light)-FTL, state-of-the-art LED-1, optimized LED-2) in the city of Vienna. They observed the walking behavior of pedestrians in a test site, Blumauergasse in the 2nd district of Vienna. They performed the observations from December 2015 to April 2017 in three stages in parallel to the change of streetlighting. As a result of observations, no significant changes were found among three lighting conditions in terms of walking speed, crossing frequency, and direction, or evasive walking behavior. They could only capture changes in the use of the walkway (Figure 2-18), however, they claimed that the change between different street lighting systems did not influence the actual mobility behavior of people since there were not any safety-critical situations that occurred in the test site.

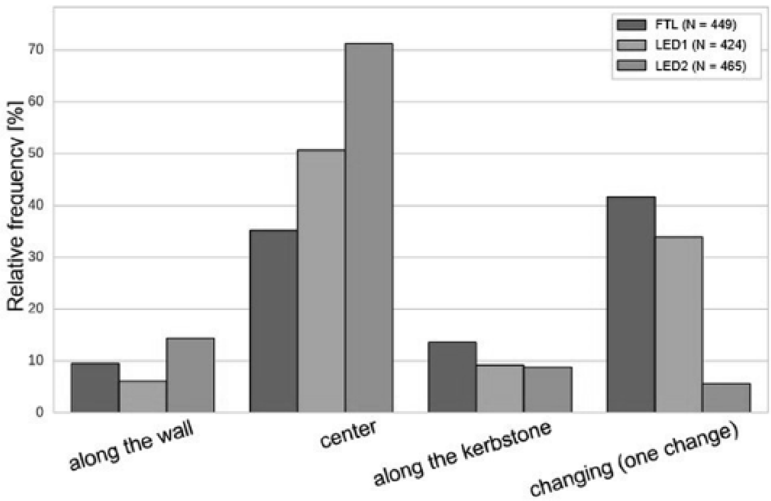

Figure 2-18: Observation of the use of walkway by pedestrians (Markvica et al., 2019)

Monitoring:

In this study, monitoring is defined as continuous measurements and recording of the targeted activities taking place in a public space. Continuous data collection can be provided via historical reports or ICT devices such as people counters and smart cameras. Although most of the studies have used person-centered approaches to investigate the reactions to changes in streetlighting, there are some studies analyzing the objective data derived from public spaces to investigate the relation between road lighting and the risk of road accidents (Johansson et al., 2009; Rea et al., 2009), walking rate (Fotios, Uttley, & Fox, 2019), cycling rate (Uttley et al., 2020), pedestrian flow dynamics (Haans, Corbetta, Kumar, & Toschi, 2017).

Rea et al. (2009) compared several metrics used in various studies to estimate the effect of lighting on accident risk and suggested the creation of safety metrics in the form of an odds ratio as a reliable method for quantifying impacts of light. Johansson et al. (2009) developed a new method for assessing the risk of accidents associated with darkness. This method estimates the risk of an accident based on the counts of accidents extracted from three data sets (i.e., A data set for Sweden covering the years 1997–2006, a data set for Norway covering the years 1996–2005, a data set for the Netherlands covering the years 1987–2006). Hours that are dark part of the year are called case hours and to control for seasonal variation in the number of accidents, a comparison hour that has daylight the whole year is selected as exemplified in Figure 2-19.

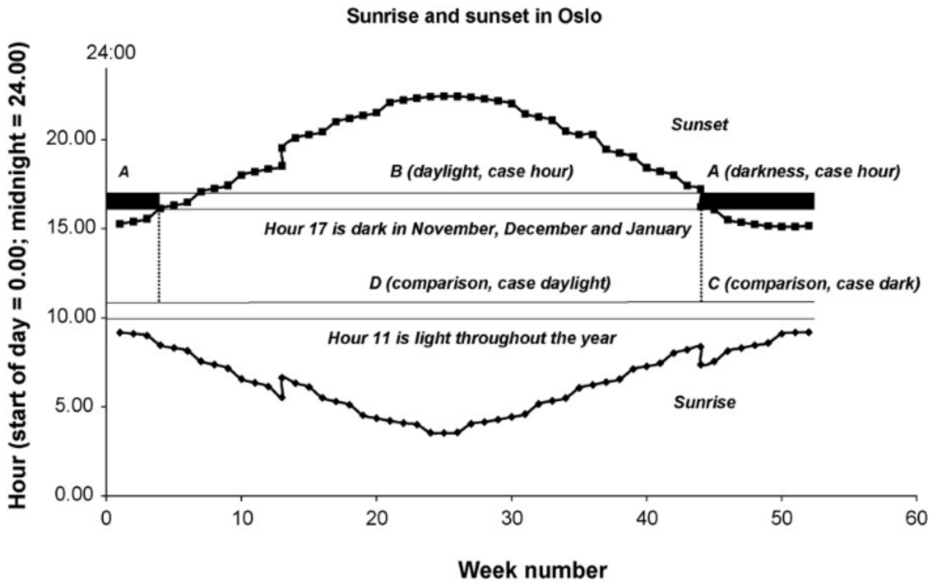

Figure 2-19: Sunrise and sunset in Oslo. Comparison of 17h and 11h with respect to daylight.
(Johansson et al., 2009)

They estimated the risk associated with darkness using the odds ratio (**Eq 1**), formed by dividing the darkness/daylight ratio for the case hour by the corresponding ratio for the comparison hour. The odds ratio (r) is defined as:

> ***r***= [(*number of accidents in darkness in a given hour of the day*) / (*number of accidents in daylight in the same hour of the day*)] / [(*number of accidents in a given comparison hour when the case hour is dark*) / (*number of accidents in a given comparison hour when the case hour is in daylight*)].

Eq 1

Uttley et al. (2020) have explored the possible negative impact of darkness on cycling rates by calculating an odds ratio of the number of cyclists in daytime and after-dark by scheduling case hours and control hours for 48 locations in Birmingham, UK. An odds ratio was calculated by **Eq 2**, showing the effect of darkness/twilight on cyclist frequency, for each counter location. Where, for counter location i, $Case_{dark}$ is the count of cyclists in the case hour when it is dark (or twilight); $Case_{day}$ is the count of cyclists in the case hour when it is in daylight; $Control_{dark}$ is the count of cyclists in the control hours when the case hour is dark (or twilight); $Control_{day}$ is the count of cyclists in the control hours when the case hour is in daylight. They obtained counts of cyclist numbers from automated cycle counters in Birmingham for each hour of the day over 4 years, 2012 to 2015.

$$Odds\ ratio_i = \frac{Case_{day,i}}{Case_{dark,i}} \div \frac{Control_{day,i}}{Control_{dark,i}}$$

Eq 2

Show rows with cells including:

Counter	OffRoad	Light	Hour	2012	2013	2014	2015	Total
CY11	Road	Twilight	Control	291	141	160	170	762
CY11	Road	Twilight	Case	284	217	186	162	849
CY11	Road	Dark	Control	915	500	508	552	2475
CY11	Road	Day	Control	792	733	693	887	3105
CY11	Road	Dark	Case	977	757	798	761	3293
CY11	Road	Day	Case	993	920	605	909	3427

Figure 2-20: Sample data output from the counters, Open Science Database
(Uttley et al., 2020)

The ambient light condition for control and case hours during different periods of the year was shown in *Figure 2-21*. *Figure 2-22* shows odds ratios using counts in the case hour and the combined control hours, odds ratios greater than one indicating that both darkness and twilight ambient light conditions significantly reduce the number of people cycling, compared with daylight. Their results suggest that odds ratios using 'case' and 'control' hours are a useful method for examining the effect of light conditions on travel behavior.

Dates	Total number of days	Case hour (18:00–18:59)	Control hour 1 (14:00–14:59)	Control hour 2 (22:00–22:59)
1 January - 6 March	65	Darkness	Daylight	Darkness
7 March - 25 March	19	Twilight	Daylight	Darkness
26 March - 7 October	196	Daylight	Daylight	Darkness
8 October - 23 October	16	Twilight	Daylight	Darkness
24 October - 31 December	70	Darkness	Daylight	Darkness

Figure 2-21: Light condition of case and control hours throughout the year
(Uttley et al., 2020)

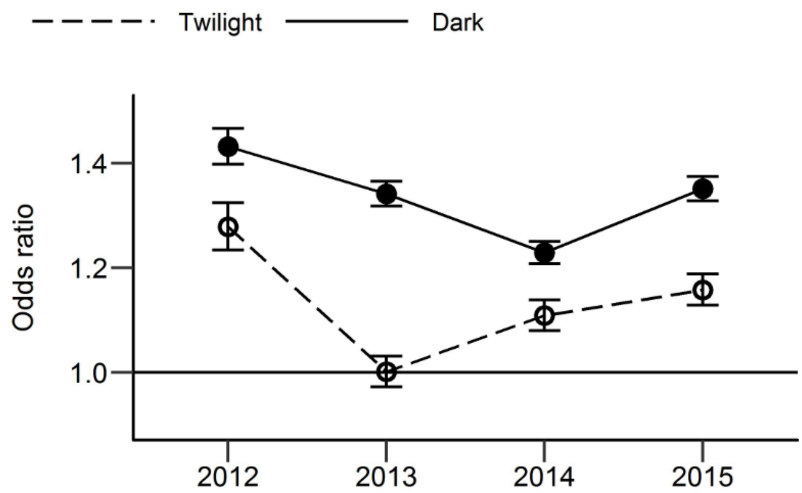

Figure 2-22: Effect of twilight and darkness on cyclist numbers between 2012 and 2015
odds ratio of 1 implies no difference in cycling rates between daylight and twilight/darkness; greater than 1 indicates significantly fewer cyclists after-dark compared with daylight. (Uttley et al., 2020)

Influx, as an interactive game and crowd management experiment installed during GLOW 2016 in the living lab Markthal in Eindhoven, is an innovative approach to measure the effect of dynamic lighting on pedestrian speed. This study explored how different dynamic light patterns affect pedestrian flow using an array of Microsoft Kinect sensors and continuous pedestrian tracking algorithms developed by Corbetta and colleagues (Corbetta, Meeusen, Lee, & Toschi, 2016; Haans, A., Corbetta, A., Kumar, P. P. & Toschi, 2017). The collected data contributed to the improvement of the pedestrian tracking algorithm further. However, any further results could not be found about the Influx experiment.

Figure 2-23: Influx, GLOW 2016 (reference: Bart van Overbeeke)

2.4. Overview of the Analyses to Define Functional Requirements

The analysis of the Smart Space Project and literature review including the components of urban lighting experience and the existing methods and tools to measure them has become the basis for the design of the UXE Toolbox together with its guidelines and the demo case(s). Considering this basis, the UXE Toolbox should facilitate monitoring and evaluation of UX for 31 lighting scenes (Figure 2-24) in three clusters (i.e. A- Improving safety for all road users, B- Enhancing leisure experiences, and C- Increasing security at nightlife) and four interaction levels (i.e., 4-Interactive, 3-Reactive, 2- Active, 1- Static). Distributions of these lighting scenes are seen in Figure 2-25 in which they were divided into six categories according to the anticipated use (i.e., cluster A, cluster B, cluster C) and smartness (i.e., 4-reactive and 3-interactive= smart, 2-active and 1-static= smart-ready).

Figure 2-24: 31 lighting scenes co-created in Smart Space Project[2]

(Valkenburg, den Ouden, & Rietjens, 2019)

Besides the coverage of three anticipated uses and five interaction levels, this toolbox should address small and medium-size municipalities' needs considering their priorities and purposes for the UX evaluation. As a result of the observations during the Smart Space Project, three prospective purposes were detected for UX research. These are (1) to obtain public opinion on smart urban lighting, (2) to finetune the lighting scene(s), and (3) to assess the impact of the smart lighting implementation. Regarding the literature review, these three purposes are respectively corresponding to three dimensions of user experience in urban areas: (1) attitude, (2) perception, and (3) behavior. The dimensions of UXE adds three options for each of the six categories as shown in Figure 2-26 (UX dimensions are presented with yellow, orange, and red triangles), thus 18 categories have emerged from the functional requirements for the UXE of smart urban lighting.

[2] 33 lighting scenes were designed in total that two of them were eliminated due to the scope of the project.

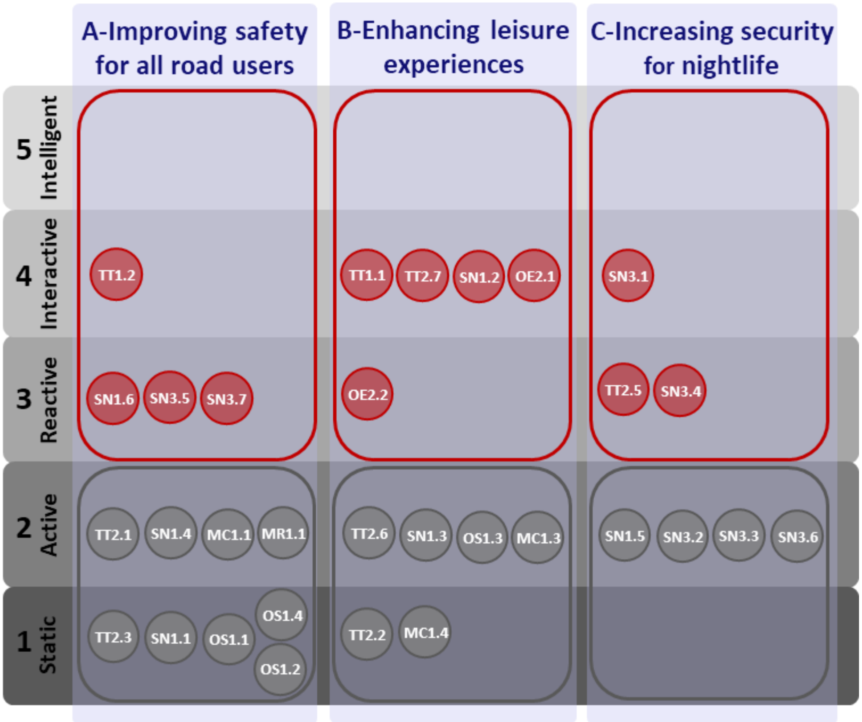

Figure 2-25: Distribution of lighting scenes according to clusters and interaction levels; red dots represent smart lighting scenes while gray dots are for not smart ones (Valkenburg & den Ouden, 2019)

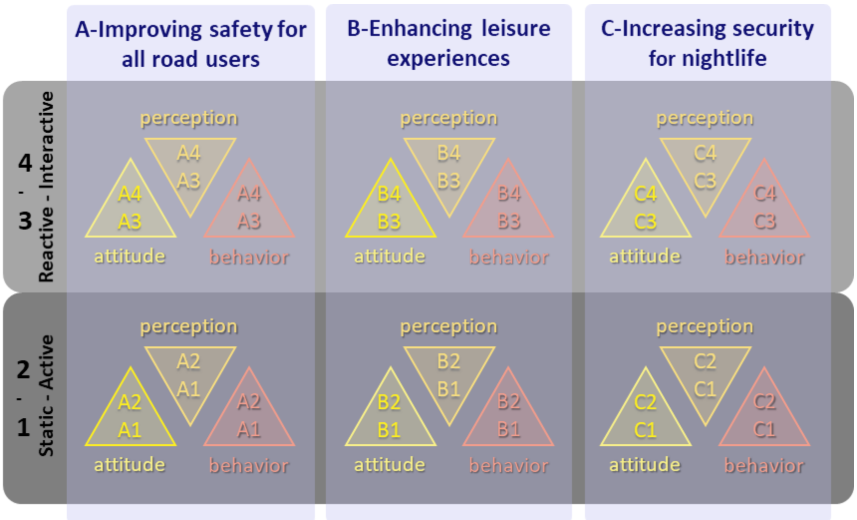

Figure 2-26: 18 UXE categories emerged from functional requirements

The UXE Toolbox is primarily designed for the small and mid-sized municipalities that are willing to adopt smart lighting solutions. By using this toolbox, the municipalities can keep their finger on the pulse of citizens. As the specific design problems, functional design requirements are defined as listed below:

R1: This toolbox should be accessible for small and medium-sized municipalities

R2: This toolbox should define the timeframes of data collection for a systematic UXE

R3: This toolbox should define parameters that can cover three clusters of anticipated use, four interaction levels, and three dimensions of UX.

R4: This toolbox should include a clear description of each parameter to be assessed

R5: This toolbox should include a broad range of methods and tools to collect both objective and subjective data from miscellaneous sources (i.e., users, an expert observation, statistical data, sensors, etc.)

R6: This toolbox should introduce the state-of-the-art technologies and methods in UX research

R7: This toolbox should include a clear description of each tool.

R8: This toolbox should provide a customized UX evaluation method in line with the needs of municipalities, the interaction level, and the specific use of a smart lighting system.

R9: This toolbox should provide clear guidelines for municipalities to conduct case-specific UX research throughout the evaluation and monitoring process.

R10: This toolbox should provide a scoring system for an overall assessment to quantify the impact of smart lighting implementation on citizens' attitudes, perceptions, and behavior.

In line with defined functional requirements, the UXE Toolbox consisting of parameters, tools, and decision tables, the guidelines explaining how to choose the relevant parameters and tools for a specific case, and a demo case showing how to use the toolbox to evaluate UX with smart urban lighting as project deliverables explained in the next two chapters.

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Chapter 3 User Experience Evaluation (UXE) Toolbox

This chapter explains the components of the UXE Toolbox within the defined UX measurement framework and presents guidelines for municipalities to choose the most suitable methods and tools in line with their needs. User Experience (UX) is defined by the International Organization for Standardization (ISO, 2010) as a person's perception and response resulting from the use or anticipated use of a product, system, or service. In this study, UX refers to what users think about and how they perceive and respond to the smart lighting system in the context of urban areas at night. User Experience Evaluation (UXE) refers to the measurement of users' attitudes, perceptions, and behaviors over time with the right tools.

The UXE Toolbox, an excel based toolbox (Figure 3-1), is designed for small and mid-sized municipalities to support the measurement of citizens' experience with smart urban lighting solutions. It consists of a set of evaluation parameters and tools for the UX assessment. These parameters are developed based upon the smart lighting scenes co-created by the Smart Space Project. This toolbox consists of seven parameters and 23 sub-parameters to evaluate UX via 25 tools. The UXE toolbox offers a customized method for each lighting scene with the help of the guidelines. These guidelines are to help small and mid-sized municipalities prepare a measurement and evaluation plan for their case by step-by-step through decision tables which leads to case-specific parameters and introduce appropriate tools accordingly.

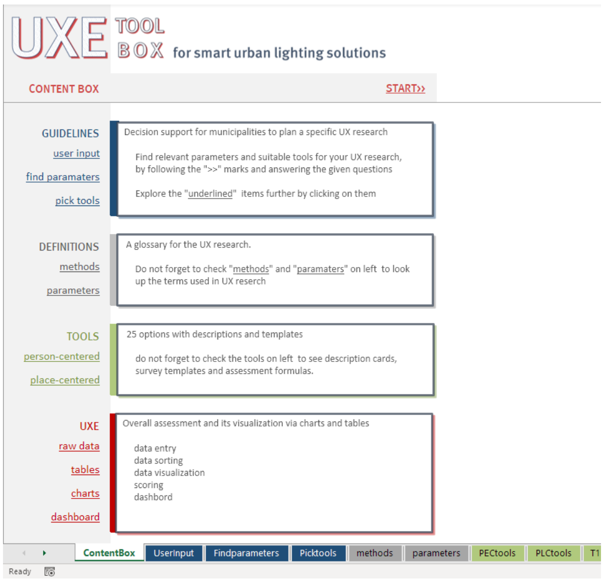

Figure 3-1: A preview of the excel-based toolbox (PDEng Design Project, deliverable 2)

3.1. The Framework of UX Measurements for Smart Urban Lighting

This study proposes a measurement framework for the UXE toolbox. The framework consists of two measurement categories (i.e., person-centered (PEC) and place-centered (PLC)) in three timeframes (i.e., before, test, and after) for a comprehensive UX assessment. Measurements are defined under two categories in terms of the source of the data: (1) person-centered (PEC) and (2) place-centered (PLC). PEC measurements are based on personal experiences obtained through self-report techniques and/or physical and physiological measurements of the individual. While PLC measurements provide collective data from a location via smart lighting system elements such as ICT and IoT, official reports such as traffic reports, police reports, and via site observations conducted by an observer. This framework covers the measurement of attitude, perception, and behavior as user experience and suggests including environmental measurements (e.g., temperature, humidity, ambient light, air quality, noise level) to make better sense of user experience in an outdoor lit environment.

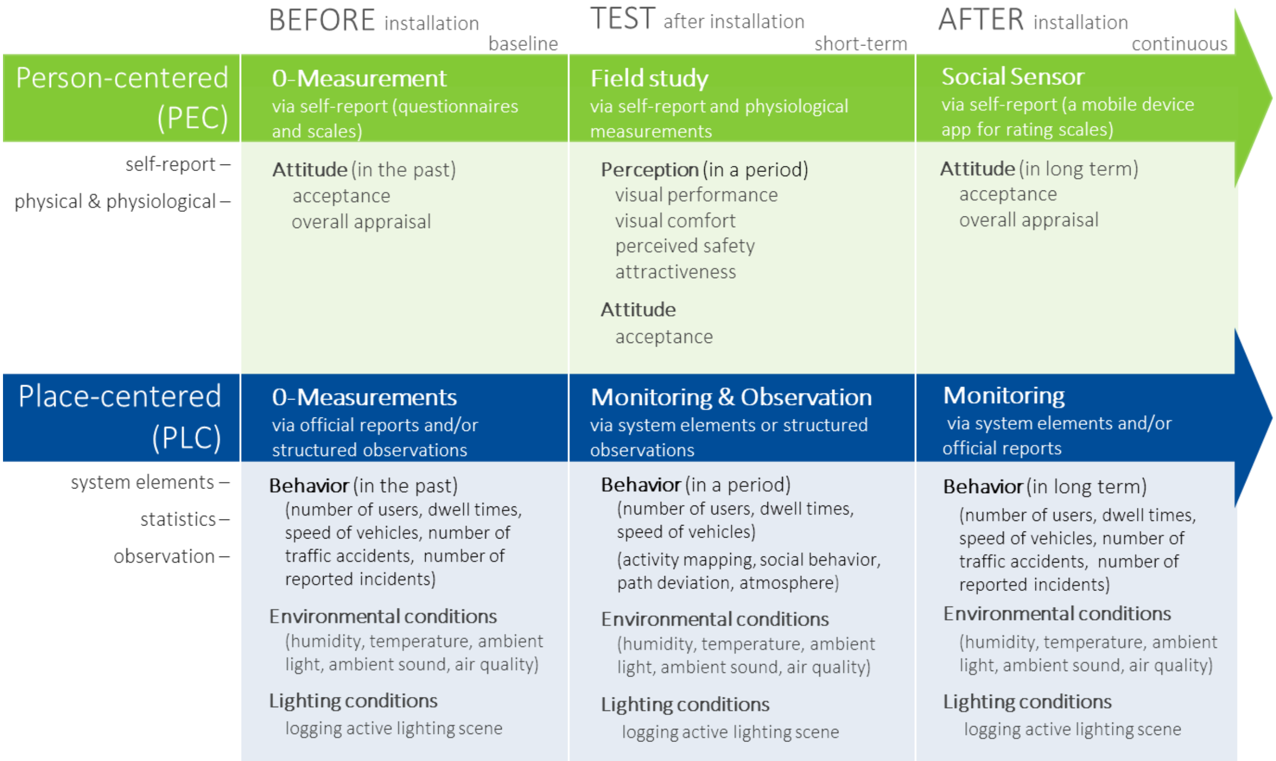

Figure 3-2: Measurement Framework

3.1.1.Measurement Methods

As shown in Figure 3-2 measurement framework, UX measurements are divided into two categories: place-centered (PLC) and person-centered (PEC). There are five types of measurement methods in total, three of them are PLC and two of them are PEC as listed in Figure 3-3. PLC measurements provide objective data collected from a location where the experience occurs in daily life, thus this is public data. Public data is gathered in three ways. The first source is system data collected via the smart urban lighting system. The second source is municipal statistics on traffic accidents and crime. The last one is observations performed by an observer on the implementation site. On the other hand, PEC measurements provide subjective and objective personal data directly from users of urban areas. PEC data can be obtained in the form of self-report through participatory meetings, questionnaires, and scales and in the form of physical & physiological measurements through tracking performance (e.g., detection time and distance) and physiological changes (e.g., heart rate variability and galvanic skin response) while experiencing a lighting scene.

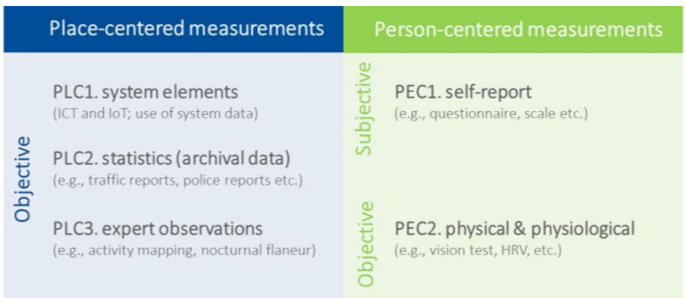

Figure 3-3: Measurement methods for UXE

3.1.2. Timeframe

The measurement framework defines three time periods for UX measurements: before the installation, during the test period, and after the installation.

- Measurements that were taken before the installation establish baselines for the impact assessment of new lighting solutions. Social survey via self-report technique is a part of this period to understand citizens' attitude towards both the existing and the to-be-installed new urban lighting systems. Moreover, data is obtained either via statistics from existing databases and archives or via structured observations to investigate existing situations.
- Measurements during the test period are crucial to finetune the lighting scene in line with the users' needs. After the installation of smart public lighting, the effect of different lighting scenes can be tested either in a real-life setting or in a field experiment. In a real-life setting, the impact of different lighting scenes on behavior can be investigated by monitoring use patterns and observing prevailing behaviors at night. In the field experiment, the user experience can be explored by asking people how they perceive their lit environment via self-report technique (i.e., questionnaires, scales) and tracking physical & physiological changes (i.e., vision test, heart rate variability, galvanic skin response, etc.) in different lighting scenes. Although both the real-life monitoring and the field experiment are in-situ, field experiments contain predefined situations to be experienced for the targeted subjects on a test site which could need more time and effort than other measurements. However, field experiments can provide valuable insights on visual performance, visual comfort, perceived safety, perceived atmosphere, and acceptance through the active involvement of citizens in the evaluation process.
- After the test period, continuous measurements are crucial to understanding the impact of smart urban lighting on the acceptance, safety, and livability in the long term. It is mostly based on monitoring through information and communication technologies (ICT) available in the smart lighting system (i.e., passerby-counter, noise sensor, etc.) which gathers place-centered objective data. The collection of place-centered objective data, which is called system data, enables the system to learn from the process to predict what users would prefer in specific situations in the future. Moreover, this framework proposes to combine system data (place-centered objective data) with continuous feedback of citizens (person-centered subjective data) to understand the impact of smart urban lighting and the underlying reasons behind it better. For instance, citizens can be 'social sensors' providing continuous feedback (including rating and reporting) on acceptance and overall appraisal of the smart system through a mobile device application that can be integrated with the system data.

To sum up, as shown in *Figure 3-4*, there are three measurement methods (i.e., PEC1.self-report and PLC2. statistics, PLC3. structured observations) available to set baselines (before phase), four methods (i.e., PEC1.self-report, PEC2.physical and physiological measurements, PLC1. system elements and PLC3. structured observations,) to improve lighting scenes (test phase) and three methods (i.e., PEC1.self-report, PLC1. system elements and PLC2. statistics,) to monitor the impact of smart lighting continuously.

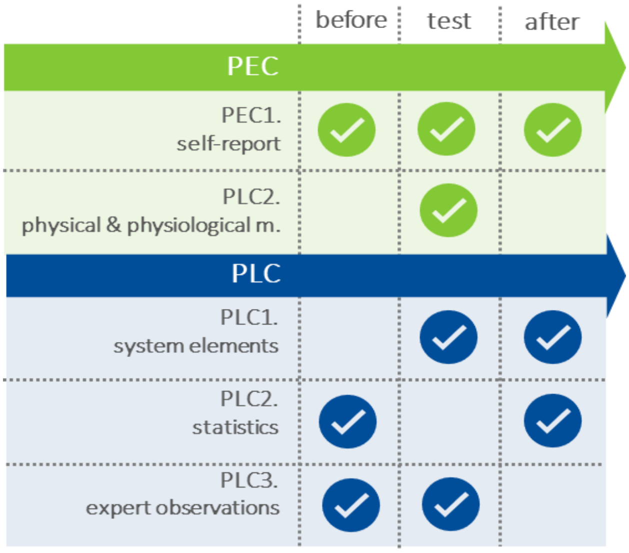

Figure 3-4: Timeframes of measurement methods

3.2. Parameters

UX evaluation parameters are the building blocks to draft a customized UXE method by using the UXE Toolbox. They form a frame to evaluate UX in urban areas for specific smart lighting use-cases. The UXE Toolbox consists of seven parameters under three dimensions (i.e., attitude, perception, behavior) which are determined based on the literature review (Chapter 2) and co-created use cases by the Smart Space Project (Chapter 1). Moreover, these three dimensions are coupled with measurement methods regarding the capabilities of the method and requirements of the dimension as shown in Figure 3-5. The defined parameters (e.g., P1. acceptance) are elaborated with sub-parameters (e.g., P1b. light level) as shown in Table 3-1.

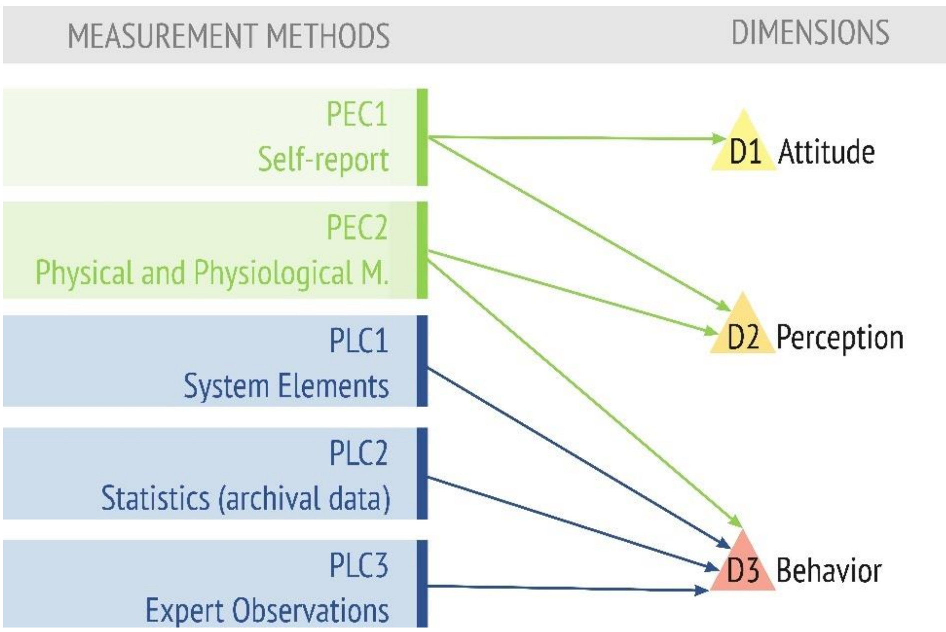

Figure 3-5: Coupling the measurement methods with the dimensions

Table 3-1: Dimensions, parameters, and sub-parameters defined for the evaluation of UX with smart urban lighting

DIMENSIONS	PARAMETERS	SUB-PARAMETERS
Attitude	P1. Acceptance	P1a. light level
		P1b. automatization
		P1c. public data collection
Perception	P2. Visual Performance	P2a. visual capacity
		P2b. obstacle detection
		P2c. sign reading
		P2d. face recognition
	P3. Visual Comfort	P3a. perceived light quality
		P3b. user satisfaction
		P3c. discomfort
	P4. Perceived Safety	P4a. overview
		P4b. feelings and emotions
		P4c. avoidance
	P5. Attractiveness	P5a. environmental appraisal
		P5b. feelings and emotions
		P5c. preference
Behavior	P6. Liveliness	P6a. use pattern of pedestrians
		P6b. use pattern of cyclists
		P6c. social interaction
	P7. Safety	P7a. use pattern of motor vehicles
		P7b. traffic accidents
		P7c. near misses
		P7d. crime
		P7e. aggression

In three UXE dimensions, seven evaluation parameters are defined including 24 sub-parameters.

P1. Acceptance is the positive attitude of citizens towards the smart lighting in terms of light level, automatization of the control including reaction time, sensor sensitivity and transition between the lighting scenes, and public data collection.

P2. Visual performance is defined in terms of speed and accuracy of processing visual information (Rea, 1991). According to Boyce (2014), visual performance is the only thing that can directly be affected by changing the lighting conditions. This parameter consists of the visual capacity (visual acuity, contrast sensitivity, and color recognition) of a person in a lighting scene and the main visual tasks of road users such as obstacle detection to move safely, reading the signs to get the intended destination, and face recognition to feel safe and comfortable.

P3. Visual comfort is mostly defined as the absence of visual discomfort in the literature. In this study, visual comfort considers not only discomfort factors such as glare, flicker, shadows, and contrast, but also comfort aspects based on perceived light quality and user satisfaction about lighting.

P4. Perceived safety is "a person's immediate sense of security, and an absence of anxiety of becoming victimized, when traveling through a particular environment" (Blöbaum & Hunecke, 2005; Haans & de Kort, 2012). This parameter measures perceived safety in urban areas at night. Perceived safety is measured via an overview of the environment, feelings and emotions during the experience, and avoidance of a particular environment.

P5. Attractiveness refers to user appraisal of public spaces under specific lighting scene(s). This parameter consists of three sub-parameters as environmental appraisal referring to the subjective impression of an environment, emotional appraisal meaning how people feel in this environment, and the preference for the use of this area.

P6. Liveliness is a parameter indicating the quantity and quality of outdoor activities in urban areas at night. This parameter measures liveliness regarding walking, cycling, and social interactions. Thus, it consists of use patterns of pedestrians and cyclists and features of leisure activities. Use pattern of pedestrians is defined by their number, direction, route, speed, and dwell time. The use pattern of cyclists is defined by their number, direction, route, and speed. Social interactions, defined by their number, type, frequency, and duration.

P7. Safety refers to the prevention of traffic accidents and the absence of crime and aggression in urban areas at night. Traffic safety can be measured via use patterns of motor vehicles, traffic accidents, and near misses. Speed of motor vehicles is the first sub-parameter defined related to traffic safety. Type, number, time and location of accidents is another factor to measure traffic safety. Near-misses can be a reliable sub-parameter to indicate the risk areas though it is difficult to measure compared to other sub-parameters (i.e., P7a, P7b). Safety from crime can be measured via the risk of crime according to official reports and aggression detected by sound sensors. Crime is defined by its number, type, time, and location. Aggression is quantified by the number, frequency, time, and location of detected incidents and hustle-bustle.

3.3. Tools

In order to measure the defined parameters, 25 validated tools were compiled in the UXE Toolbox. They were presented in the form of description cards, survey templates, or calculation sheets, to be introduced to the municipalities. The names and functions of these tools were shown in Table 3-2 together with their function. These tools were divided into five groups according to the measurement methods stated in part 3.1.1

Table 3-2: Tools in five groups together with corresponding parameters and what they measure.

	Tools	what is measured
PEC 1	T1 Public Opinion Panel	opinion and acceptance
PEC 1	T2 Acceptance Survey	acceptance of light level, automatization and data collection
PEC 1	T3 Perceived Outdoor Lighting Quality (POLQ)	subjective lighting quality
PEC 1	T4 Citizen Satisfaction Score (CSAT)	overall lighting satisfaction
PEC 1	T5 Visual Discomfort Scale	discomfort level due to glare, flicker, contrast, and shadows
PEC 1	T6 Perceived Safety Questionnaire	safety feeling, overview, avoidance
PEC 1	T7 Atmosphere Metrics	environmental appraisal
PEC 1	T8 Environmental Appraisal Survey	environmental appraisal and preference
PEC 1	T9 Self-Assessment Manikin (SAM)	feelings
PEC 2	T10 Vision Test	visual acuity, contrast threshold, color recognition
PEC 2	T11 Obstacle Detection Task	obstacle detection
PEC 2	T12 Sign Reading Task	sign reading
PEC 2	T13 Face Recognition Task	face recognition
PEC 2	T14 Electrocardiography (ECG)	heart measurements to indicate emotional arousal and stress
PEC 2	T15 Galvanic Skin Response (GSR)	skin conductivity to indicate emotional arousal and stress
PEC 2	T16 Eye Tracking	fixation and gaze points, heatmaps
PEC 2	T17 Facial Expression Analysis (FEA)	emotions from facial expressions
PLC 1	T18 Passerby Counter	use pattern (number, path, speed, and dwell time) of objects (pedestrians, bicycle, motor vehicles)
PLC 1	T19 Crowdflow (Kinect+OpenOPTV or Trackpy)	flow of pedestrians
PLC 1	T20 Sound Sensor	aggression detection
PLC 2	T21 Traffic Reports (accidents)	time and number of traffic accidents
PLC 2	T22 Traffic Reports (speed monitoring)	number, direction, and speed of vehicles
PLC 2	T23 Police Reports (crime)	number and type of crime
PLC3	T24 Activity Mapping	activity (type, user diversity)
PLC3	T25 Nocturnal Flaneur	social interactions, near-misses, accident and crime risks

3.3.1.Tools for PEC1 method

Self-report is a method of asking participants about their attitudes, feelings, and opinions. Tools of self-report method apply various platforms (i.e., panel for voting dots, paper, and pencil, mobile application, interview) for citizens to express their feelings and opinions about the smart urban lighting. There are eight self-report tools in the UXE Toolbox to assess the attitude and perception of citizens.

T1. Public Opinion Panel: It is a public survey asking citizens how they evaluate street lighting in their cities (Figure 3-6). It is organized at the closest gathering area to the project site (e.g., main square). This survey includes a project poster introducing the smart lighting implementation to be assessed and a white poster with questions to be voted on using colorful stickers (see appendix 1 for the poster template).

Figure 3-6: Public Opinion Panel on climate action day in Rostock, Dynamic Light Interreg project (Römhild, 2019)

T2. Acceptance Survey: It is a 7-point rating scale to understand citizens' acceptance level in terms of light level, automatization, and public data collection. Level of acceptance is graded 1 to 7 as 1-very unacceptable, 2-unacceptable, 3-slightly unacceptable, 4-neutral, 5-slightly acceptable, 6-acceptable, 7-very acceptable (see appendix 2 for the survey template).

T3. Perceived Outdoor Lighting Quality (POLQ) (Johansson et al., 2014): This tool consists of ten 7-point bipolar scales. The items form two dimensions as strength and comfort. The paired items to determine perceived strength quality are clear-drab, strong-weak, focused-unfocused, brilliant-subdued, and light-dark, and the paired items for perceived comfort quality are sharp-mild, hard-soft, warm-cool, shaded-glaring, and natural-unnatural. The seven points of the scale are graded 1 to 7 from left to right (see appendix 3 for the POLQ template)

T4. Citizen Satisfaction Score (CSAT): It measures citizen satisfaction with a smart urban lighting system. It’s one of the most straightforward ways to measure satisfaction and it's obtained by asking a simple question, such as 'How satisfied were you with your experience?'. It can be applied in a physical environment (e.g., paper-pencil, or public panel to mark on) or online (e.g., interactive response buttons or mobile device app). (see appendix 4 for the template of CSAT).

T5. Visual Discomfort Scales: It is a 9-point rating scale consisting of four dimensions. This scale asks participants if they feel visual discomfort from a specific location in terms of glare, flicker, contrast, and shadows. This survey is suitable for a field experiment in which participants can assess their discomfort level with changing lighting scene(s) and viewing angles momentarily.

T6. Perceived Safety Questionnaire (Haans & de Kort, 2012): This tool consists of three statements (i.e., “I feel uncomfortable with the idea of having to walk into this street”, “I would walk down this street at a higher pace than I usually walk” and “I would rather avoid this street”) to assess via five-point response scale (1-disagree to 5-agree) and a map to indicate unsafe areas on it.

T7. Atmosphere Metrics (Vogels, 2008): These metrics quantify environmental appraisal, specifically perceived atmosphere, using 38 descriptors with 7-point response scales. Subjective evaluations using 38 descriptors measure perceived atmosphere by four factors: coziness, liveliness, tenseness, and detachment (see appendix 5 for the Perceived Atmosphere Questionnaire).

T8. Environmental Appraisal Survey (EAS) (Nasar & Bokharaei, 2017b): This tool measures the attractiveness of a lit environment. It consists of twelve 7-point bipolar scales to measure citizens' appraisal of their surroundings in terms of pleasantness, excitement, restfulness, and behavioral intent. The scale is graded 1-7 referring to negative appraisal to positive appraisal (see appendix 7 for the survey template).

T9. Self-Assessment Manikin (SAM) (Bradley & Lang, 1994): It is an emotion assessment tool that uses graphic scales, depicting cartoon characters expressing three emotional elements: pleasure, arousal, and dominance. It can be used to measure the emotional state of participants which is a sub-parameter of perceived safety and attractiveness (see appendix 8 for the SAM scales).

3.3.2.Tools for PEC2 method

The tools in this group provide objective data directly from participants through physical and physiological measurements. The collected data help to understand how citizens perceive their lit environment. Physical tests investigate the relation between the physical stimuli (e.g., light) and the response of participants based on distance, response time, and the correctness of the answer (e.g., name of the color or sign). Physical tests are to examine visual performance under specific light conditions. The tools of psychophysiology (e.g., eye tracking) provide implicit measurements to investigate human perception through measuring micro-behaviors and body signals to understand the emotion and attention in a specific situation. Physical and physiological measurements need a well-planned field experiment, special equipment, and expert knowledge. This research can be challenging and time- consuming but results will bring valuable insights into the user perception of smart lighting.

T.10 Vision Test: In a field experiment, it measures visual capacity under specific lighting scenes using Landolt Ring Chart for acuity, Pelli-Robson Test for contrast sensitivity, Ishihara Plate Color Test for color blindness, and color naming test for color recognition in different lighting conditions (see appendix 9 for the visual test templates).

T11. Obstacle Detection Task: It is a field experiment measuring distance and time of obstacle detection (see appendix 11 for a sample experiment protocol).

T12. Sign Reading Task: It is a field experiment measuring the correctness of sign and legibility distance by manipulating light such as light level or color temperature. (see appendix 12 for a sample experiment protocol).

T13. Facial Recognition Task: It is a field experiment measuring the correctness of recognition and legibility distance by manipulating light as light level or color temperature. (see appendix 13 for a sample experiment protocol).

T14. Electrocardiography (ECG): Heart rate variability (HRV) is an indicator of physiological stress or arousal, with increased arousal associated with a low HRV and a decreased arousal associated with a high HRV. HRV is a measure of the variation in time between each heartbeat. According to Harvard Medical School, the chest strap monitor tends to be more accurate than wrist or finger devices. It recommends a chest strap heart monitor (i.e., Polar, Wahoo) and a free data analysis app (e.g., Elite HRV) as the easiest and cheapest way to calculate HRV. Moreover, professional wearable ECG sensors are available in the market such as Shimmer3 ECG Unit as shown in Figure 3-7.

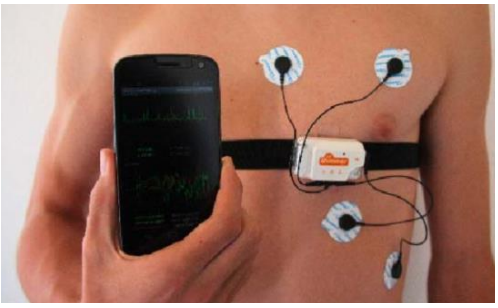

Figure 3-7: Wearable ECG unit (Shimmer)

T15. Galvanic Skin Response (GCR): Our skin provides much information on how we feel when we are exposed to any kind of stimuli (e.g., light, noise, etc.). No matter whether we are stressed, nervous, fearful, or surprised, whenever we are emotionally aroused, the electrical conductivity of our skin subtly changes. GSR, also known as Electrodermal Activity-EDA or Skin Conductance-SC, is one of the most sensitive measures for emotional arousal. It can be tracked via a wearable GSR sensor unit as shown in *Figure 3-8*.

Figure 3-8: Wearable GSR unit (Shimmer)

T16. Eye Tracking: Eye-tracking glasses (Figure 3-9) allow objective measurements of eye movements in real-time by recording eye movements. Together with an inertial measurement unit (IMU), it makes quantifying visual attention possible by analyzing captured fixations and gaze points.

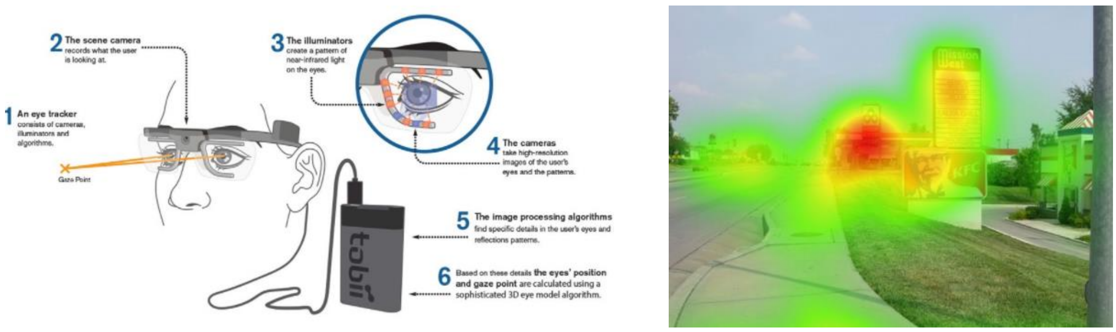

Figure 3-9: How the wearable eye tracker works (source: Tobii) and how eye tracking is analyzed (source: iMotion)

T17. Facial Expression Analysis (FEA): Facial expressions are one of the main indicators of emotions experienced at any given time. The high-quality video records are analyzed by an expert using software based on The Facial Action Coding System (FACS) to decipher emotions following the steps shown in *Figure 3-10*. Thus, by knowing whether participants are afraid, angry, surprised, or joyful, urban lighting can be improved in line with user experience.

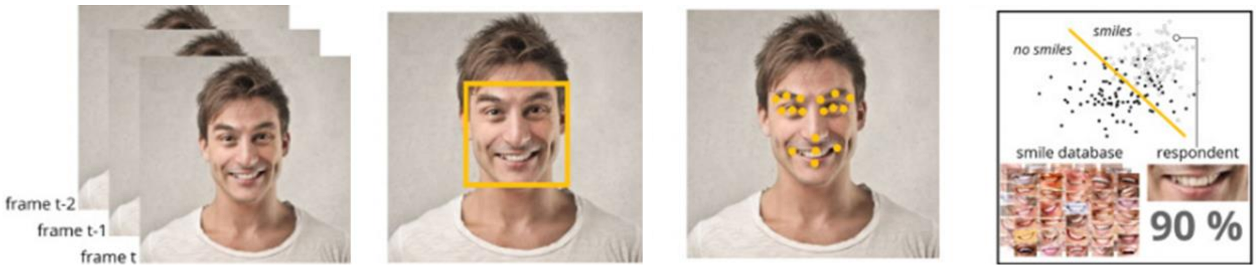

Figure 3-10: How facial expression analysis work; high-quality video input, face detection, feature detection, feature classification (iMotion)

3.3.3.Tools for PLC1 method

PLC1 tools collect objective, real-time and continuous data about user behavior through ICT and IoT (e.g., sensors, lidars, radars, video cameras, etc.). An integrated sensor system embedded into a smart lighting system measures the dynamic of urban areas such as use patterns of pedestrians, bicycles, and motor vehicles, and sound level which can be used to assess the safety and liveliness of urban areas. Monitoring via system elements consists of two aspects; the first part is the installation of the integrated sensor system to collect public data and the second part is the analysis of big data to make sense out of it. Thus, municipalities need to work with a service provider/ technology partner consistently if they use these UXE tools.

T18. Passerby Counter: Numina claims to measure all kinds of curb-level activity anonymously and in an integrated way. It detects the type of object (i.e., pedestrians, bicycles, cars, trucks, busses) and measures the numbers, paths, speeds, dwell times, proximities, and interactions of the detected objects. Numina provides sensors and a dashboard (*Figure 3-11*) configured in accordance with the needs of municipalities. In a smart lighting context, the impact of light on liveliness and safety can be assessed based on street activities.

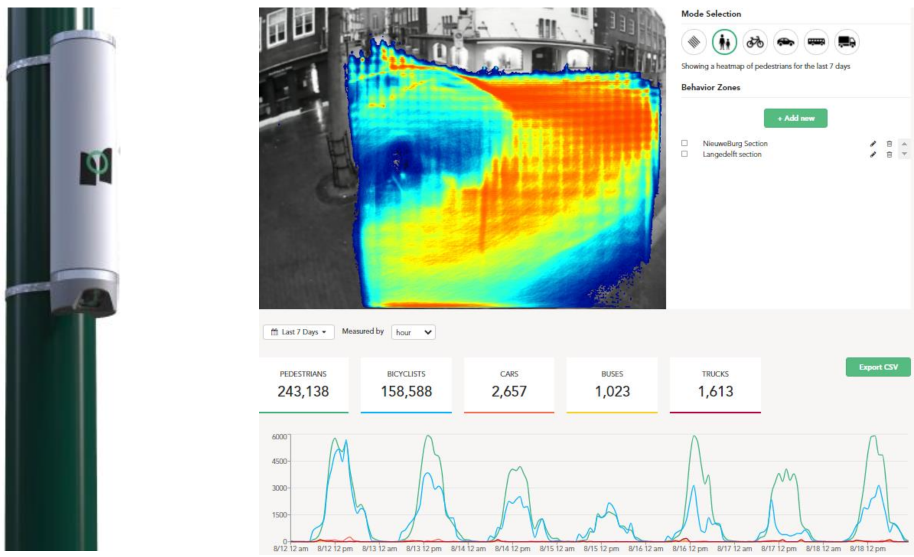

Figure 3-11: **Preview of Numina sensor** (on the left) **and dashboard** (on the right)

T19. Crowdflow (overhead depth sensors + OpenOPTV): Crowdflow research group investigates the dynamics of pedestrians walking in crowds via overhead depth sensors (e.g., Microsoft Kinect), openPTV method, and the algorithm developed by the research group. This algorithm makes it possible to localize and track pedestrians anonymously (Figure 3-12). Considering the nature of urban lighting, it is important that these overhead depth sensors can work well even in the dark. Municipalities can collaborate with the Crowdflow research group to measure the impact of smart lighting on safety (e.g., near-misses) and liveliness (e.g., the flow of pedestrians).

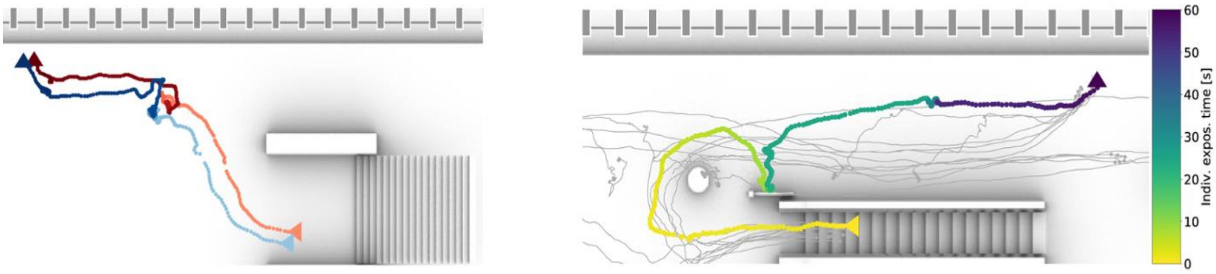

Figure 3-12: Trajectory of travelers monitored real-time with overhead depth sensors at Utrecht Central Station (Pouw, Toschi, van Schadewijk, & Corbetta, 2020)

T20. Sound Sensor: A network of sound sensors can be used to detect the escalating aggression level in urban areas and alert police through giving a notification, in real-time, to let them know where the incident is taking place. The safety of public spaces can be assessed using the number and frequency of detected incidents (e.g., the soundscape of the area or hustle and bustle as shown in *Figure 3-13*).

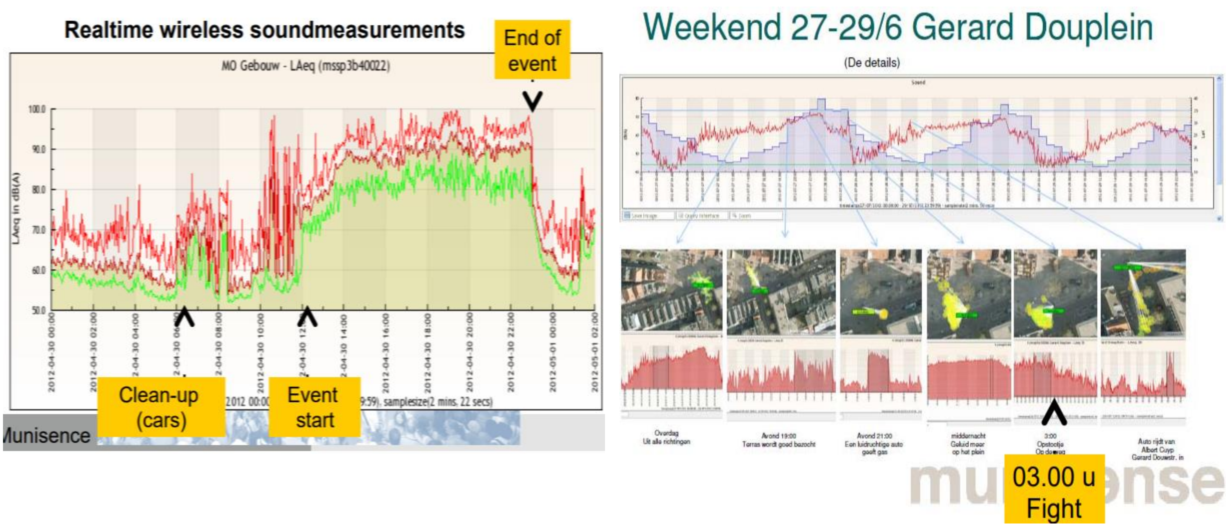

Figure 3-13: Real-time sound measurements; Stratumseind 2.0 project on the left, Amsterdam Gerard Douplein on the right (Kanters, 2013)

3.3.4.Tools for PLC2 method

The data source for PLC2 tools are official reports or databases (e.g., traffic department, police department, local or national database). These tools provide objective data to assess the impact of smart lighting on safety. One of the important tasks for this study is data analytics, thus well-structured datasets and data analysts are crucial to interpret bulky urban data. Only after categorizing the data obtained from the primary sources, the impact of smart lighting on safety can be calculated by comparing the numbers before and after the implementation of a smart lighting system. Research (Rea et al., 2009) shows that the odds ratio is one of the most reliable methods to quantify the impact of lighting on safety. Thus, UXE

Toolbox offers the odd ratio calculations for the data analysis. The odds ratio "r" represents the impact of smart lighting on safety for the given sub-parameters in the formulas below **(Eqn 1, Eqn 2, Eqn 3).**

T21. Reports on Traffic Accidents: The data of traffic accidents can be classified according to the given template below (Table 3-3). The impact of smart lighting on traffic accidents can be calculated based on the odd ratio using **Eqn 1.**

Table 3-3: Data sortin template for traffic accidents

timestamp (interval variable)	smart lighting (nominal variable)	time (nominal variable)	type (optional) (nominal variable)	number (interval variable)
dd-MM-yyyy HH:mm	yes / no	night / day	fatal / injury / property damage	

$$\mathbf{r} = \frac{(\text{number of accidents before smart lighting}_{\text{dark}}/\text{number of accidents before smart lighting}_{\text{day}})}{(\text{number of accidents after smart lighting}_{\text{dark}}/\text{number of accidents after smart lighting}_{\text{day}})}$$

if r=1 then no impact, if r>1 then traffic accidents decrease if r<1 then traffic accidents increase

Eqn 1

T22. Traffic Monitoring Data: The speed data can be classified according to the given template below (Table 3-4). The impact of smart lighting on the mean speed can be estimated based on the odd ratio using **Eqn 2.**

Table 3-4: Data sorting template for speed monitoring

timestamp (interval variable)	smart lighting (nominal variable)	time (nominal variable)	vehicle (nominal variable)	speed (interval variable)
dd-MM-yyyy HH:mm:ss	yes / no	night / day	car / truck / two-wheelers	

$$\mathbf{r} = \frac{(\text{mean of speed before smart lighting}_{\text{dark}}/\text{mean of speed before smart lighting}_{\text{day}})}{(\text{mean of speed after smart lighting}_{\text{dark}}/\text{mean of speed after smart lighting}_{\text{day}})}$$

if r=1 then no effect, if r>1 then positive effect, if r<1 then negative effect

Eqn 2

T23. Police Reports on Crime: The crime data can be classified according to the given template below (Table 3-5). The impact of smart lighting on crime can be estimated based on the odd ratio using **Eqn 3**.

Table 3-5: Data sorting template for crime

timestamp (intervalvariable)	smart lighting (nominal variable)	time (nominal variable)	type (optional) (nominal variable)	number (interval variable)
dd-MM-yyyy HH:mm	yes / no	night / day	robbery / assault / burglary / vandalism	

$$\mathbf{r} = \frac{(\text{number of crime before smart lighting}_{\text{dark}}/\text{number of crime before smart lighting}_{\text{day}})}{(\text{number of crime after smart lighting}_{\text{dark}}/\text{number of crime after smart lighting}_{\text{day}})}$$

if r=1 then no effect, if r>1 then positive effect, if r<1 then negative effect

Eqn 3

3.3.5.Tools for PLC3 method

Expert observations include investigations of natural behaviors occurring in its natural environment. An observer, preferably an expert in the field of urban lighting or urban sociology, conducts a field study to collect information about user activities and behaviors occurring on the site.

This method can provide valuable insight to assess the safety and liveliness of urban areas at night. To perform field observation, there is no need for any technological infrastructure (e.g., sensors or surveillance cameras) but expert knowledge and labor. An additional advantage of this method is that it is safe considering data privacy issues. However, it is a time-consuming and labor-intense method. There are two tools offered for this method:

T24. Activity mapping: This tool provides an observation sheet for surveyors including boxes for general information (i.e., the name of surveyor, location, date, weather, start time, and end time of observation), a map box, and a tally box to record the type of users and activities taking place during the observation.

T25. Nocturnal Flaneur: Nocturnal flaneur (Casciani, 2020) is a method for observing the city at night. A nocturnal flaneur is a night detective that explores the night-time landscape by observing user experience. The nocturnal flaneur aims to see the space through the eyes of people to reveal citizens' daily (or nightly) practices during the observation hours. The lighting design can be improved based on the data collected through expert observation.

3.4. Guidelines

Guidelines are prepared to help municipalities plan case-specific UX research. Municipalities can find relevant parameters and suitable tools by following the defined steps below. The guidelines can be used either in the form of decision diagrams as given below (Figure 3-14, Figure 3-15, and Figure 3-16) or in the form of interactive form in excel (deliverable 2).

Step 1 Get Ready for the UX Research

Define the scale of UX research.

- ☐ site
- ☐ neighborhood
- ☐ city

Determine the purpose(s) of UX evaluation.

- ☐ To obtain public opinion on the smart lighting system
- ☐ To get feedback on how to improve the lighting design
- ☐ To monitor the impact of the smart lighting implementation

Describe the lighting scene(s) to be evaluated by citizens.

Choose the main goal of the implementation in terms of social aspects.

- ○ A-Improving safety of all road users,
- ○ B-Enhancing leisure activities,
- ○ C-Increasing security for nightlife

Choose the interaction level of the lighting system.

- ○ 1-Static or 2-Active
- ○ 3-Interactive or 4-Reactive

Identify target group(s).

- → Who uses the public area at night? (variety of users - e.g., children, visitors, cyclists, people with visual impairments, etc.)
- → What do they do? (necessary activities such as walking, cycling, driving; optimal activities such as shopping, doing sport, strolling around, sitting outdoors to watch around; social activities such as greetings, conversation, gatherings, playing at the street)
- → How often do they use the area? (use frequency – e.g., at the weekends, on weekdays after work, on weekdays early morning, etc.)

Identify enablers of UX research.

- → Which stakeholders are available in the process of UX research? (e.g., shop owners, NGOs, knowledge institutes, companies, traffic department, police department, public lighting department, etc.)
- → What could be their roles? (e.g., initiator, participant, mediator, planner, supporter, etc.)
- → How could they contribute? (e.g., reach citizens, spreading knowledge, research, providing technology, providing data, technical adjustments)

Step 2 Determine the Dimension(s) and Measurement Method(s)

Use the decision diagram shown in Figure 3-14 below to determine the dimension of your UX evaluation and to find the matching measurement method(s).

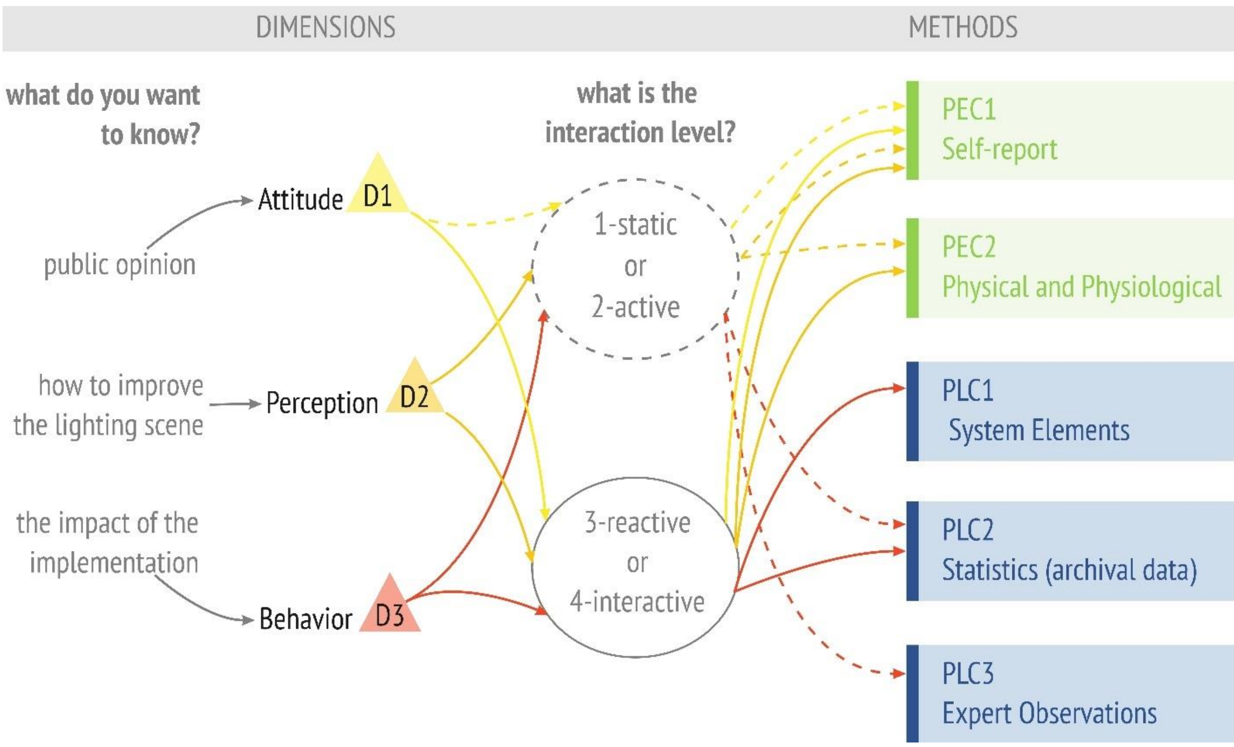

Figure 3-14: Decision diagram for dimension(s) and measurement method(s)

Step 3 Determine Parameters and Sub-Parameters

After noting the case-specific dimension(s) and measurement method(s), it is time to find the case-specific UX evaluation parameters. Follow the goal and interaction level of the implemented smart lighting system to find out case-specific parameters per dimension. The parameters which are obligatory for the assessment are categorized as must-haves and the ones that are optional though highly recommended as nice-to-haves.

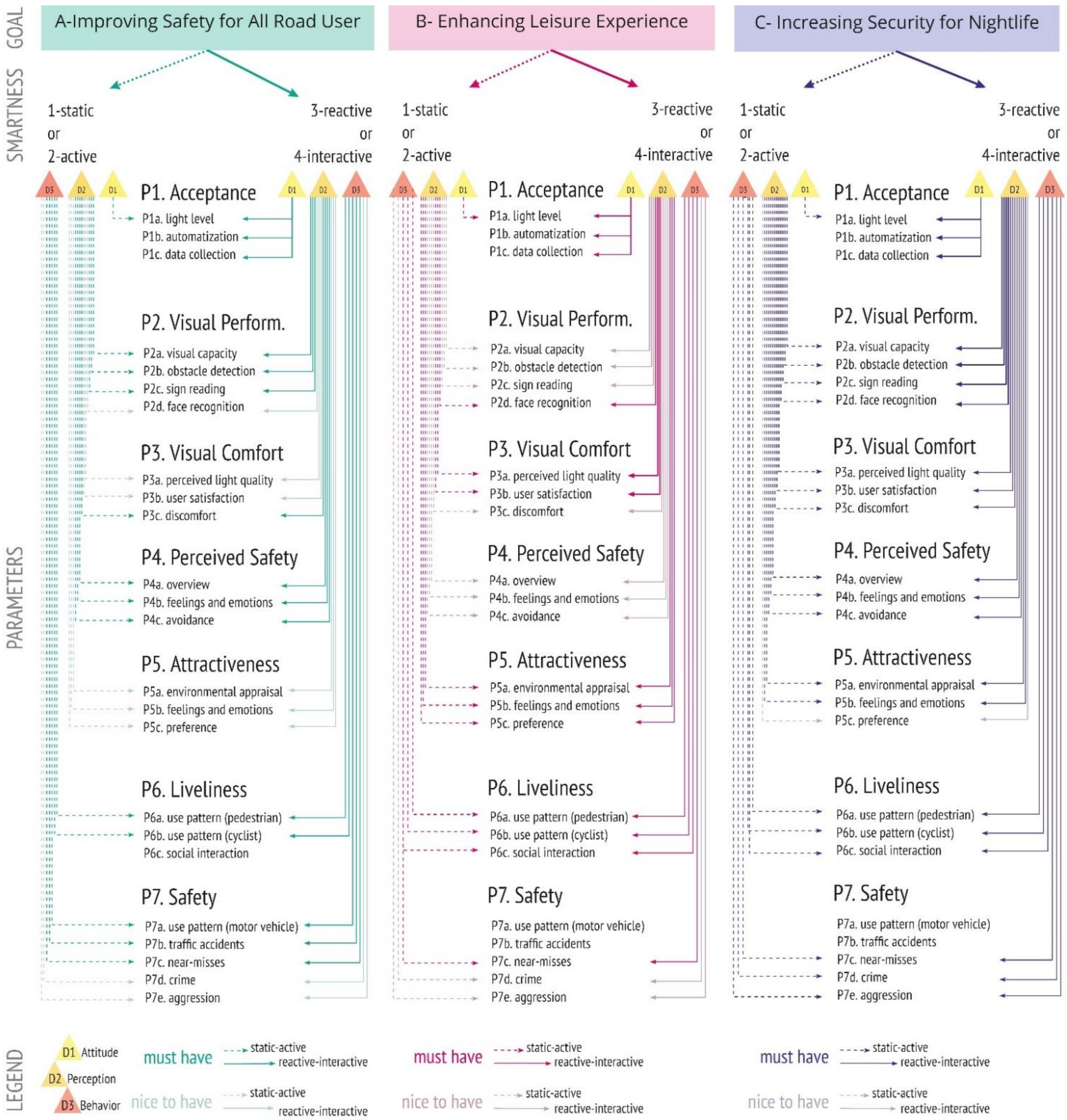

Figure 3-15: nice-to-have and must-have parameters in line with the purpose of UX evaluation based on the goal and interaction level of the case.

Step 4 Find the Most Suitable Tools

Having decided the UX evaluation parameters and available measurement methods for your case, now you can find the most suitable tool(s) by using the decision diagram below (Figure 3-16). Mark your parameters and methods on the diagram, follow the arrows to see the matching tools. You can find detailed information and templates of the tools both on appendices and on the excel workbook (project deliverable 2).

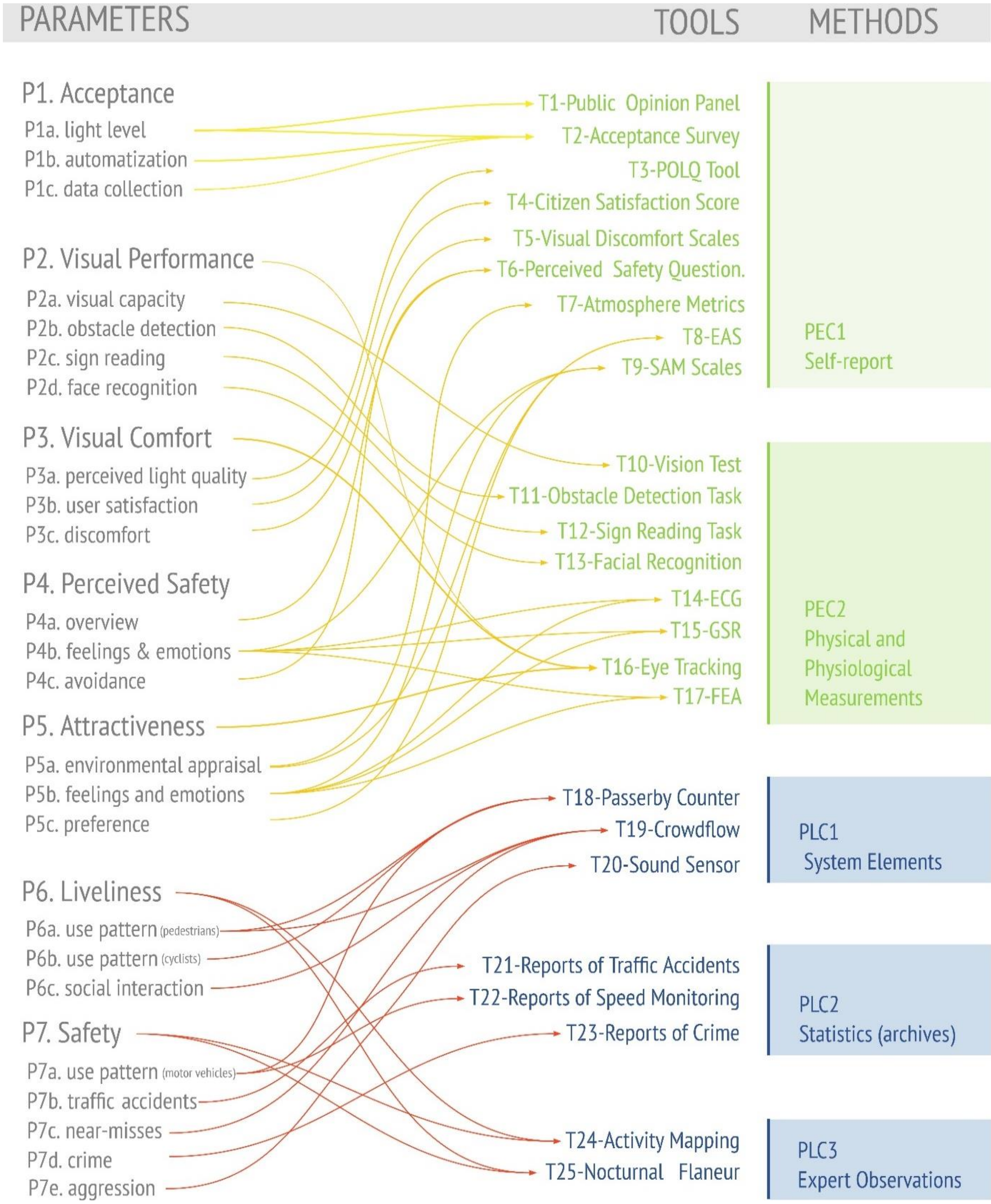

Figure 3-16: Decision diagram to find case-specific tools

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Chapter 4 Demo of the UXE Toolbox via Specific Use Cases

The excel platform hosts the UXE content generated in this PDEng project. The UXE content is presented under four main sections: (1) Guidelines, (2) Definitions, (3) Tools, and (4) Overall Assessment. These sections take place on the main page (i.e., "Content Box") at the navigation pane on the left. The user is informed about how to proceed through the explanation boxes as shown in Figure 4-1. Underlined items (i.e. user input, methods, parameters, etc.) are hyperlinked to the relevant content or steps. Thus, users can explore the UXE toolbox by following the instructions and clicking on the underlined titles. Further information about the use of the toolbox was provided in deliverable 3 through three demo cases in the form of a video record.

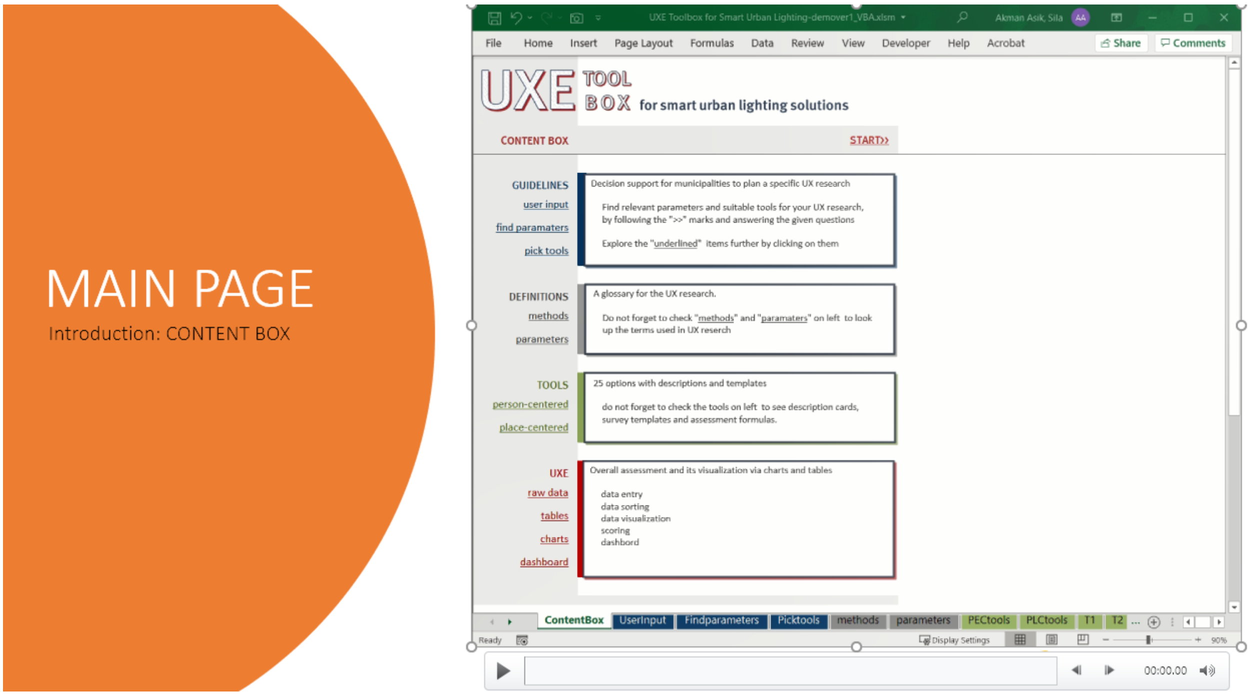


Figure 4-1: Demonstration of the master page of the toolbox on excel (deliverable 3)

4.1. Selection of use-cases and lighting scenes for demo case

As a result of the analysis of eight use-cases consisting of 31 lighting scenes, co-created within the Smart-Space Project, two use cases have been selected from two pilot cities to test the usability of the UXE Toolbox via demos. The selection criteria are (1) to find a use-case with the highest realization possibility within the Smart Space Project period and (2) to provide representative demonstration by including three clusters of anticipated use and both smart (4-interactive and 3-reactive) and smart-ready (2-active and 1-static) lighting implementations.

To demonstrate the use of the UXE Toolbox for smart lighting implementations, Sint-Niklaas seems to be the most promising pilot city considering the realization time of smart lighting implementation. The priorities of the use case in Sint-Niklaas are to improve security for nightlife (cluster C) and to enhance leisure activities (cluster B). Thus, it has been selected as a demo case to demonstrate the toolbox over smart lighting implementations for cluster B and cluster C. As a sample case for road safety (cluster A), Middelburg is found to be the most suitable pilot city to demonstrate a smart ready (2-active) implementation in terms of its realization possibility during the Smart Space Project. Therefore, three lighting scenes have been selected; two of them from Sint-Niklaas (Use case SN3: Sint-Nicolaasplein) and one of them from Middelburg (Use case MR1 Rooseveltlaan).

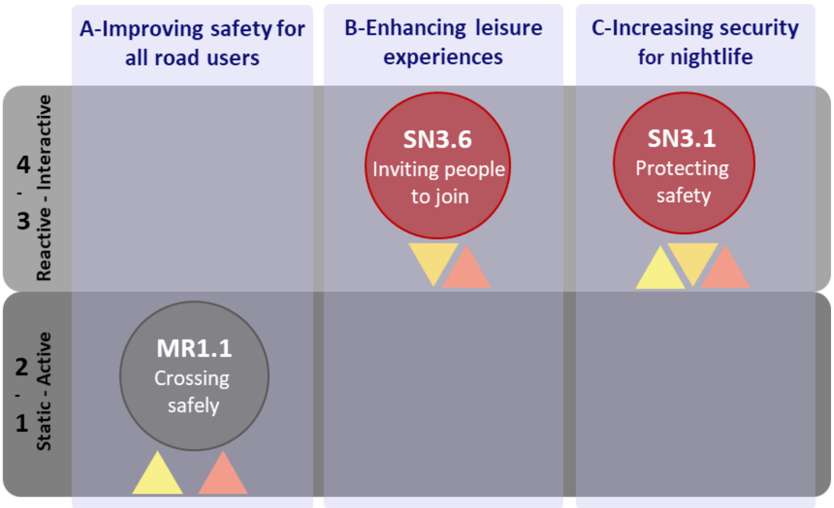
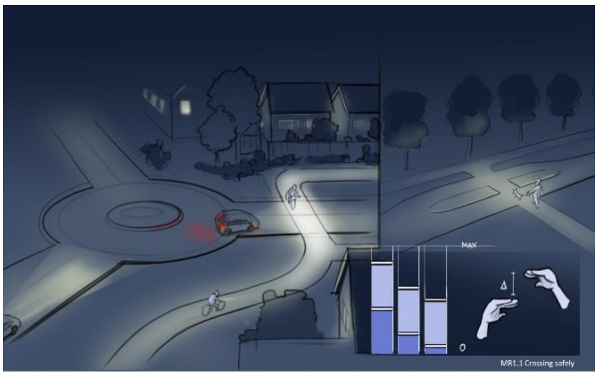


Figure 4-2: Distribution of selected lighting scenes and to be assessed UX research dimensions (yellow triangle representing D1-attitude, orange triangle is for D2-perception and red one indicating D3-behavior) by clusters of anticipated use and smartness

Use case MR1: Roseveltlaan Middelburg



Use case SN3: Sint-Nicolaasplein Sint-Niklaas

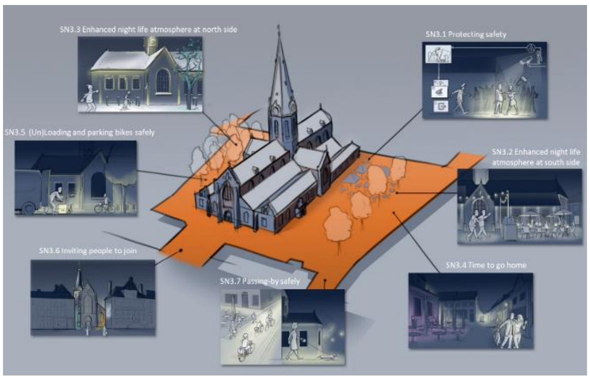
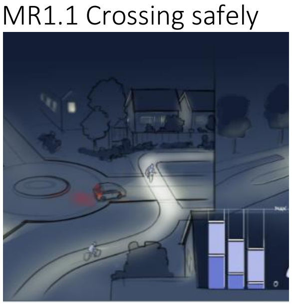
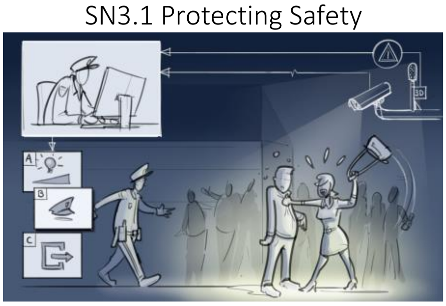


Figure 4-3: Selected use cases for demo cases

MR1.1 Crossing safely



SN3.1 Protecting Safety



SN3.6 Inviting people to join

Figure 4-4: Selected Lighting Scenes

4.2. Use Case MR1: Safe cycling and walking, Rooseveltlaan in Middelburg

The storyboard of the Use Case MR1 (Figure 4-3) consists of one lighting scene that describes how good visibility of cyclists and pedestrians crossing the road is provided to increase their (perception of) safety. With multiple lighting scenes that dim further over the course of the evening and night, with constant contrast for a brightly illuminated crossing, a bicycle/footpath leveling up and down towards this intersection and a maximum dimmed or no lighting on the main road (Valkenburg et al., 2019). For further explanation please look at the deliverable 3 demo case 1.

4.2.1. Demo Case 1: Lighting Scene MR1.1 Crossing safely

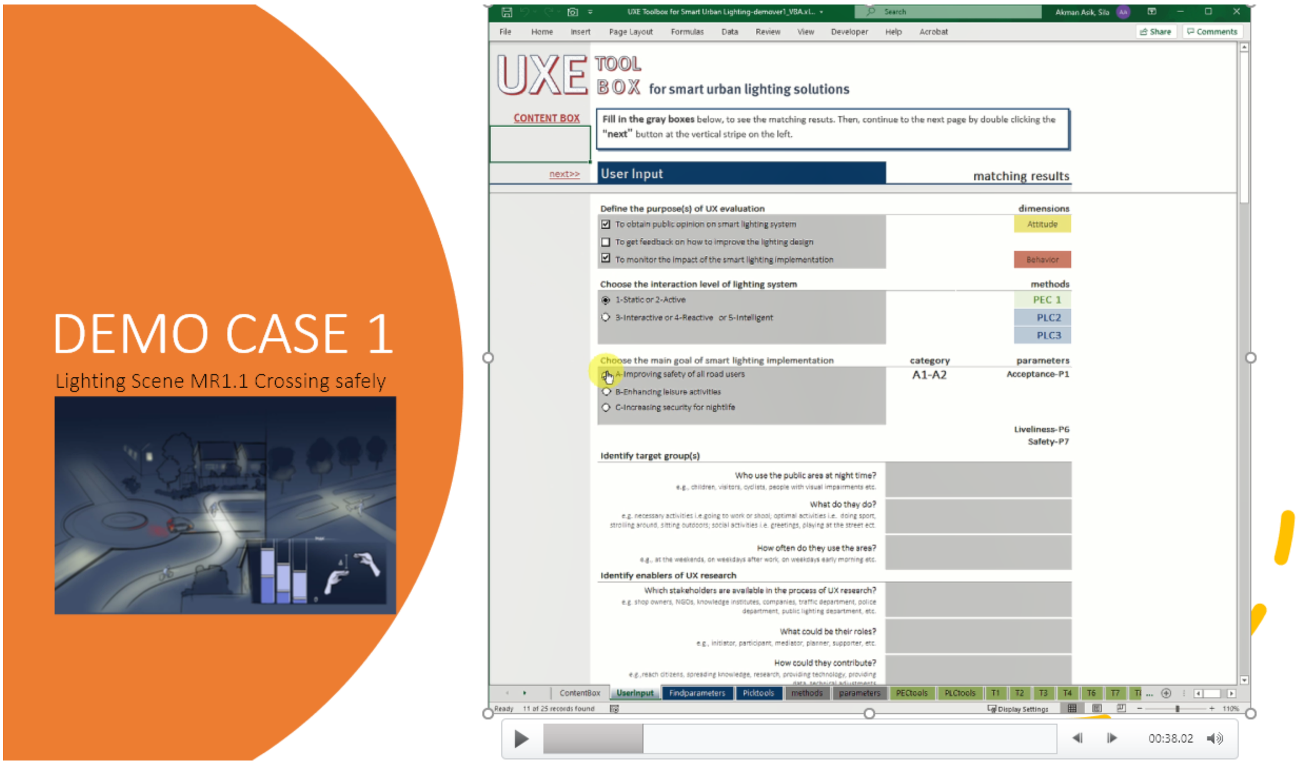


Figure 4-5: Video record of demo case 1 (deliverable 3)

4.3. Use Case SN3 Perceived safety at the nightlife in Sint-Niklaas

During the analysis phase of the Smart Space Project, people in Sint-Niklaas indicated the need for a nice and safe nightlife atmosphere, where unwanted behavior is avoided and surveillance is supported. Based upon this need, the Use Case SN3 was designed and illustrated in the total storyboard (Figure 4-3) consisting of seven lighting scenes that reflect different use by different target groups, related by the position within the area (Valkenburg et al., 2019)

4.3.1. Demo Case 2: Lighting Scene SN3.1 Protecting Safety

Ensuring safety on the entire square by supporting the guards in their jobs with technology to detect and locate incidents and de-escalate aggressive behavior, as well as lighting up available escape routes to enable smooth evacuation of the square in case of a calamity. With an interactive system that reports the occurrence and location of incidents to the control room, reacts with controllable light spots, and supports different evacuation routes in case of calamities (Valkenburg et al., 2019). For further explanation please look at the deliverable 3 demo case 2.

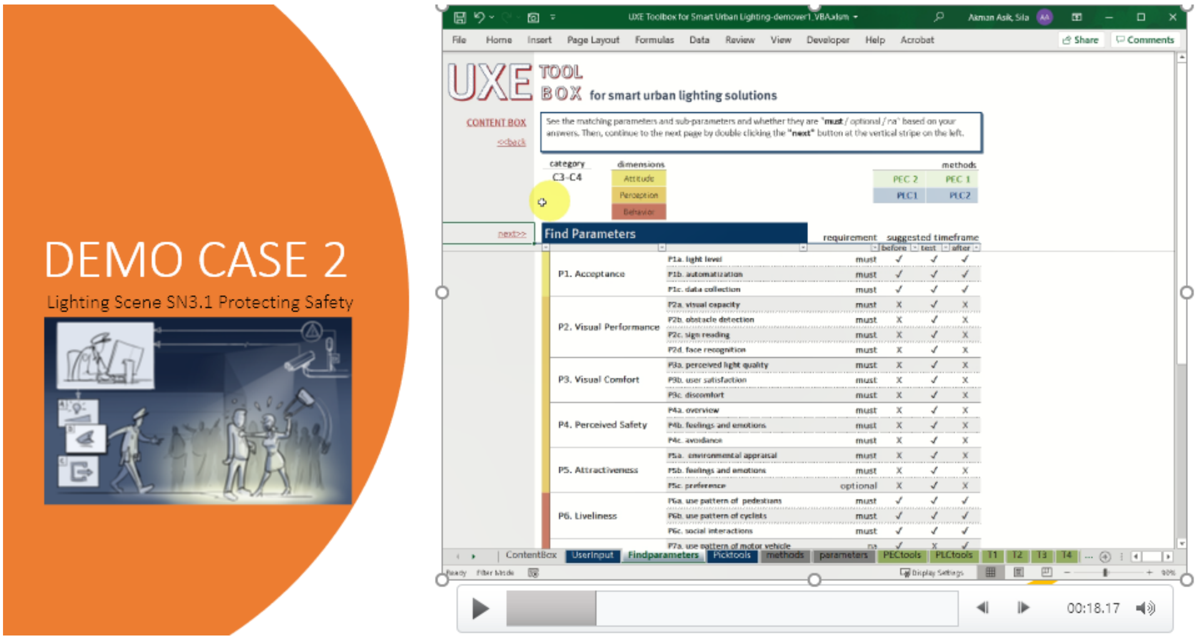


Figure 4-6: Video record of demo case 2 (deliverable 3)

4.3.2. Demo Case 3: Lighting Scene SN3.6 Inviting people to join

Creating a welcoming entrance to the square in front of the church entrance to make people aware of the activities on Sint-Nicolaasplein and to invite them to take a look and enjoy themselves. With multiple lighting, scenes highlight the higher elements of the church facade (to be seen from the marketplace) and the sidewalls of the 'entrance'. changing according to the event or the season (Valkenburg et al., 2019). For further explanation please look at the deliverable 3 demo case 3.

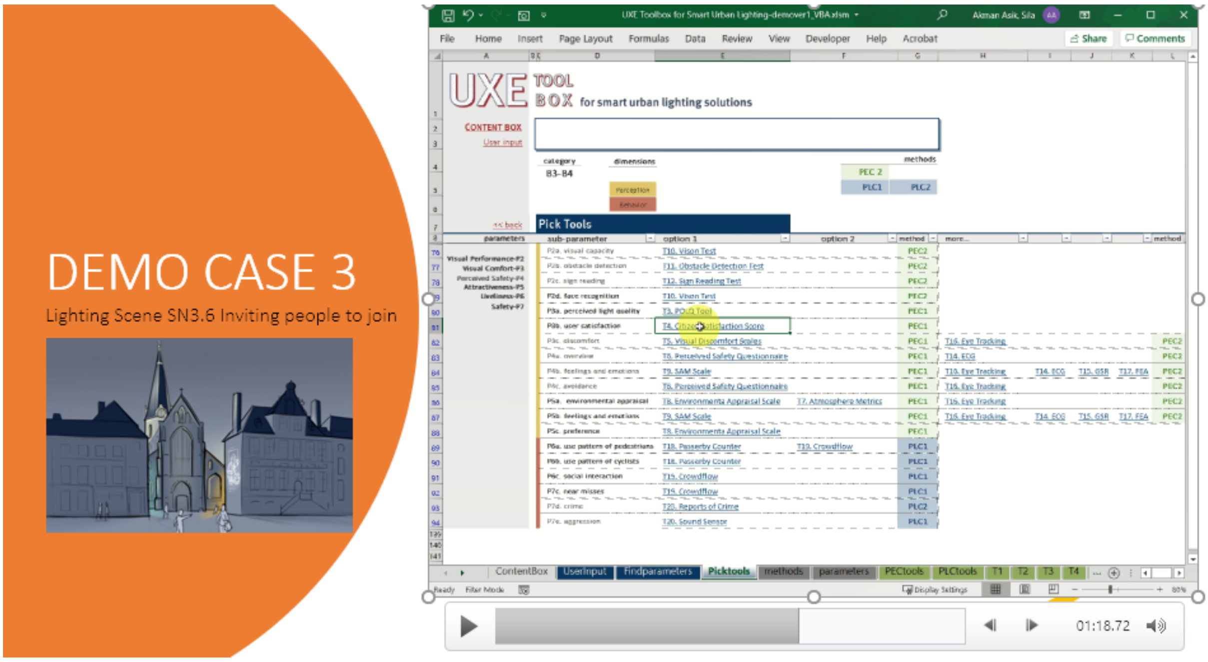


Figure 4-7: The video record of the demo case 3 (deliverable 3)

Chapter 5 Conclusion

The main goal of this project was to design a toolbox to support municipalities in finding appropriate methods and tools to monitor and evaluate their citizens' experience with the smart lighting system. The UXE Toolbox was designed prioritizing the needs of the small and mid-sized municipalities. The functional requirements were based on the relevant activities within the Smart Space Project (use-case workshops, partner meetings, and bilateral meetings) and the literature review in the field of urban lighting and environmental psychology. To sum up the design project, the functional requirements were revisited to check whether they were met as listed below.

✓ **R1:** This toolbox should be accessible for small and medium-sized municipalities

The UXE Toolbox facilitates an integrated database for guidelines, validated tools, defined parameters, and methods besides interactive worksheets on Excel. Excel is one of the most common software used in municipalities so the toolbox can easily be used by small and medium-sized municipalities.

✓ **R2:** This toolbox should define the timeframes of data collection for a systematic UXE

A measurement framework was structured for the UXE toolbox. The framework consists of two measurement categories (i.e., person-centered (PEC) and place-centered (PLC)) in three timeframes (i.e., before, test, and after) for a systematic data collection.

✓ **R3:** This toolbox should define parameters that can cover three clusters of anticipated use, four interaction levels, and three dimensions of UX.

The UXE Toolbox covers all the use cases co-created in the smart Space Project through seven parameters (i.e., P1-Acceptance, P2-Visual Performance, P3-Visual Comfort, P4-Perceived Safety, P5-Attractiveness, P-6 Liveliness, and P7-Safety) divided into 24 sub-parameters that take place under three dimensions (i.e., D1-Attitude, D2-Perception, D3-Behavior).

✓ **R4:** This toolbox should include a clear description of each parameter to be assessed

The UXE Toolbox provides clear descriptions of each parameter that can be found in section 3.2 and the 'Definitions' section on the excel-based tool.

✓ **R5:** This toolbox should include a broad range of methods and tools to collect both objective and subjective data from miscellaneous sources (i.e., users, expert observation, statistical data, sensors, etc.)

The UXE Toolbox presents 25 tools in five categories (i.e., PEC1-Self Report, PEC2-Physical and physiological measurements, PLC1-System Elements, PLC2- Statistical Data from official documents, PLC3-Expert Observations).

✓ **R6:** This toolbox should introduce the state-of-the-art technologies and methods in UX research

The UXE Toolbox included emerging technologies in UX research like biosensors (i.e. T14-ECG, T15-GSR), image processing algorithms (i.e., T16 - Eye Tracking, T17- Facial Expression Analysis, and T19-Crowdflow), and other ICT applications (i.e., T18-Passerby Counter and T20-Sound Sensor).

- ✓ **R7:** This toolbox should include a clear description of each tool.

  The UXE Toolbox presented description cards (see appendices) and worksheets for each of the 25 tools.

- ✓ **R8:** This toolbox should provide a customized UX evaluation method in line with the needs of municipalities, the interaction level, and the specific use of smart lighting systems.

  Guidelines, in the form of decision diagrams in section 3.4 and the customized selection worksheets (i.e., user input, find parameters, pick tools) in the excel-based toolbox, provides 14 different paths that covers six categories (i.e., A1-A2, A3-A4, B1-B2, B3-B4, C1-C2, C3-C4) for three UX dimensions (i.e., attitude, perception, behavior).

- **R9:** This toolbox should provide clear guidelines for municipalities to conduct case-specific UX research throughout the evaluation and monitoring process.

  The guidelines provide instructions and decision diagrams for the preparation phase as the first phase of UX research. However, they need to be expanded to cover data collection, data analysis, and evaluation phases to support municipalities throughout the whole process.

- **R10:** This toolbox should provide an overall scoring system to quantify the impact of smart lighting implementation on citizens' attitudes, perceptions, and behavior.

  The UXE Toolbox does not consist of an overall assessment function yet since the scoring system has not been completed yet. However, it is planned to be added to the Excel workbook by December 2021 within the Smart Space Project period.

The UXE Toolbox meets eight requirements out of ten as explained above. Thus, there is still room for further developments as elaborated in the next section.

5.1. Future Work

As explained in the conclusion, R9 and R10 could not be completed in this PDEng Project. Since the Smart Space Project was extended until December 2021, the missing part is planned to be finalized in these three months. The missing activities are;

- Usability test of the excel-based toolbox with the municipalities

  As the first step after this PDEng Project, the final version of the excel-based toolbox will be shared with the target users. The target users are primarily four municipalities in the Smart Space Project: Middelburg(NL), Sint-Niklaas (BE), Oostende (BE), and Tipperary(IR). The usability tests are planned to be conducted both remotely and in person.

- Field studies to test the proposed protocols for tools and methods in pilot sites

  By having the UXE toolbox as a blueprint for UX measurements for smart urban lighting, data collection will start as soon as smart lighting scenes operate in the pilot site(s). The proposed methods will be tested in real life through field studies (e.g., public opinion wall to gather citizens' acceptance and appraisals) and monitoring using system elements and statistics (e.g., user behavior in urban areas to assess the impact on liveliness and safety). Sint-Niklaas is expected to be the first pilot site, so probably it will be the testbed for the UXE.

- Testing Excel templates for data sorting and analysis through the collected data in a field study

  After the first step of the functional test in the field study, the proposed templates will be tested using the collected data.

- Scoring Proposal for the overall assessment

  A scoring framework will be prepared, and the result of the case study will be shown on an Excel Dashboard considering the scoring proposal to visualize the overall assessment of the user experience with smart urban lighting.

5.2. Recommendations

Considering the literature review conducted in this PDEng project (Chapter 2), I can state that the research in the field of smart urban lighting is still in its early stages mostly focusing on technical issues and energy efficiency. What is more, the social aspect of smart urban lighting is not on the stage yet. Therefore, I strongly recommend that future research should take the social aspects of smart urban lighting into consideration.

Considering UX measurement methods and tools, the toolbox offers at least one measurement method and tool corresponding to each parameter. However, these tools and methods are neither efficient and nor feasible for all the parameters. For example, there is a lack of innovative methods and tools to monitor social interaction (P6c), near-misses (P7c), and aggression (P7e), apart from expert observations which are time-consuming and labor-intensive. I can point out that there is a gap in the literature in this field. Thus, future research should consider this gap, and provide new methods and tools to measure the safety and liveliness of urban areas at night.

Appendices

appendix 1 T1 - Public Opinion Panel

This gathering can be organized in the field (e.g., pilot site, main square) , in a meeting room (city hall) or an online platform (i.e., Miro Board) by stimulating citizens with visual materials (i.e., maps, cards, sticky dots etc.) to share their opinion on the smart lighting.

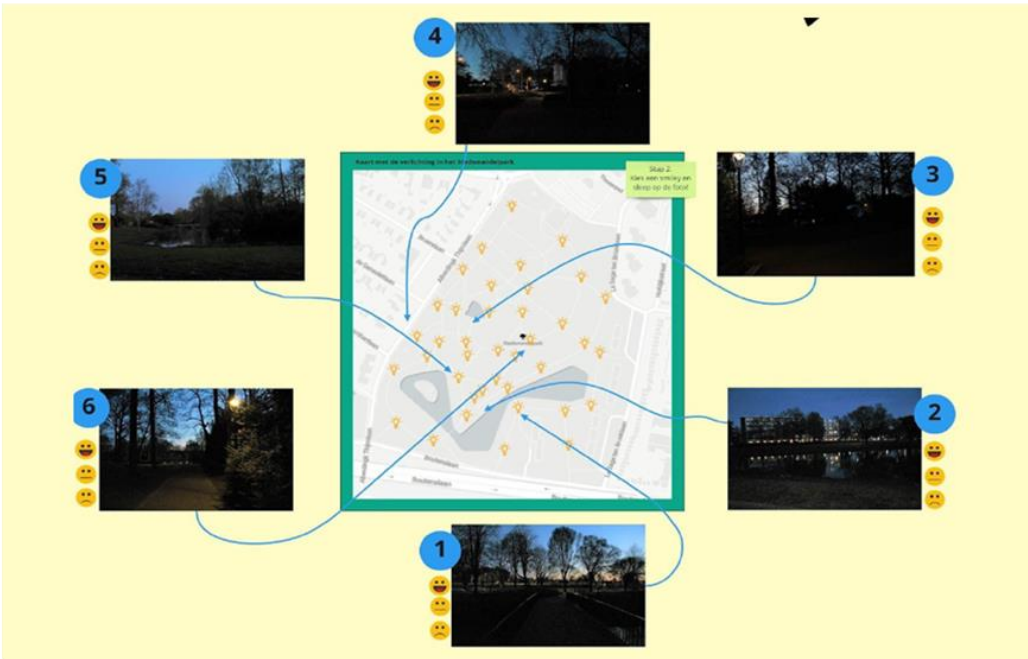
Sticky Dots (in the field)

source: Interreg Dynamic Light

Vision cards (in a meeting room)

source: lhc.org

Mapping (virtual platform)



source: Placemaking in the Park (HTI master project -group 2, 2020)

appendix 2 T2 - Acceptance Survey

T1a-Acceptance of Light Level

T2a. I am aware of the refurbishment of urban lighting in ....

strongly disagree 1 2 3 4 5 6 7 strongly agree

T2a1) The light level is acceptable in .... strongly disagree 1 2 3 4 5 6 7 strongly agree

T2a2) There is sufficient amount of light in .... strongly disagree 1 2 3 4 5 6 7 strongly agree

T2a3) There is more than enough light in .... strongly disagree 1 2 3 4 5 6 7 strongly agree

T1b-Acceptance of Automatization

T2b. I am aware of the automatic lighting control system in ....

strongly disagree 1 2 3 4 5 6 7 strongly agree

T2b1) Changing light level is acceptable in.............. strongly disagree 1 2 3 4 5 6 7 strongly agree

T2b2) Changing light color is acceptable in........... strongly disagree 1 2 3 4 5 6 7 strongly agree

T2b3) The reaction time is acceptable in .... strongly disagree 1 2 3 4 5 6 7 strongly agree

T1c-Acceptance of Public Data Collection

T2c. I am aware of public data collection through ICT in ....

strongly disagree 1 2 3 4 5 6 7 strongly agree

T2c1) Public data collection is acceptable. strongly disagree 1 2 3 4 5 6 7 strongly agree

T2c2) I find counting users acceptable. strongly disagree 1 2 3 4 5 6 7 strongly agree

T2c3) I find sound record acceptable. strongly disagree 1 2 3 4 5 6 7 strongly agree

T2c4) I find video record acceptable. strongly disagree 1 2 3 4 5 6 7 strongly agree

appendix 3 T3 - POLQ Questionnaire

(Perceived Outdoor Light Quality)

How would describe your environment in terms of lighting?

clear	O	O	O	O	O	O	O	drab
strong	O	O	O	O	O	O	O	weak
unfocused	O	O	O	O	O	O	O	focused
subdued	O	O	O	O	O	O	O	brilliant
dark	O	O	O	O	O	O	O	light
mild	O	O	O	O	O	O	O	sharp
hard	O	O	O	O	O	O	O	soft
warm	O	O	O	O	O	O	O	cool
glaring	O	O	O	O	O	O	O	shading
natural	O	O	O	O	O	O	O	unnatural

appendix 4 T4 - CSAT (Citizen Satisfaction Score)

appendix 5 T6 – Perceived Safety Questionnaire

Overview

1) How well or poorly can you see what is happening in this street?

poor 1 2 3 4 5 6 7 good

2) How good or poor an overview do you have over this street?

poor 1 2 3 4 5 6 7 good

3) How good or bad can [could] you see the objects in this street?

strongly disagree 1 2 3 4 5 6 7 strongly agree

Perceived Safety

1) I feel uncomfortable with the idea of having to walk into this street.

strongly disagree 1 2 3 4 5 6 7 strongly agree

2) I would walk down this street in a higher pace than I usually walk

strongly disagree 1 2 3 4 5 6 7 strongly agree

3) I would rather avoid this street

strongly disagree 1 2 3 4 5 6 7 strongly agree

appendix 6 T7 - Atmosphere Metrics

For each word from the list below to what extent this word applies to the **atmosphere** in ....

On a scale of absolutely not applicable to very good applicable:

	Absolutely not applicable	Hardly applicable	Not that applicable	Neutral	Somewhat applicable	Good applicable	Very well applicable
Aloof	0	0	0	0	0	0	0
Frightening	0	0	0	0	0	0	0
Stuffy	0	0	0	0	0	0	0
Threatening	0	0	0	0	0	0	0
Snugly	0	0	0	0	0	0	0
Oppressive	0	0	0	0	0	0	0
Colourful	0	0	0	0	0	0	0
Dark	0	0	0	0	0	0	0
Depressing	0	0	0	0	0	0	0
Exciting	0	0	0	0	0	0	0
Formally	0	0	0	0	0	0	0
Welcoming	0	0	0	0	0	0	0
Salvaged	0	0	0	0	0	0	0
Kindly	0	0	0	0	0	0	0
Tense	0	0	0	0	0	0	0
Sociable	0	0	0	0	0	0	0
Inspiring	0	0	0	0	0	0	0
Intimate	0	0	0	0	0	0	0
Chilly	0	0	0	0	0	0	0
Snug	0	0	0	0	0	0	0

	Absolutely not applicable	Hardly applicable	Not that applicable	Neutral	Somewhat applicable	Good applicable	Very well applicable
Vivid	0	0	0	0	0	0	0
Cold	0	0	0	0	0	0	0
Luxurious	0	0	0	0	0	0	0
Mysterious	0	0	0	0	0	0	0
Unconstrained	0	0	0	0	0	0	0
Uncomfortable	0	0	0	0	0	0	0
Restless	0	0	0	0	0	0	0
Relaxed	0	0	0	0	0	0	0
Personally	0	0	0	0	0	0	0
Romantic	0	0	0	0	0	0	0
Safe	0	0	0	0	0	0	0
Spatially	0	0	0	0	0	0	0
Soothing	0	0	0	0	0	0	0
Boring	0	0	0	0	0	0	0
Lethargic	0	0	0	0	0	0	0
Stimulating	0	0	0	0	0	0	0
Accessible	0	0	0	0	0	0	0
Hostile	0	0	0	0	0	0	0
Cheerful	0	0	0	0	0	0	0
Warm	0	0	0	0	0	0	0
Cheerful	0	0	0	0	0	0	0

appendix 7 T8 - Environmental Appraisal Survey (EAS)

Pleasantness:

P1) How beautiful is this square/street to you?	ugly................ 1 2 3 4 5 6 7 .....beautiful
P2) How pleasant is this square/street to you?	unpleasant..... 1 2 3 4 5 6 7 .....pleasant
P3) How appealing is this square/street to you?	unappealing... 1 2 3 4 5 6 7 ...appealing

Excitement:

E1) How exciting is this square/street to you?	boring.............. 1 2 3 4 5 6 7 ....exciting
E2) How lively is this square/street to you?	dull.................... 1 2 3 4 5 6 7 ....lively
E3) How stimulating is this square/street to you?	unstimulating... 1 2 3 4 5 6 7 ...stimulating

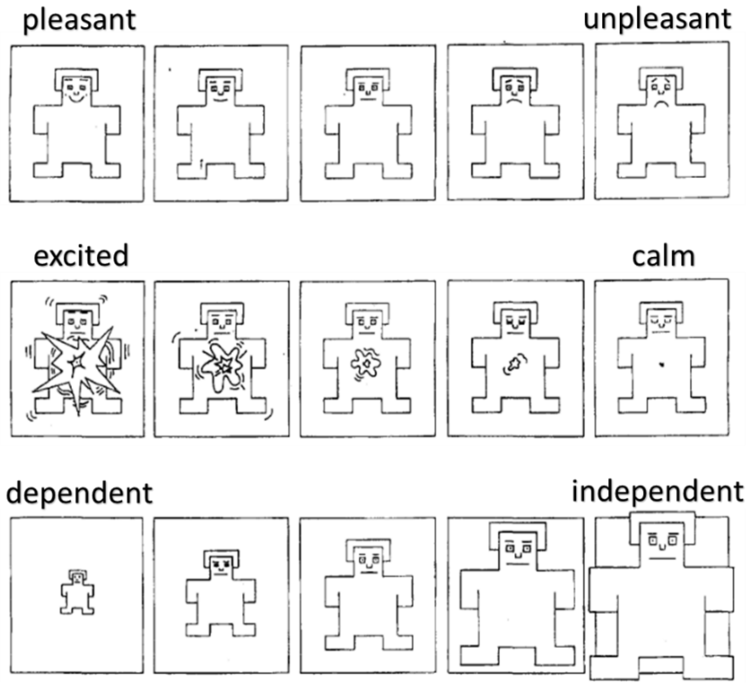
Restfulness:

R1) How relaxed is this square/street to you?	tense......... 1 2 3 4 5 6 7 ....relaxed
R2) How calming is this square/street to you?	upsetting... 1 2 3 4 5 6 7 ...calming
R3) How safe is this square/street to you?	unsafe........ 1 2 3 4 5 6 7 ....safe

Behavioral Intent:

B1) I would walk out of my way to visit and spend time in this place.	not at all... 1 2 3 4 5 6 7 ...completely
B2) I would stop at this place if I happened to be passing by.	not at all... 1 2 3 4 5 6 7 ...completely
B3) I would regularly visit this place.	not at all... 1 2 3 4 5 6 7 ...completely

appendix 8 T9 - SAM Scale (Self-Assessment Manikin)



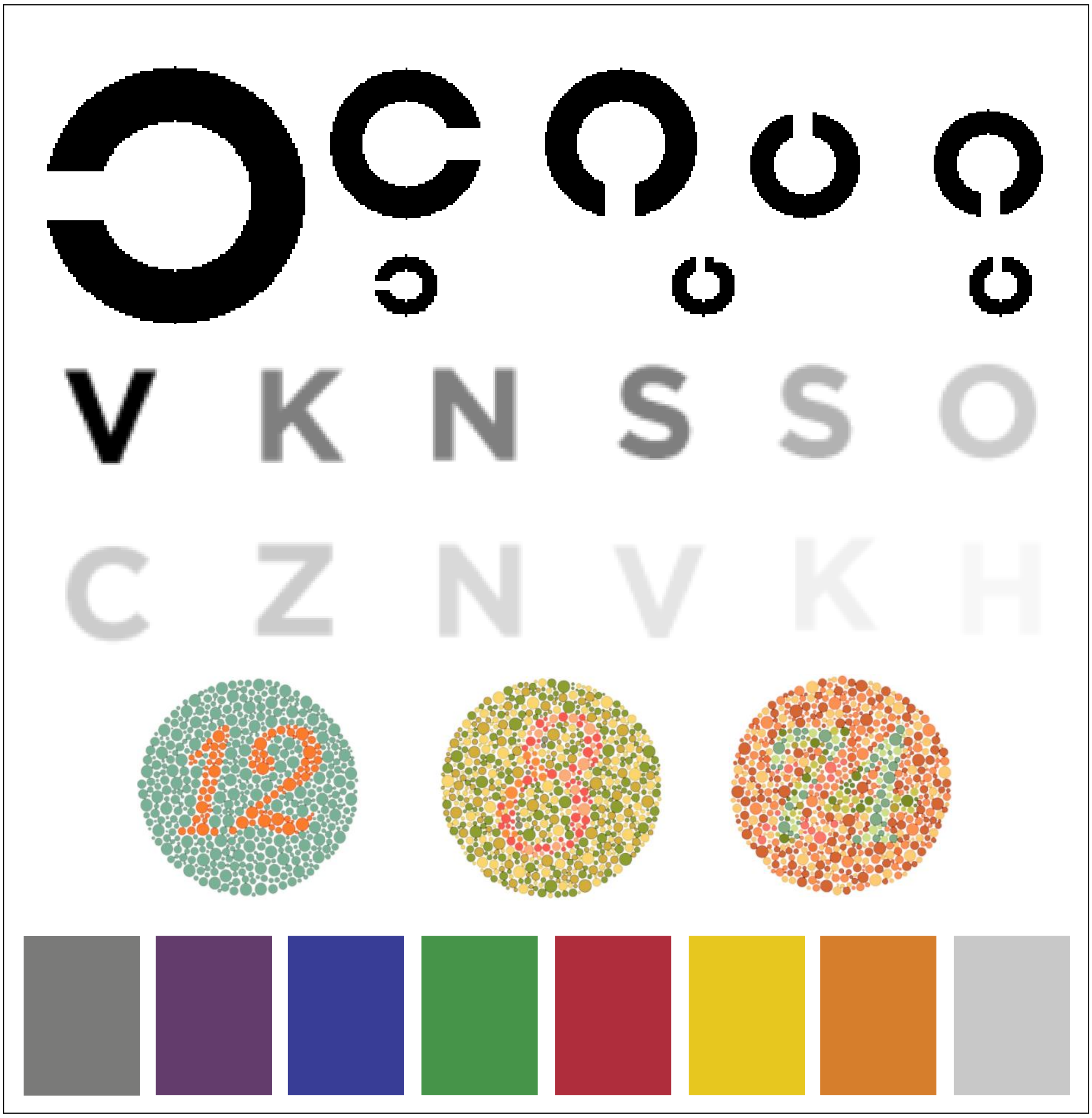
appendix 9 T10 - Vision Test

Description: It measures visual capacity under specific lighting scene using Landolt Ring Chart, Pelli-Robson Test, Ishihara Plate Color Test and Gretag Macbeth color checker

Corresponding Parameter(s): Visual capacity

Requirements: Field experiment, researcher, vision test board

Metrics: Visual acuity, contrast sensitivity and color recognition



appendix 10 T12 – Sign Reading Task

In the sign reading task, the participants are asked to walk along the route towards a street signpost* and to stop when the text on the street signpost becomes legible. Then participants are asked to give a verbal statement of the sign.

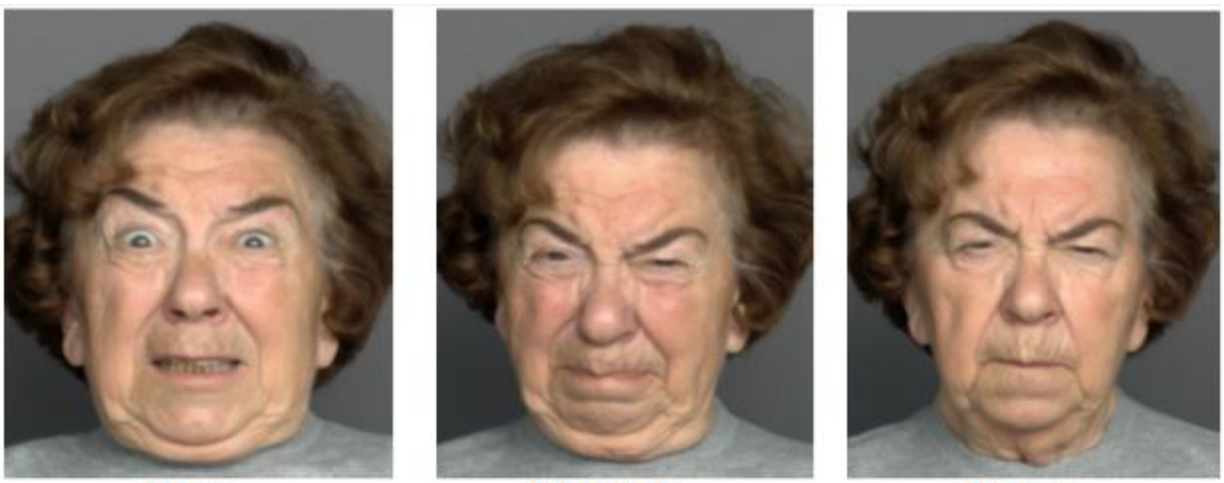
*The signpost at a height of 2.10 m is placed 4 m to the right of the route, 15 m from the starting point, and 15 m from the lampost.

attribute	M	SD	id 01	id 02	id 03
correctness of the sign	#DIV/0!	#DIV/0!			
sign reading distance	#DIV/0!	#DIV/0!			

appendix 11 T13 – Facial Recognition Task

In the facial recognition task, the participants walk along a road towards a photograph* of a woman's face placed on the right of the path 15m from the lamppost. The participants stop when they could discern the facial expression of the woman. Then, participants are asked to give a verbal statement of the perceived emotion.

*175 × 200 mm; positioned at a height of 1.65 m; printed on non-glossy paper.



Fear Disgust Anger

the FACES database (Ebner et al., 2010)

appendix 12 T14 – ECG (Electrocardiography)

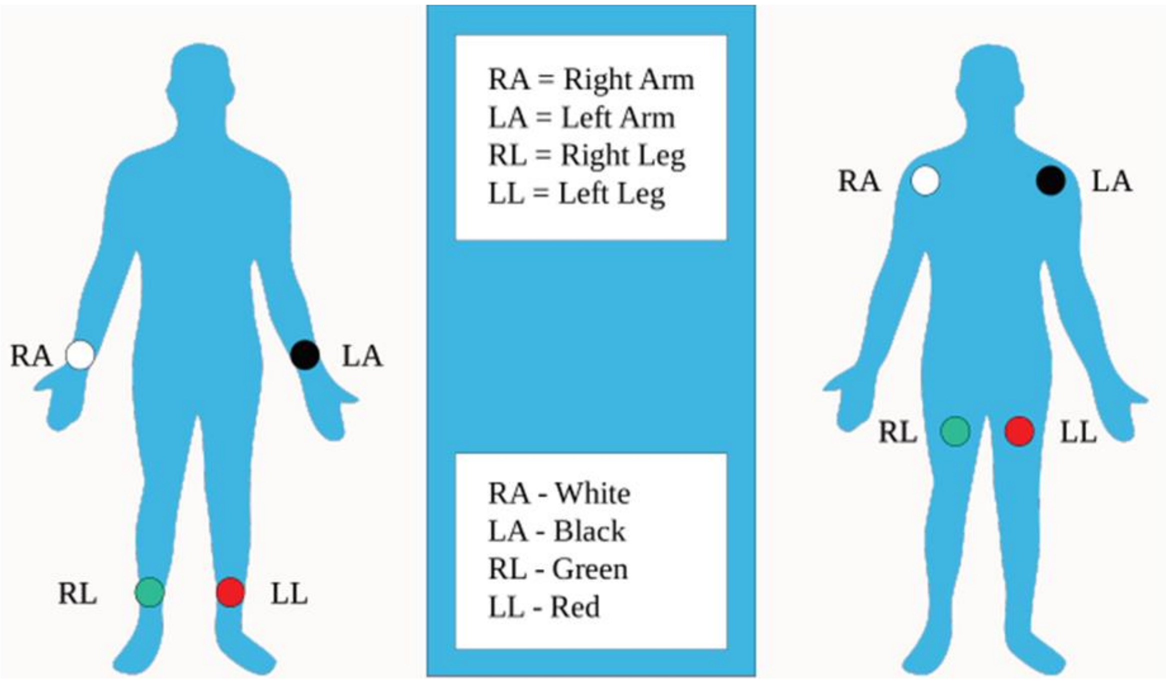
Description: ECG is ideal measures to track emotional arousal by tracking heart rate or pulse to get insights into respondents' physical state, anxiety and stress levels (arousal)

Corresponding Parameters: Visual Comfort, Perceived Safety, Attractiveness

Period of experience: Momentary, periodical

Requirements: wearable device, expert support

Metrics: Heart Rate(HR), Inter-Beat Interval(IBI), Heart Rate Variability(HRV)



appendix 13 T15-GSR (Galvanic Skin Response)

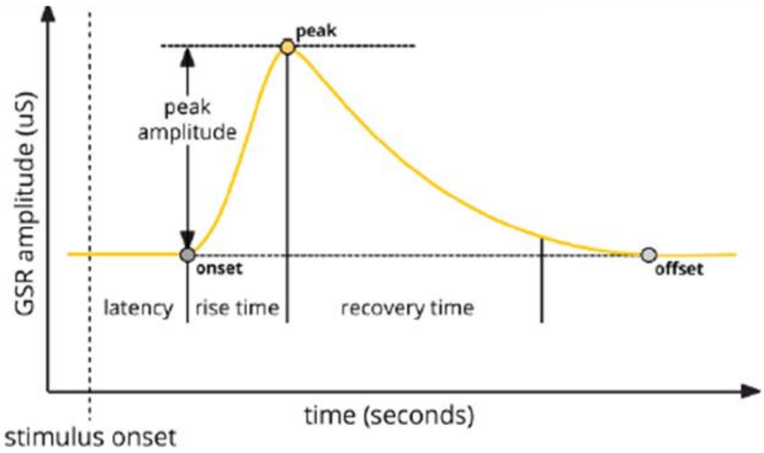
Description: GSR refers to changes in sweat gland activity that are reflective of the intensity of our emotional state also known as emotional arousal.

Corresponding Parameters: Perceived Safety, Attractiveness

Period of experience: Momentary

Requirements: wearable device, expert support

Metrics: Latency, peak amplitude, rise time, recovery time



Empatica E4 Wristband

Shimmer3 GSR+ (GSR, PPG)

BIOPAC MP150 + EDA100C

appendix 14 T16-Eye Tracking

Description: Eye tracking glasses allow objective measurements of eye movements in real-time.

Corresponding Parameters: Visual performance, Visual Comfort

Period of experience: Momentary, periodical

Procedure: One user at a time

Requirements: Special equipment and software, trained researcher

Metrics: Fixation and gaze points, heat maps, pupil size and dilation

appendix 15 T17-Facial Expression Analysis

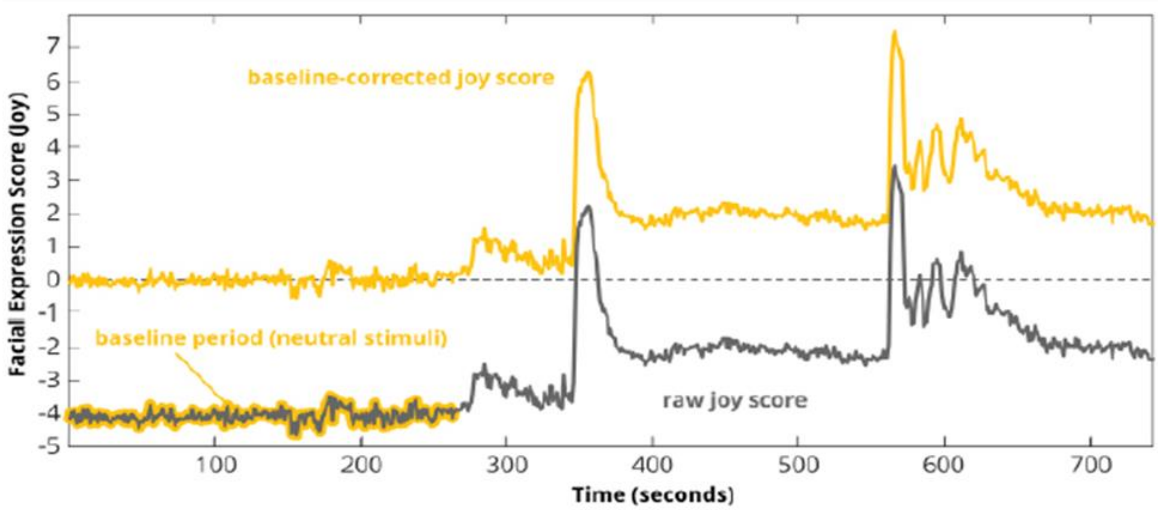
Description: It measures emotions through facial expressions by using automated facial coding

Corresponding Parameters: Visual Comfort, Perceived Safety, Attractiveness

Period of experience: Momentary

Requirements: High quality video record, software

Metrics: Facial expression, head orientation



Acknowledgments

At the very first moment of this journey when I received the news on the Enschede train, I couldn't even imagine having such a tough and unforgettable two years. No matter how tough it was, it has been a great learning experience for me. Now, while writing the final page of my thesis, I am happy to have a chance to thank all those amazing people who supported me relentlessly and helped me get there.

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To conclude, I must commemorate Ursula Le Guin and Maya Angelou with their own words: “It is good to have an end to journey towards, but it is the journey that matters in the end”

Thank you all who have *“become a rainbow in my clouds”* during this journey!