Master Thesis

Industrial design of sensor integrated lamp

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Division of Machine Design • Department of Design Science

Faculty of Engineering LTH • Lund University • 2014

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Preface

This report describes the result and process of our Master thesis at Lund University, Division of Machine Design at the Department of Design Sciences. The project was made in collaboration with Axis Communications AB at the Department of Product Concepts and New Ideas (PCNI).

We would like to thank Thomas Ekdahl head of the Department of PCNI and Carl-Axel Alm, our supervisor for the opportunity to write this Master thesis at their Department.

We would also like to thank our supervisor Per Kristav at the Division of Machine Design at Lund University.

Special thanks to Andrea Sorri, Global Business Development within City Surveillance at Axis Communications for all the encouragement and kind words inspiring us.

And thanks to Morten Bergström for sharing some expert knowledge with us in the final stage of the project.

Finally we would like to thank the rest of the colleagues at the PCNI office for input on our project and making us feel at home at the office and a memory for life.

Lund, June 2014

Anton Östberg & Henrik Lundgren

Abstract

This report is the result of a Master thesis project performed in collaboration with Lund University and Axis Communications AB. Axis Communications develop network cameras for security surveillance and the headquarter is located in Lund, Sweden.

The goal of this project was to identify an opportunity where the combination of a camera integrated in a lamp can be useful and in a development process generate a concept.

Lighting and cameras are used in a variety of environments, the first stage of the process was to gain knowledge about trends, market opportunities and segmentation within the two markets. The information was collected through interviews and reports and was used as foundation for the ideation process. The ideation process generated a primary market in streets, squares and parks, and involved creating a luminaire prepared for a camera installation in a simple and aesthetic fashion.

Concept designs were generated and screened against requirements created from information collected in the pre-study and from customer needs. One concept was chosen to further develop through tests, calculations and further design refinement.

The result is a concept for a modular street light luminaire system where focus is to increase the perceived security with a camera or other sensors and enable energy efficiency through modern and automatized lighting technology.

Keywords:
Lighting, Camera, Product development, Axis Communications, City surveillance

Sammanfattning

Denna rapport är en del av ett examensarbete utfört i samarbete mellan Lunds Tekniska Högskola och Axis Communications AB under våren 2014. Axis Communications lanserade som första företag i världen en nätverkskamera och är än idag det marknadsledande företaget inom nätverkskameror. Axis Communications ville genom detta arbete utforska var kombinationen säkerhetskamera och en lampa kunde kombineras till en gynnsam produkt.

Projektets första del utgjordes av en förstudie där både belysnings- och kameraövervakningsmarknaden studerades i avseende på trender, regelverk och segmentering. Detta utfördes genom rapporter, besök av mässor och intervjuer med nyckelpersoner inom Axis produktsegment.

Lärdomarna från förstudien analyserades och användes till att finna ett område och en tillämpning där en produkt som kombinerar en lampa och en kamera hade bäst förutsättningar för att lyckas både ekonomiskt och funktionsmässigt. En idégenerering baserad på områden där den tänkta produkten skulle vara gynnsam utfördes genom brainstorming och workshops i grupp. De genererade idéerna viktades och gallrades sedan genom ledord som valts ut utifrån förstudien och uppdragsbeskrivningen från Axis Communications. Processen ledde till att områdena gator, parker och torg valdes som det tilltänkta segmentet för produkten. Genom diskussioner inom företaget ansågs störst möjligheter finnas i att tillverka en armatur anpassad för stolpinstallation. En uppdragsbeskrivning skapades som användes som ett ledande dokument i den fortsatta utvecklingen.

Vidare genomfördes en kundundersökning riktad mot kommuner i Sverige, där ytterligare information och trender inom utomhusbelysningsmarknaden sammanställdes och analyserades. Med informationen från analysen tillsammans med förundersökningen kunde en lista av krav på produkten skapas som användes för att utvärdera och välja framtida koncept.

Konceptgenereringen delades upp i två delar: teknik och design. Teknikdelen beskriver hur produkten ska kunna anpassas till den infrastruktur som råder tillsammans med en jämförelse mellan olika belysningstekniker och kommunikationsteknik. Ett koncept för en systemarkitektur togs fram där de individuella LED-lamporna (Light-Emitting Diode) och kamerorna kan styras via

trådlös eller trådbunden teknik och automatiskt ställa in belysningsnivå baserat på omgivningsljus och närvaro med hjälp av teknik från kameran.

Designdelen av konceptgenereringen gjordes genom workshops med företaget och skisser. Ett antal av de framtagna koncepten valdes vidare till två utvärderingar baserade på krav som framtagits tidigare i processen, efter de två gallringarna återstod två koncept. Ett modulärt koncept där ett flertal av Axis olika kameror skulle kunna placeras i centrum av en cirkulär armatur med stag som fäster armaturen mot stolpen. Det andra konceptet baserades på en cirkulär kona placerad under belysningen, infäst mot stolpen. I konan skulle upp till fyra små diskreta kameror kunna placeras vilket renderade ett stort synfält. Efter vidare utforskning av de två koncepten genom beräkningar och CAD-underlag, bestämdes att det modulära konceptet skulle väljas vidare.

Det valda konceptet utforskades vidare genom att en testrigg konstruerades där tester angående kameravinklar och eventuella blädningsproblem kunde utforskas ytterligare för att få större en förståelse för vissa designparametrar. Dessa tester analyserades och bidrog till att vissa designparametrar kunde övervägas. Dessa togs med i formstudier för hur konceptet skulle utformas för bästa funktionalitet. Formstudierna utfördes med enkla skissmodeller och skisser där en känsla för hur vissa vinklar och former på armaturen kunde ge olika intryck. Ett designkoncept togs fram där två stag bestämdes skulle hålla uppe konstruktionen, en utbytbar mittplatta i konstruktionen för olika kameror och toppdelen av konceptet är en avtagbar del för enkel installation och underhåll av utrustningen. Konstruktionens hållfasthet validerades med hjälp av en FEM-analys avseende krafter från vind och självsvängning.

Resultatet av arbetet är en produkt i ett konceptstadie där fördelarna av produkten återges av att det blir en enklare och snyggare installation av en kamera i en stadsmiljö. Detta kombinerat med att kunna erbjuda en helhetslösning för ett belysningssystem där fokus riktas på att öka den upplevda tryggheten med en installerad kamera och möjliggöra energibesparing genom modern och automatisk belysningsteknik.

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1 Introduction

This chapter gives the reader account for what this project is about, why it came to interest to Axis Communications, a short background of Axis as a company and the aims and delimitations of the project.

1.1 Background

In many surroundings there is a need of both lighting and camera surveillance. A camera requires good lighting conditions to be able to capture proper content, often camera installations require extra lighting installations to create good light conditions for the camera. Hence, this both increase the time and cost aspects of an installation, as well as it many times renders the installation less appealing aesthetically, figure 1.1. This project investigates if there is a beneficial combination of a product combining a lamp and camera.

Figure 1.1 Unaesthetically examples of camera and light installations

1.2 Collaboration between departments

Axis has chosen to divide this project into two different parts; this thesis that is about the product development, considering technical and aesthetical aspects of a product combining a lamp and a camera. The other part covers the economic aspects, can such a product generate money for the company and would the product fit into the Axis sales channel and business model. That project is written by Nina Gustafsson and Michaela Kamp of the Technology management program at Lund University. Considering there is no decided environment or application for the product in the brief from Axis, the authors of the projects decided it was desirable to cooperate in the research for potential environment and application. This would ensure that Axis ended up with two projects striving for the same result and not a product with no market or vice versa.

1.3 Axis Communication AB

Axis Communications is a Swedish-based company founded 1984 in Lund, Sweden. In 1996 Axis developed and introduced the industry's first network camera. Today Axis is the marked leader in network camera technology. Axis camera application platform is an open Application Programming Interface, enabling third parties to develop and install applications on Axis products. The company does not have any production of its own, but relies on contract manufacturers. Axis products are installed in multiple public surroundings as airports, highways, universities, casinos, banks and retail stores. Axis offers a wide portfolio of network cameras, from small bullet cameras to large PTZ cameras enabling pan, tilt and zoom capabilities, figure 1.2. [1], [2]

Figure 1.2 From left to right: Covert P12 camera, fixed dome camera and a PTZ camera.

1.4 Aims and delimitations

The aim given by Axis Communications for this project was to develop a product that combined a lamp and a camera into one product. The aims included:

- Investigate possible mounting places and environments
- Study technical requirements for the lamp.
- Study technical requirements for the camera
- Study lamp technologies
- Make a design (designs) for the lamps/cameras in 3D CAD
- Investigate and test suitable materials for the design
- Manufacture prototypes using 3D print technologies

The project will keep to the existing line of Axis cameras, no new camera design will be developed.

2 Method

This chapter describes the method used in the project. Methods are inspired by Product Design and Development by Ulrich & Eppinger [3] and Vilda ideér och djuplodande analys by Jan Landquist [4].

2.1 Project plan

To fulfill the requested result in a reasonable time period a project plan will be created, see Appendix A. Some checkpoints will be set to make sure that the project is running smoothly and that the goals will be reached. Appendix A also contains the distribution of work between the two authors.

2.2 Pre-study

Understanding of the market for a new product is fundamental in a product development process. A pre-study will therefore be performed to acquire this knowledge. This study will be divided in three categories the lighting market, the surveillance market and the combination of the two. The key point with this is to identify trends and technologies on the market today and regulations from governments and the European Union. A patent search will also be conducted to see what products are already on the market or yet to come.

2.3 Opportunity identification

In this phase the primary market will be identified. This will happen in collaboration with Nina Gustafsson and Michaela Kamp the Master thesis students working with the economics and the business plan.

2.3.1 Ideation

An ideation will be conducted on the premise to find which environment and application the combined product could be useful. All of these ideas will then be reduced in steps by using the *idea inventory* [4 pp. 80-82] and reducing the alternatives through analytic hierarchy process and other evaluation models.

2.3.2 Mission statement

The previous work will generate a mission statement that will be used as a base for the continued development process. This will include product description, benefit proposition, key business goal, primary and secondary market, stakeholders and assumptions and constraints.

2.4 Concept development

Concept designs will be generated based on the ideation and mission statement, one or several concepts will be selected for further development.

2.4.1 Identify customer needs

The customer needs will be identified by utilizing the knowledge gained from the pre-study and from gathering information from potential customers.

2.4.2 Product requirements

The customer needs will be concretized in a list of product requirements that help design and engineer the product.

2.4.3 Concept generation

A number of concepts will be generated through sketch sessions, workshops and inspiration from mood boards.

2.4.4 Concept selection

The generated concepts will be evaluated through concept screening and concept scoring, and one or several concepts will be selected for further refinement.

2.5 Concept refinement

The selected concept will be refined through computer aided design, calculations, choice of material and manufacturing.

2.5.1 Prototype

The refined concept will be visualized as a 3D printed prototype.

3 Pre-study

To get an understanding of the market a pre-study has been carried out, divided into three different categories, the lighting market, the surveillance market and a combination of the two. This was to identify trends, technologies and regulations within the different segments. Information was gathered through reports, interviews and fairs.

3.1 The lighting market

To be able to compete with a product on the lighting market, an understanding of the market, its segmentation and trends is crucial. Two reports were used as the foundation of the lighting market analysis, *Lighting the way - perspectives on the global lighting market*, McKinsey & Company [5] and *Advanced lighting market insight: Overview & segmentation analysis*, Cleantech Group LLC [6].

3.1.1 Trends

The general lighting market is growing and has an expected compound annual growth rate (CAGR) between 2011 and 2016 of 6 percent and 3 percent between 2016-2020, making it a €83 billion market by 2020. [5, figure 5]

LED in particular and other energy efficient technologies show immense growth in the coming years [6, p. 7]. LED lighting is expected to increase with an expected CAGR of 45 percent between 2011 and 2016 and 15 percent 2016 to 2020, taking the leading position against traditional energy efficient technologies at 2016 [5, pp. 21-22].

Three key drivers push the adoption: policy, high energy-use markets and basic economics.

Subsidizing the price of energy efficient types of lighting and regulations from governments fuels the penetration of energy efficient lighting, e.g. the European commission's eco design directive which considers requirements for energy-related products. [6, p. 7], [7], [8]

High energy use markets are early adopters of efficient technologies since operational and maintenance cost make up a significant part of lightings lifetime, see figure 3.1.

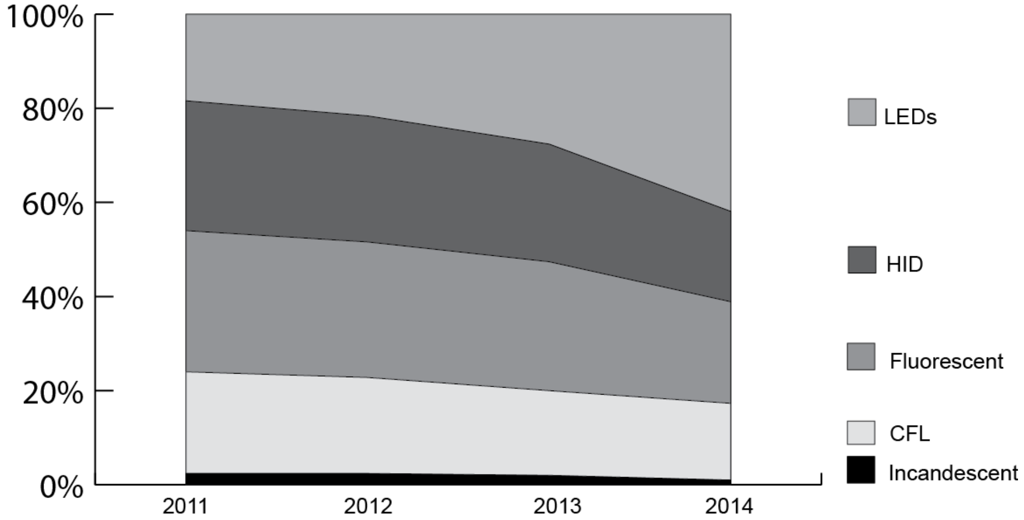

Figure 3.1 1 Lighting market penetration in Industrial & Outdoor segments [6, p. 9]. LED, Light Emitting Diode. HID, High-Intensity Discharge lamp. CFL, Compact Fluorescent lamp.

The LED penetration of the market is also driven by the reduction of prices of LED technology, predicted to drop 13-14 percent annually between 2010 and 2015 [5, p.18].

Intelligent or smart lighting is another trend that is noticeable within the lighting market. The idea is that a sensor, software or a combination of them control the lighting conditions based on daylight or occupancy and reduce the energy consumption. This is a rather common system used in office surroundings but the technique is spreading towards outdoor environment. The city of Oslo in Norway has an ongoing project with intelligent street lighting were 7,500 luminaries with intelligent lighting has been installed [9, p 35]. The city of Jönköping, Sweden have installed luminaires with proximity sensors in a park called Liljeholmsparken and are currently evaluating how it affect energy consumption, perception of security and the usage of the area [10]. Lighting control system is expected to have a CAGR of 18 percent between 2011 and 2020 with expected market value of €7.7 billion by 2020, see figure 3.4 [5, figure 22].

3.1.2 Segmentation

The lighting market is usually divided into a number of sub segments; Mckinsey & Company divides it into residential, office, shop, hospitality, industrial, outdoor and architectural [5]. The market size (EUR billions) and CAGR for each segment can be seen in figure 3.2.

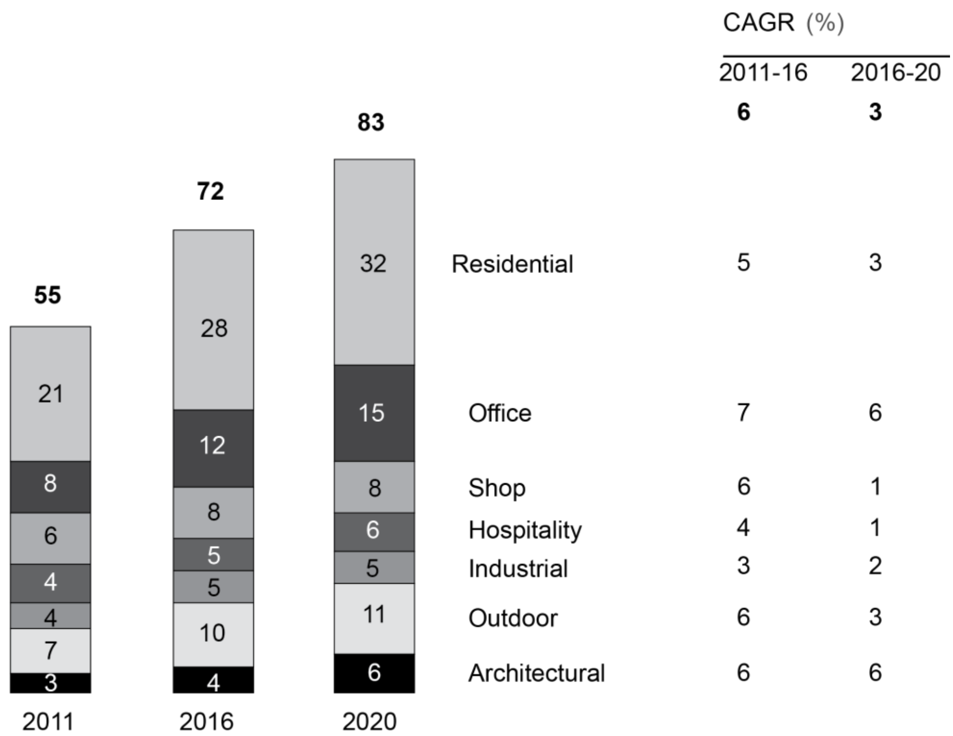

Figure 3.2 Market size and CAGR in the general lighting market [5, figure 13]

Residential is the largest market with almost 40 percent (2011) as can be concluded from figure 3.2. It is also the largest in number of sockets but has the lowest energy consumption, figure 3.3.

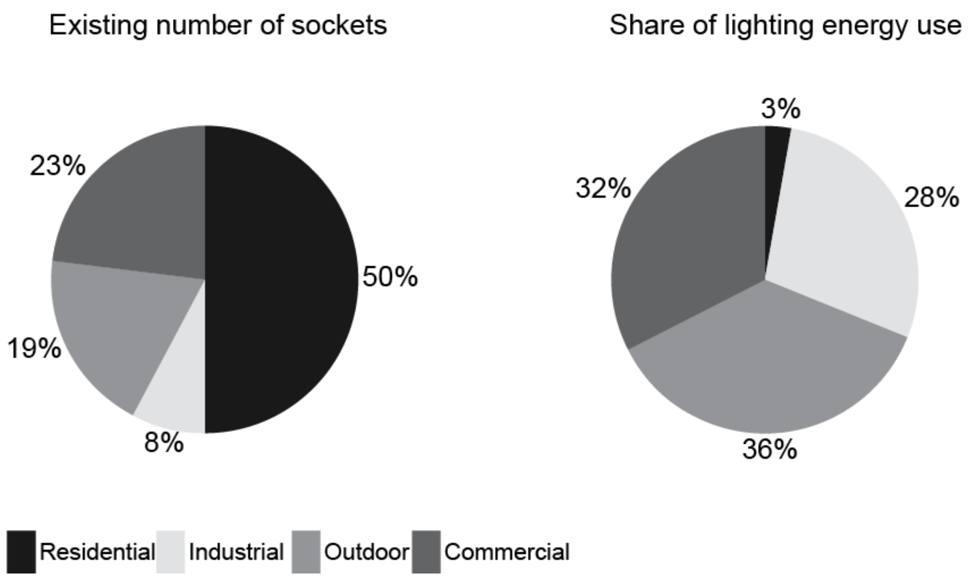

Figure 3.3 Global numbers of sockets and energy use by lighting segment [6, p 5]

Office is the second largest market in general lighting and accounts for more than 15 percent (2011) and is expected to have the highest CAGR the coming years. Fluorescent lighting technology is dominating this market, making it difficult for other high efficiency technologies to break ground. Another issue with new technology within the office segment is that maintenance is managed by someone else then the tenant or owner of the facility. Resulting in the purchase of lighting and potential energy savings fall into different pockets.

The outdoor market is highly exposed to decision making from municipality and government and thereby more influenced by public policy interventions [5, p 24]. The energy use per socket within the outdoor and industrial segment is much higher than other segments. The industrial segment already features technologies with high efficiency performance but at high power per socket, where the outdoor segment has a high percentage of old technology [6, p 5].

When investigating the lighting control system market the biggest market is expected to be office with €3.3 billion. The other segments expected market share and the CAGR can be seen in figure 3.4.

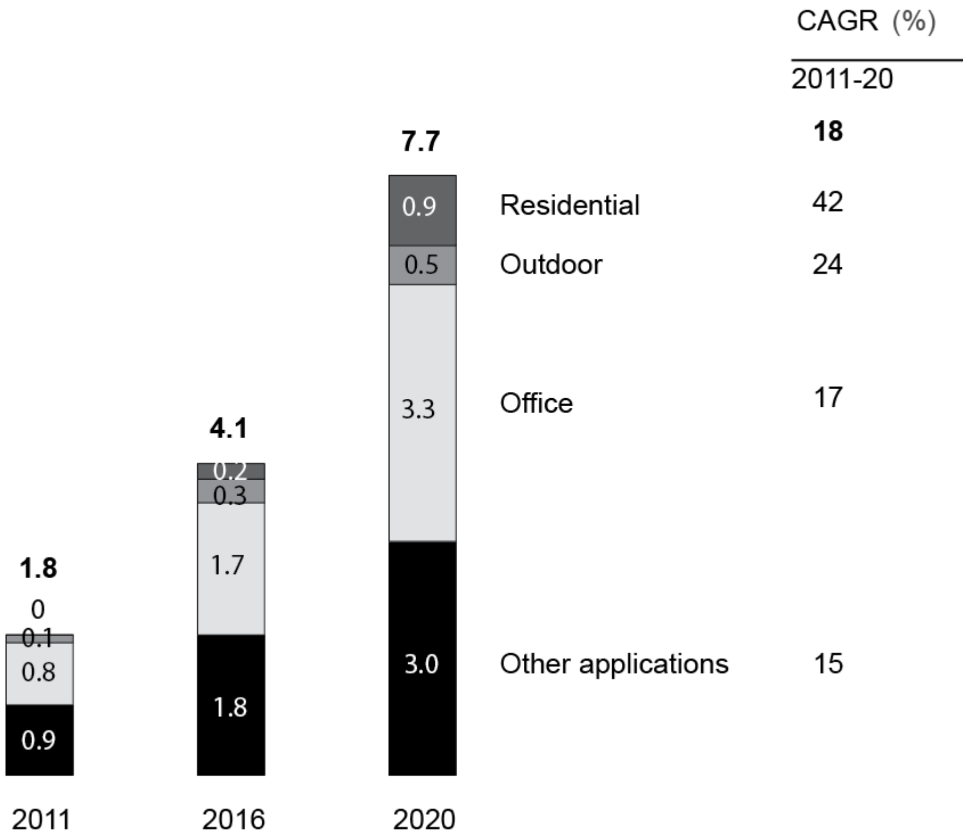

Figure 3.4 Lighting system control components [5, figure 22]

3.2 The surveillance market

The trends within the surveillance market are something Axis Communications naturally is monitoring very closely. Information about the market is therefore gathered through interviews with Axis employees and information inside the company together with the report *The world market for CCTV & video surveillance equipment*, IHS Inc. [11].

3.2.1 Trends

The market of video surveillance is forecast to grow at a CAGR of 13 percent from 2012 until 2017. Network video products are estimated at a CAGR of 22 percent over the same period of time, meaning that 57% of total worldwide security camera sales will be network cameras by 2017 [11]. When more and more cameras are being deployed the amount of information gathered has created a need for video analytics. The analytics can be real-time events that for example can identify motion or to help search for a person with a certain description or a car with license plate recognition. One major obstacle with this technology is that it has not matured enough. Motion detection for example generates a lot of false alarms due to sensitivity for snow, rain etc. and human verification are still necessary in critical applications.

3.2.2 Segmentation

Just like the lighting market the surveillance market is segmented. The segments from the IHS report were analyzed and sweet spots identified. Due to restrictions in publication the numbers cannot be presented but will be considered in future decisions.

3.2.3 Interviews

Three interviews were conducted with key employees within Axis business development.

- Andrea Sorri, director Global Business Development - city surveillance
- Patrik Andersson, director of Business Development - transportation
- Johan Åkesson, director of Business Development - retail

The interviews were conducted through open questions regarding trends, problems and the future within their segment and also if and how a combined camera and lamp product would fit the market they are responsible for, see appendix B for the complete set of questions.

Andrea Sorri was interviewed two times during the time of the pre-study. This text summarizes the two interviews. Andrea mentioned that it is popular within his segment - city surveillance - to talk about *smart city/safe city* and social media connecting with safety and cameras. Lamp manufacturers are also trying to cooperate with camera manufacturers to get cameras to blend in with the lamp at the moment.

When it comes to a product combining a lamp and a camera Andrea Sorri's view is that cameras should be placed where the infrastructure is, if the target is light poles - use existing poles. In the future, poles will be the main support for cameras.

The lamp need to be intelligent, it is easier to get into the trends of the lamp, optimizing the lamp with features like power on when passing by. *"You can look at the camera as the brain of the lamp, the beauty of the ship".* A public camera is a service of the citizens, not to control people. He also mentions that the camera should be discreet, not hidden.

Installers could be a problem for such a product; they need to be trained or scaled up to install a camera and not just lighting equipment. In the city surveillance segment it is important with a side angle from the camera, not just a top down view.

In the interview with Patrik Andersson he pointed out that his customers have high demands on certification, life-span and quality of the product. He said that Gothenburg have come far in lighting and cameras in the transportation segment, especially traffic light. He thinks that the product could be interesting in railway depots which have big problems with vandalism that costs millions. The product should be mounted on a pole and be a part of a bigger system where every luminaire works as a guard that detects trespassers. For this application he doesn't see the need for a camera, the detection could be done with a PIR (Passive Infrared) sensor. For surveillance cameras he mentions that airport is an interesting market since the regulations forces them to upgrade their system every 8 years. To create a sense of security the camera needs to be noticeable and can't be hidden. In general Patrik Andersson sees a lot of problems with the combined product in the transportation segment, but adds that street light is a possibility.

In Johan Åkesson's segment the customer have very different needs when it comes to discreet installations. It varies from very discreet ones in luxury retail to high visibility in big retail stores. The trend in retail is that the camera is being used for more than surveillance. The camera can help in marketing, counting people in stores, visualize the flow of people through the stores etc. This development is being pushed by the fact that cameras are getting more and more functions. He also thinks that cameras will be specialized for different purposes. The combined product will only fill the purpose of being a carrier for the camera and won't add anything else. On a direct question to implement a light control system in the product he thinks that it could be interesting. The combined product have been discussed on Johan Åkesson's department and initial contact were made with two luminaire manufacturers for a collaboration but it fell through and he don't know why. When asked about developing a product mounted on a pole he thinks it's a better idea since it's a natural carrier for the camera and will reduce installation cost significantly.

3.3 The combined market

A benchmark was conducted to see if products which combined a lamp and a camera in one product already existed on the market. The outcome of the search was moderate, and the search was extended to include lamps defined as intelligent lighting, indoor as well as outdoors.

The products were positioned in a number of product positioning matrices with different parameters on the two axes, figure 3.5 [12].

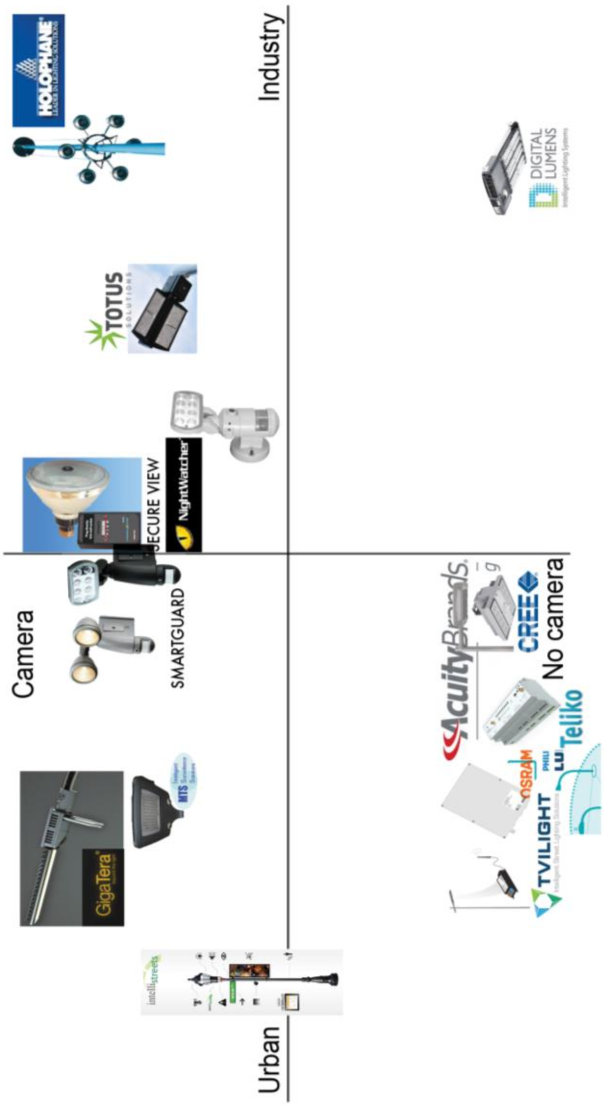

Figure 3.5 Product matrix comparing products between environment and existence of camera

Most of the products combining a camera and a lamp were aimed towards industry or the home user. Only a few products could be identified as products suited for an urban environment, and the aesthetics reminded more of a product suitable for the industry. Most of the matrices were difficult to conclude any significant outcome of, but can be seen in appendix C.

3.3.1 Patents

An attempt to find patents regarding a product combining lighting and a camera resulted in a number of patents. Most of which concerns outdoor fixtures with a covert camera mounted inside. The following patents were examined further, see table 3.1.

Table 3.1 Patent search

Name	Patent number	Date of patent
Covert security camera within a lighting fixture	US 8,622,561 B2	Jan 7, 2014
Lighting fixture with a covert security camera	US 6,259,417 B1	Jul 10, 2001
Cobra head streetlight fixture surveillance system	US 8,382,387 B1	Feb 26, 2013
High power led light having an integrated security video camera for street lighting	WO2012177113 A1	Dec 27, 2012
Outdoor lighting fixture and camera systems	US 2014/0078308 A1	Mar 20, 2014
Lamp with integrated camera	EP 2 618 051 A1	Jul 24, 2013
LED street lamp with security monitoring function	CN201401686 Y	Feb 10, 2010
Street lamp	US 2009/0185376	Jul 23, 2009
Spotlight with security camera	US 8,599,254 B2	Dec 3, 2013

Most of these patents had the form factor of a cobra head fixture and were very general in terms of where and how to mount the camera and light source. The focus was on the combination and a flow chart of the interaction between the parts.

4 Opportunity identification

This chapter describes the process of defining the intended segment for the product. Based on the collected information from the pre-study, multiple ideas and possible environments were generated. The number of ideas and environments were then narrowed down and a mission statement was written and was used as guidance for the future development of the product.

4.1 Ideation

The first step was to identify a lot of ideas where cameras and luminaires are installed, see step one in figure 4.1.

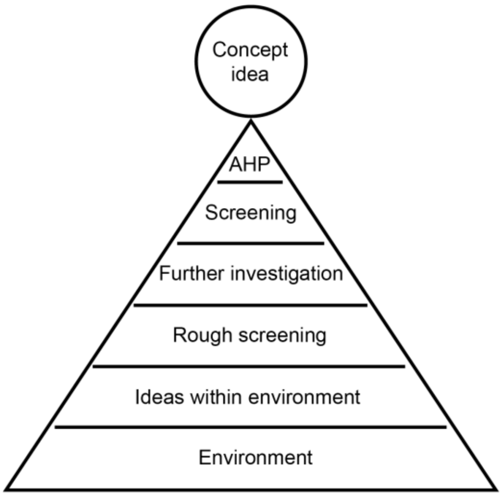

Figure 4.1 Idea inventory [4 p. 80]

These were done in brainstorming sessions in collaboration with the two Master thesis students of Technology Management. The ideas were then grouped together based on similarities in installation environment or end user, a total of 19 groups was identified. For each mounting place ideas were generated on how to use the combination of a lamp and camera and what kind of features and function the product could have. An example of this can be seen in figure 4.2.

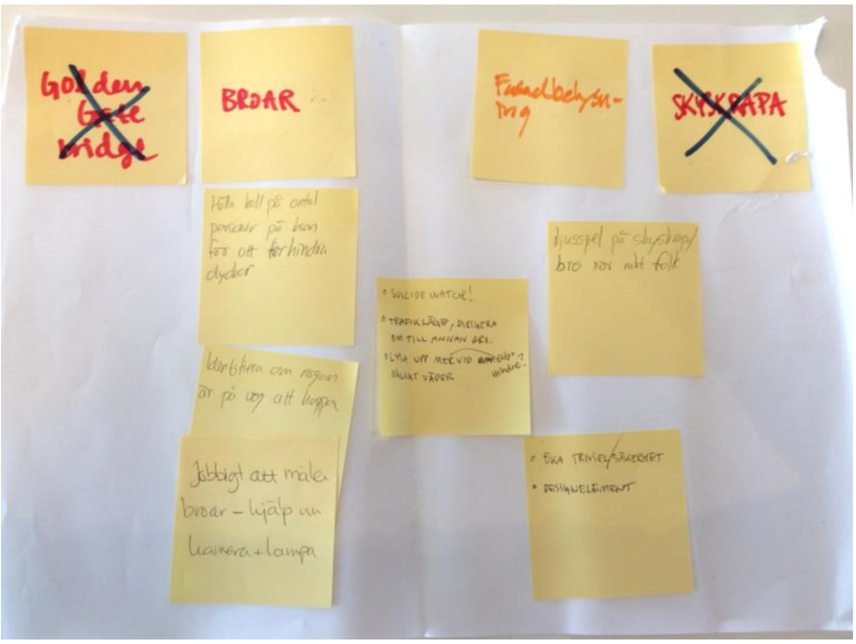

Figure 4.2 Brainstorming environments and ideas

All these ideas were on a conceptual level and were a broad exploration of defining the product. At this point some of the ideas were crossed off because the need of the product could not be identified or that the application would be to narrow. This left 10 realistic concepts that had been identified.

1. *Bridges* - identify accidents on the bridge, automatic control the light depending on the weather and traffic situation.
2. *Streets, squares and parks* - adapt the light after presence of people and light condition, city surveillance.
3. *Agriculture* - Crowd control of the animals.
4. *Fitness facilities* – Interactive training facility using light and cameras.
5. *Campus* - SOS-button, surveillance, light.
6. *Private homes* - Light with motion detection for garage door or entrance.
7. *Parking lots* - Detect burglary, guidance to free parking lot, automatic payment through license plate recognition.
8. *Amusement Parks and casinos* - Guidance with light, light shows, crowd control.
9. *Mobile solutions* - For festivals and other similar events where crowd control only is needed for a limited time.
10. *Petrol stations* - Payment with license plate recognition, identify and illuminate cars that don't pay, identify gas leakage.

To make sure that no application or possibilities were missed, concepts were once again generated for these 10 areas. But no more interesting ideas that were worth further exploration were found.

4.2 Further investigation

The remaining 10 concepts were then screened using two parameters, market size and if the combination could be useful, table 4.1.

Table 4.1 Screening of ideas.

Parameter/Concept	1	2	3	4	5	6	7	8	9	10
Useful combination	x	x	x	x	x	x	x		x	
Market size		x			x	x	x	x	x	x

To decide which concept to pursuit of the remaining five the scoring method Analytic Hierarchy Process (AHP) was used [13]. To do this evaluation a list of criteria's were defined by using the knowledge gained from the pre-study, interpretation of the brief from Axis and the function analysis that had been produced, see appendix D. The criteria's were then prioritized according to the AHP method.

1. Increase perceived security
2. Simplify camera installation
3. Value to remotely control the concept
4. Value of aesthetics
5. Reduce energy consumption
6. Increase actual security
7. Recyclable

The result of the AHP can be seen in the list below. For a more details of this scoring see appendix E.[1]

1. Streets, squares and parks
2. Mobile solution
3. Private homes
4. Parking lots
5. Campus

[1] An error was identified in the AHP calculation afterwards rendering Mobile solutions as the actual winning concept. It had no actual effect on the result although considering the result was discussed and the chosen concept was based on the discussion.

The result of the AHP were discussed whether the team had been biased and preferred the winning concept. This resulted in all five concept were kept open and retail were added as an alternative after an interview with Johan Åkesson. A workshop with the PCNI department was organized to get perspective on the different concepts from another perspective. This made it possible to cross off private houses and the mobile solution. Private houses since Axis does not focus on products for private consumers and the mobile solution because the need for it to be aesthetically appealing compared to the other remaining concepts could not be seen. Streets/squares/parks and parking lots were outdoor applications and this market is according to the pre-study where LED will have the biggest penetration and therefore will drive the change of luminaires. When this were compared with retail that is predicted to have a low exchange rate because of its high use of fluorescent luminaires that easily can be retrofitted with energy efficient T5 fluorescent tubes. The extra iteration made it possible to conclude that the right primary market for this product were streets, squares and parks since the gap to the remaining where significant and the parking lots and campus could be secondary market since the product also could be fitted there.

4.3 Preliminary design concepts

Once the environments were decided three different development strategies were identified as interesting to pursuit. The reason for this was to define the product even further so Nina Gustafsson and Michaela Kamp could develop a go to market strategy for the product. This should also make it easier to define a mission statement. The three alternatives that were identified were:

1. *Standard* - By creating a market standard luminaire manufacturers can design their own luminaire and leave a predefined room for the possibility to install a camera inside.
2. *Add-on* -Design a camera housing that fits between the pole and luminaire. This will make it possible to retrofit new camera installations in old street lighting.
3. *Luminaire* -Design a luminaire that provides both light and the possibility to install a camera.

The first alternative was dismissed since axis would become a passive partner in such arrangement and depend on the interest of the luminaire manufacturers to promote such a product. The second alternative was assessed to be too far away from the original brief but still interesting for another project. This left the design of a luminaire which make it possible to create an interesting integration between the camera and the lamp. This also have the biggest potential in creating revenue since the luminaire needs to be replaced when the light source technology is replaced by LED.

The installation place for a luminaire in the outside segment varies a lot. There are wire, bollards, high poles next to roads, low poles in parks, wall mounted etc. According to Andrea Sorri poles will in the future be the main support for cameras and Johan Åkesson also believe pole would be the natural carrier for this product. The future development was therefore focused on developing a luminaire to install on poles.

4.4 Mission statement

At this point all the information needed to create a mission statement were obtained. This document cleared out a lot of the questions about the project and gave a more clear definition of the product for further development.

Table 4.2 The mission statement

Product description	• IP camera compatible street light luminaire for pole installation
Benefit proposition	• *Ease of camera installation* • *Cheap installation of camera* • *Aesthetically appealing installation of camera* • *Increase safety/security* • *Decrease the costs and time for maintenance and service (e.g. municipality)* • *Decrease the energy consumption*
Key business goals	• *Increase revenue* • *New product platform*
Primary markets	• *Streets* • *Parks* • *Squares*
Secondary markets	• *Campus'* • *Parking lots*
Assumptions and constraints	• IP camera • Communicate with existent infrastructure • Fit into existing infrastructure
Stakeholders	• End user • Installer/electrician • Purchaser (e.g. municipally, government)

5 Identify customer needs

Once the targeted environment was decided, next step was to explore the segment and its customers. This was made through interviews, reports and some short survey questions. The gathering of information was mainly focused on municipality since they usually are responsible for most lighting along sidewalks and bike paths within the city perimeter.

5.1 Interviews

Two interviews were conducted:

- Johan Moritz, lighting designer at Malmö city
- Martin Hadmyr, city development at Helsingborg city

The interviews were based on a prepared interview guide, see appendix F, with open questions with both authors making notations. The questions regarded among others: *procurement of lighting products, trends, visions, proximity controlled lighting* and *safety/security through lighting.*

Procurement within lighting is a thorough process, which can be widely different from case to case. It could be a matter of technical matters that the luminaire need to achieve: e.g. IP class, light quality, distribution of light, continuity of spare parts or based purely on aesthetics, says Martin Hadmyr. In the interview with Johan Moritz he mentions that Malmö city thoroughly test all luminaires and lights in a 3-4 year process.

In the interview with Martin Hadmyr he mentions that white light and LED is on its way into the market, but that LED technology still has a problem with glare, although in the long run LED will be the natural choice. Although Johan says that the LED technology is produced with an unhealthy and non-environmental method. (The authors could not find a source to this claim). He also mentioned that there is no present standard when it comes to replacing broken LED equipment, leading to the entire light fixture being replaced.

When it comes to visions for the future, Johan Moritz talks about the ability to use the full part of a day more efficient with the help of lighting, and also a more satisfying way of recycling products is brought up. Martin Hadmyr expects energy consumption to go down and lifetime of the light source will go up and that tests have been made with dimmer switches to lower the energy consumption but that they have had problems with maintenance of the equipment.

The use of proximity controlled lighting is something both respondents feel hesitant about. *"Different aspects, you won't see the facility until you're there. When the entire facility light up it will attract attention. If it's already lit you'll wonder where the other person is. Not sure that it will convey a good feeling"*, says Martin Hadmyr.

In the interview with Johan Moritz he says: *"Difficult. Imagine an 800m long bike path and it will light up in phases, problematic. Residential areas would be most satisfactory, difficult to see any real effect in central parts of a city. Too much people that move around, it would be unnecessary to switch on and off the light every 30 minutes. You should use available technology but it should not be self-seeking"*

Increasing the security through lighting is not possible according to Martin Hadmyr, but to increase the perceived safety through lighting is important. *"A lot of light on the walking path but none around the path will counteract safety. Spotlights on surroundings are important".*

5.2 Reports

Reports regarding lighting and safety within municipalities were examined in the effort to get a broader understanding of how municipalities work with these questions.

5.2.1 Technical properties of a lighting fixture

In the report *Rapport UK Upphandling gatubelysning* [14] from Jönköpings kommun important factors regarding procurement of lighting is defined. Five factors is defined as extra important,

- Energy efficiency
- Installation and maintenance
- Price
- Visual comfort
- Lifespan

As a conclusion it is stated that the material of procurement could increase the demand on several factors; environmental issues, price and especially maintenance.

5.2.2 Safety properties of a lighting fixture

The traffic department of Malmö city released a report in august 2010 called *Trygghetsprogram* [15]. The report aims to picture what should be considered and rectified so inhabitants and visitors of Malmö city feel safe and not refrain from utilizing what the city has to offer.

In the report it is stated that lighting is the single most important factor to feel safe according to multiple investigations. One factor to increase the sense of safety could be to use lightning sources with a high color rendering index (CRI). To reside in an environment where colors become clear can improve the feeling of safety, contrary to environments with low CRI where difficulty to distinguish faces and color of clothes will feel unsafe. Additionally it is mentioned that lighting closer to the ground contributes to a more comfortable and intimate feeling and increase the feeling of safety [14 pp. 21-24].

5.2.3 Integrated infrastructure

During the examination of the market *Smart city* and *safe city* are common words, used describing the connected society in a sense that sensors and cameras will be integrated in the infrastructure. This information is then collected in a centralized system that helps the city more effective manage their resources and respond quicker to events [16 p. 4]. An example of such a system is *Infracontrol online* which is being used by over 30 municipalities in Sweden. This system enables the citizens to file error reports on littering, graffiti, vandalization etc. using a smartphone and can be extended to incorporate hardware to control streetlights. When a location is in a state of degradation it signals that no one is responsible or care and makes people feel unsafe [14 pp.]. These reports inspired the authors to investigate the possibility further, how the product in the selected environment could make this process more effective and by doing so add value for the customer.

5.3 Surveys

A list of questions was sent out to the twenty most populated municipalities in Sweden, appendix G, with questions regarding expenditures and maintenance within the municipality. The purpose was to find cost bearers within the outdoor lighting segment and also to explore other substantial costs that the municipality had, with intention that it might be possible to remedy with a camera system. Unfortunately the response was insufficient with four answers out of twenty approached.

The received responses indicate that maintenance and energy consumption varies of being the higher cost and the difference in distribution can be quite substantial. Some responses indicated that there are tasks within the municipality that could be simplified through automatization, e.g. notice when trash cans are full or report broken light fixtures.

6 Product requirements

This chapter describes the list of requirements that were generated from customer statements and the pre-study, and later used in the concept selection.

6.1 Two groups of requirements

The collected information from the pre-study and customer statements from interviews were translated into customer needs, see appendix H. These statements were then divided into two different groups of requirements where the first list represents requirements that are crucial for the product to function properly, table 6.1. The second list of requirements is not vital for the product to function but desirable to elevate the concept, table 6.2.

Table 6.1 Requirements

Requirement		Units
Vandal safety		IK class
Weather protection		IP class
Withstand Cleansing agent		
Temperature interval	Externally Internally	C° C°
Offer light	Color Area Illumination	CRI m^2 Lux
Enable camera installation		
Enable pole installation		m
Withstand external forces		N

Table 6.2 Needs

Need	Units
Camera angle, face recognition	Pixels/m, degrees
Camera angle, overview	Area/degree
Simple installation	Time
Identify damaged lamp	
Identify damaged camera	
Camera functional in different weather conditions (snow, rain)	
Measure energy consumption	
Fit existing infrastructure, voltage	
Fit existing infrastructure, software	
Fit existing infrastructure, communication	
Identify damaged pole, angle	
Identify damaged pole, oxidation	
Enable video analysis	
Adjust flow of light	
Installation wall	
Installation during rain	
Panic button	
Enable repair work	
Aesthetics	Subjective
Even distribution of light	Max/min
Avoid light pollution	% of distribution
Low effect	Watt
Recyclable	
Remotely monitored	
Minimize glare	Contrast
Prevent insect nesting	

7 Technology

The concept generation was divided into two parts, technology and design. This chapter describes the process of technology concept generation.

7.1 Infrastructure

The infrastructure can be divided into two categories, the distribution of power to the luminaire and the physical mounting constraints for the luminaire. Power is distributed to the street light by connecting a group of luminaires to a lighting access point, the group consist of up to 200 streetlights. In the access point a relay is triggered by either a schedule or by light sensors in the city. In figure 7.1 Malmö city street light grid can be seen.

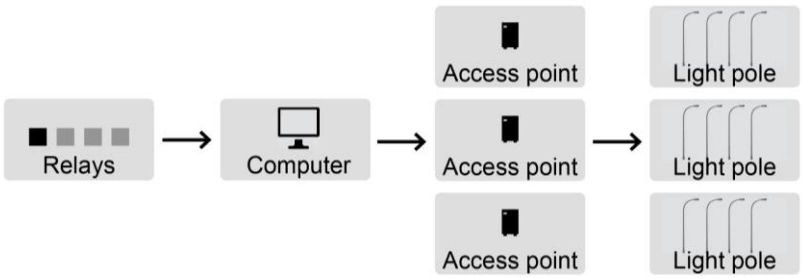

Figure 7.1 Malmö city Street light grid in a simplified architecture

Intelligence in existing systems is implemented on a group level or individual level. Outside Gothenburg for example a group of lamps can be dimmed on hours when the traffic is low [17]. In other cities PIR sensors have been installed on each individual pole in an area to reduce the light output when no one is in the proximity [10]. The dimensions of a street pole are standardized and the top outer diameter is 60mm independent of the height of the pole.

7.2 Light technology

According to the customer requirements the product needs to produce a high efficiency good quality light. The available technologies on the market today were therefore analyzed to select a light source that meets these requirements.

7.2.1 High intensity discharge

The luminance from a discharge lamp is created by letting two electrodes discharge through a chamber filled with metal vapor. The wavelength of the emitted light depends on the metal vapor inside this chamber. The most common metal in these lamps are sodium that gives a warm monochromatic light with a low CRI value but a high luminous flux. The efficiency in a low pressure sodium lamp can be as high as 180 lm/W and for a high pressure sodium 45-110 lm/W [18, p.1]. Studies have shown that the luminance from light sources can be reduced with sustained visibility if the light has a colder temperature and better CRI [19, p. 158]. In the report it is stated that they reduce the power consumption with half when they changed from sodium (warm) to LED (cold) and the pedestrian still experiences the area as illuminated as before, they also preferred the colder light. The efficiency for a metal halide is 60-100 lm/W [18, p.1]. All types of discharge lamps need time to heat up before reaching full luminous flux which takes up to 15 minutes. After they are heated the light can be dimmed up to 50 percent but it will reduce the light quality [20, p.3]. The expected life of a discharge lamp is 10 000 -24000 hours [18, p.1].

7.2.2 Light emitting diode

A LED is also a monochromatic light source where the wavelength of the light emitted is determined by the band gap which determines the energy change when electrons are moving in the semiconductor. To create white light with an LED the most common way is to use a blue diode coated with fluorescence that transform the blue light to red and green light. By doing this some light is lost in the fluorescence but a high CRI is reached, a good modern white LED have a CRI value of above 90.
The power consumption is nonlinear in a diode, the typical characteristic of how the forward voltage and the forward current depend on each other can be seen in figure 7.2.

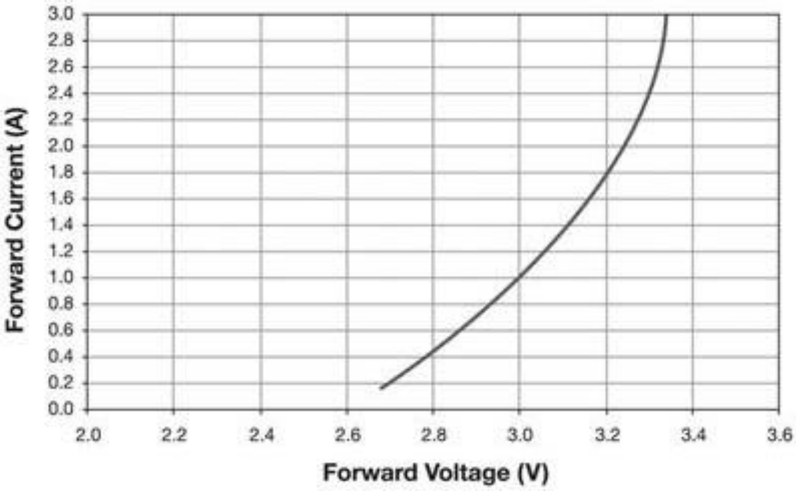

Figure 7.2 Forward current as a function of voltage

The luminous flux from a LED depends on the forward current as seen in figure 7.3.

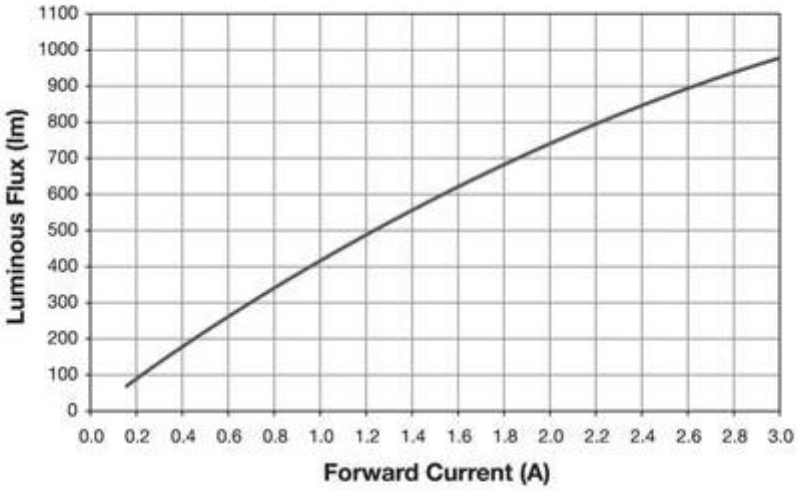

Figure 7.3 Luminous flux as a function of current

The efficiency for LED varices with the light output because of the voltage required to drive the current through the diode is nonlinear. The efficiency provided by the manufacturers for a certain diode is measured at a specific current level and the efficiency can be as high as 200 lm/W [21], [22]. A LED is sensitive to high temperature and the luminous flux decreases with increased temperature. This might make it necessary to mount the LEDs on heat sinks that will transport the generated heat away.

The light output deteriorates over time for an LED and the expected life time is given by a service time where at least 80 percent of the original luminous flux remains. This time is often claimed by the manufactures to be 50,000 to 100,000 hours [23], but this is just a theoretical number given by the rate of deterioration of the light output. The absolute number for a LEDs lifetime has not been tested in a controlled environment [23]. Another known problem with a coated diode is that the fluorescence coating ages so the wave length distribution changes and with that the color temperature value increases and the CRI decreases. There have not been any studies on the degradation of the coating but it is a known problem. The response time for a LED is instant and the luminous flux reaches 100% once the power is turned on.

7.2.3 Plasma lamp

Another interesting light source technology is light emitting plasma (LEP). The LEP is a quartz lamp between two ceramic plates, a standing wave is generated between the plates and this energy turns the halides into plasma that emits light. The light emitted has an even wave length distribution similar to sunlight. This technology has similar to the discharge lamp a heat up time to reach hundred percent light output and is after this dimmable. The manufacturer Luxim claims that the efficiency for their LEP is 115-150 lm/W and maintains 70% light output after 50,000 hours [24], [25].

7.2.4 Selection of light technology

The customer needs that were applied when the light source were chosen was high CRI, low power consumption and "dimmability". An even light distribution is more dependent on the design of reflector and lens/diffuser then the light source itself. The discharge sodium lamp were discarded because of the low CRI and the fact that studies have shown that the total amount of lumen can be reduced with better CRI and thereby reduced power consumption. The LEP were not a realistic alternative because of its high power, according to [26] where the light were mounted on 12 m poles and were still too bright. The manufacturers struggle with creating low power LEP light. Another problem with this technology is the reliability of the driver creating the standing wave, in [19, p.141] the result from the test show that 9 out of 13 luminaires had stopped working after a year. The LEP is a promising technology for this product if the power can be reduced and the driver problems solved. Left to evaluate were LED and metal halide they both have a good CRI but the LED have a much better expected life time and the fact that it lights up immediately made the LED the best alternative, this were also confirmed by the pre-study.

7.3 Driver

For the LED to work properly the current and/or voltage needs to be regulated. Different methods were investigated to find the most efficient way to do this since it will affect the overall efficiency for the light source.

7.3.1 AC/DC converter

The most common way to design a driver for a LED is to use a full-wave rectifier and then a buck converter. This converts the AC voltage to a reduced DC voltage. After this step a constant current or constant voltage regulator needs to be implemented to ensure that the LED is running on proper levels. This regulator also makes it possible to dim the LED by changing the set point for the regulator. The efficiency for this kind of driver is 80-96 percent at full load but will decrease with the load. The lifespan for this kind of driver is often lower than for the LED because of the electrolyte capacitors fails caused by high operation temperature. This makes it important to choose high quality components when designing the driver to get a reliable system.

7.3.2 AC LED

The term AC LED is rather misleading but is the industry term for a new type of driver technology. The principle is to get rid of the AC/DC converter and more directly connect the LEDs to AC power source. The easiest way to do this is to use two strings of LED where each string is connected in opposite polarity, known as antiparallel configuration, see figure 7.4. The current is limited by using a resistor. By doing so the system becomes very reliable with a lifetime comparable to the LEDs but with a low efficiency since the voltage drop over the resistor generate pure losses. To be able to dim this set up a TRIAC needs to be added in the circuit. The TRIAC works as a phase cutting dimmer that reduces the power through the LEDs.

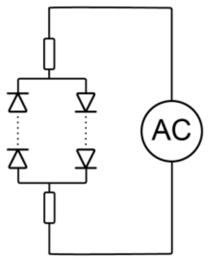

Figure 7.4 Antiparallel circuit

A more efficient way is to use a number of LED strings where each string can be shorted with a switch. This requires that a full-wave rectifier is used, and the switch is triggered by the voltage level in the circuit. In figure 7.5 a schematic diagram of such a circuit can be seen and figure 7.6 shows how the different LED strings lights up dependent on the phase of the voltage. To control the light output a current regulator or TRIAC needs to be added to the circuit

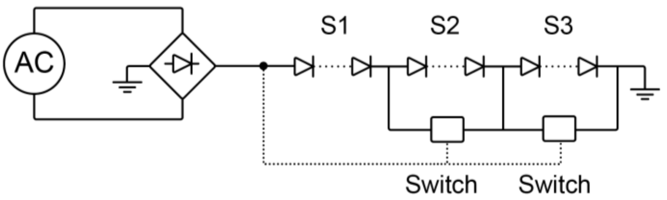

Figure 7.5 Principal schematic of an AC LED

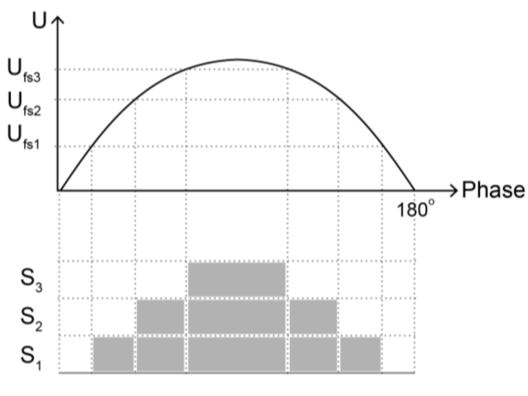

Figure 7.6 How LED strings turns on and off dependent on the phase.

The intellectual property of this technology is owned by a few IC-manufacturers, these are Soule Semiconductors, Texas Instruments and Lynk Labs. The efficiency for this kind of driver is compatible with the traditional AC/DC driver but with less components. The manufacturer’s claims that this kind of driver has a lifetime comparable to the LEDs.

One possible problem with these kind of driver might be flicker since the light is dimmed on and off with a frequency of 100 Hertz. The fact that not all of the LEDs is powered all the time means that a larger number of LEDs needs to be used to get the same luminous flux when compared to the conventional driver.

7.3.3 Selection of driver technology

When comparing the three alternatives the AC LED alternative with resistor to control the current where crossed off because of its low efficiency compared to the others. The primary problem with AC LED compared to the conventional AC/DC converter is exchangeability. The conventional driver gives the customer more freedom if the driver needs to be replaced. This was pointed out in the interview with Johan Moritz as a problem. Another possible problem with the AC LED driver is that the light might be perceived as flickering. In the AC/DC driver the current is reduced in the buck converter by switching but at a much higher frequency which eliminates the problem with flicker. This analysis resulted in that the AC/DC driver technology was chosen.

7.4 Communication

The platform needs to be remotely accessible to control the camera and the light. It is strongly preferred that the communication can operate when installed in existing poles without any extra cables needs to be drawn. The only existing cable in the infrastructure is the power cable therefore the possibility to use this to communicate was investigated together with wireless alternatives. To stream a full high definition video compressed with H.264 would require a minimum bandwidth of 10 Mbit/s and the data needs to be transferred from the luminaire to a surveillance central which can be several kilometers away.

7.4.1 Power line communication

The IEEE Std 1901-2010 is an industry standard for communicating over power line with a speed up to 500 Mbit/s with a range of up to 1500 meters. For distances beyond that repeaters are necessary to maintain signal strength to prevent data loss. Without the use of repeaters the standard IEEE 1901.2-2013 can be used which offers a transfer distance of multiple kilometers with a speed of up to 500 kbit/s.

7.4.2 Wireless

The wireless alternative gives a lot of options e.g. Wi-Fi, 3G, 4G, LTE and in the future 5G all of which provides enough bandwidth except 3G. Wi-Fi requires that it exist in the area or needs to built-up for the installation. The 4G infrastructure in modern cites already exist and 5G will in the future be build. So the best alternative is to use 4G since the infrastructure is in place and in the future use 5G. 4G was chosen as the systems way of communication.

7.5 System architecture

In figure 7.7 a diagram over the components and how they interact with each other can be seen. The goal was to make a modular architecture to increase lifespan of the luminaire.

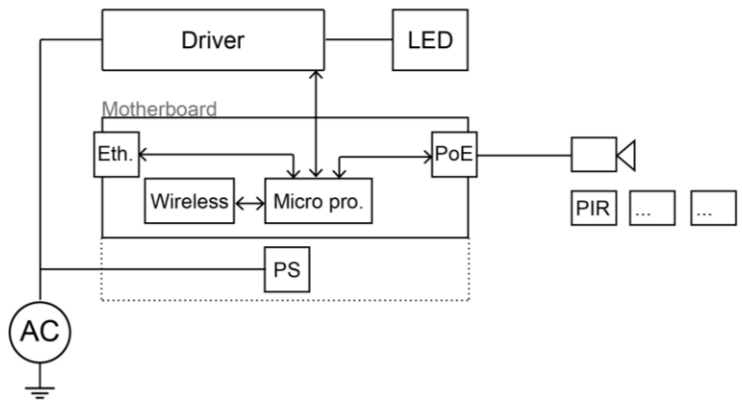

Figure 7.7 System architecture

The lighting part including the LEDs and driver are separate components to make them exchangeable. The driver is equipped with an interface that makes it possible to dim the LEDs and turn them on and off. This signal comes from a microprocessor on the “motherboard” which also contains wireless communication and a power over Ethernet connection (PoE). The signal to control the light is either generated by message sent over wireless communication or from the PoE port. Different sensors that support the Ethernet protocol can be connected to the PoE port. The power to the “motherboard” will be supplied by a separate power supply. One alternative would have been to use the LED driver to supply the power but this would require multiple independent outputs and reduce the options when the driver needs to be replaced. The “motherboard” will also be equipped with a regular Ethernet port to prepare for installations in a modern infrastructure environment where Ethernet cable might be available in the ground.

7.5.1 Discussion

The product is supposed to be a part of a bigger system where multiple luminaire are installed in an area and connected to a management system that controls the cameras and the lighting. The need for a camera in every luminaire might not be necessary. The luminaire can then be equipped with other sensors or other accessories in the space where the camera is supposed to be installed. In an area where only a small number of luminaires are intelligent i.e. fitted with sensors, these can communicate and control the light of the others. The idea behind the architecture is basically to provide a communication platform installed on a street light luminaire where different sensors and other equipment can be connected.

8 Design

This chapter describes the design process of the product design.

8.1 Concept generation

The concept generation derived from the ideas from customer needs, product requirements and the intended environments.

8.1.1 Image board

The intended markets for the product was set to be city streets, parks and squares, an image board with the intended environments were used to inspire in the concept generation phase, figure 8.1.

Figure 8.1 Environments for the product

8.1.2 Sketch session

A sketch session together with Viktor Gustafsson, design engineer at the PCNI office focused on getting a lot of ideas on paper. Ideas were shared and concepts were built on each other's concepts in an effort to evolve the ideas, excerpts from the session can be seen in figure 8.2

Figure 8.2 Sketches up on the wall from the sketch session

8.1.3 Workshop

After the authors had emptied themselves off ideas a workshop was arranged with the PCNI office, which consists of a number of engineers with different expertise together with three other master thesis students, and a designer from Axis design office. The workshop covered both ideas of design of the product and ideas of technology that could be incorporated into the product. At first the team could generate ideas freely and were later presented with directives like: “How could you place the camera to avoid glare, but at the same time have a good diffusion of light?” “How can the camera be placed to maximize face recognition?”

The outcome of the workshop generated a number of concepts and ideas that could be added to the existing concepts.

8.1.4 Concept ideas

A number of concepts were chosen to explore further, where focus lay on how the camera was positioned relative to the light source. Many concepts can be varied in different styles but are represented as a generic concept in simplified CAD models, figure 8.3-6.

Figure 8.3 Concepts 1-4.

Concept 1 consists of four bendable arms that support both lighting and small cameras, as the P12, figure 1.2, positioned in the different arms. This allows a flexible solution considering both camera angles and light distribution. Concept 2 is based on the presumption of a broken light fixture, the camera looks like a broken light bulb. The third concept is a cobra lighting fixture with the possibility to place multiple covert cameras in different directions within the fixture. This concept is similar to most patent claims that could be found during the pre-study. Concept 4, the disco ball consists of mixed squares of light and panels concealing hidden cameras.

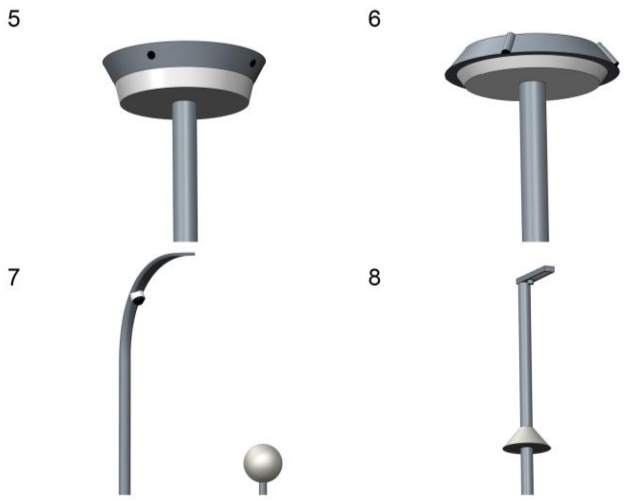

Figure 8.4 Concepts 5-8.

Both concept 5 and 6 portray small covert cameras placed in a downwards angle on top of a lighting rig, allowing a panorama view around the lamp. Concept 7 is based on a two-pole concept where lighting and the camera is placed on one pole and a mirror ball is situated on a different pole and the camera can catch information in the opposite direction as well. The 8th concept is similar but with a camera directed downwards from the luminaire and mirrored on a lower level to capture images in a height suitable for face recognition.

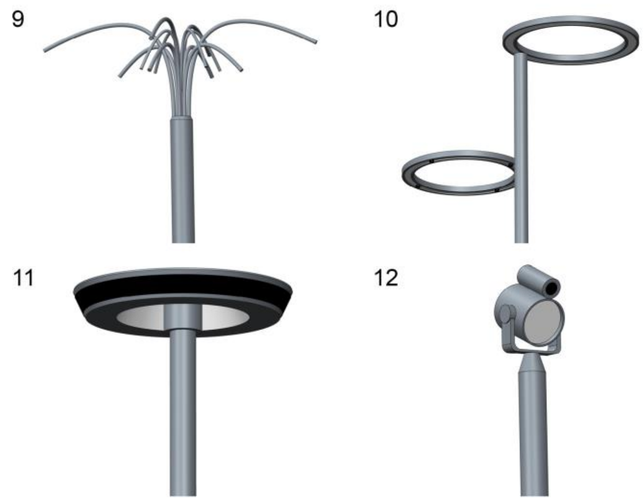

Figure 8.5 Concepts 9-12.

Concept 9 consists of multiple fiber optic cables with lighting and small covert cameras aimed in a variety of directions. In concept 10 two circles placed on different heights and directions offer both light and cameras placed in multiple angles and directions. Concept 11 is similar to 5 and 6, small cameras are concealed behind a transparent surface and the light is placed beneath. The 12th concept is a flood light concept with a camera placed on top where extra light and attention can be directed in a specific direction.

Figure 8.6 Concepts 13-17.

Concept 13, 14 and 16 are similar concepts which describes a dome camera placed in the center of a lighting rig. The different concepts offer support to the luminaire through three different ways, concept 13 is supported by a transparent glass structure, concept 14 by two bars in an angle and the last, concept 16 with a top mounted pole console. Concept 15 consists of multiple covert cameras placed in an angled cylinder contraption beneath the actual luminaire, allowing for a full 360 degree view around the lamp post. The cylinder offers ways of opening the construction from the outside, allowing installation with ease. Concept 17 features a camera placed on top of the light fixture, offering free view in all horizontal directions.

8.2 Concept selection

Some concepts were deemed impractical and were discarded without greater hesitation, it could be out of the sheer complexity in the construction as in concept 4, 7, 8 and 9 or problems with glare in concept 13. The more detailed concept selection was based on methods from *Product Design and Development by Ulrich & Eppingers* [3 pp. 143-159]. This was a useful method to get an effective team decision and documentation of the process. The selection was divided into two different stages, with the first decision matrix representing selection criteria from the first list of product requirements in chapter 6, requirements vital to the functional design of the product.

8.2.1 Concept screening

The first decision matrix represents a quick, simple way to evaluate the concepts considering the low degree of development that been put into the concepts early stage. The different concepts were presented at the same level of detail no matter how far the concept had been developed prior to the evaluation. One of the concepts, concept 15, was selected as a reference all other concepts were compared and rated against with a ‘+’. ‘-’ or a ‘0’ based on the concepts advantage relative to the reference, see table 8.1.Concept 15 was chosen because it was a concept both authors felt very familiar with.

Table 8.1 Concept screening

Requirement / Concept		1	3	5	6	10	11	12	14	15	16	17
Vandal safety		-	0	0	0	0	0	0	0	0	0	0
Weather protection		0	0	0	0	0	0	0	0	0	0	0
Withstand cleaning		-	0	0	0	-	0	0	0	0	0	-
Temperature interval	Externally	0	0	-	-	0	0	0	0	0	0	-
	Internally	0	0	0	0	0	+	0	+	0	0	0
Offer light	CRI	0	0	0	0	0	0	0	0	0	0	0
	Area	+	0	0	0	-	+	0	0	0	0	0
	Lux	0	0	0	0	0	0	0	0	0	0	0
Enable camera installation		0	+	+	+	+	+	+	+	0	0	0
Enable pole installation		0	0	0	0	0	-	0	0	0	-	0
Withstand external forces		-	0	0	0	0	-	0	0	0	0	0
Plus		1	1	1	1	1	3	1	2	0	0	0
Minus		3	0	1	1	2	2	0	0	0	1	2
Sum		-2	1	0	0	-1	1	1	2	0	-1	-2
Rank		**5**	**2**	**3**	**3**	**4**	**2**	**2**	**1**	**3**	**4**	**5**

The matrix show that seven concepts scored in par or above the reference concept and therefore were selected to transfer to further development and the next selection matrix, the remaining concepts were discarded. Three of the concepts, concept five, six and eleven were deemed similar, they all feature a circular luminaire with small covert cameras placed on the top, and there for combined into one concept, from now on called concept 12.

8.2.2 Concept scoring

In the second round of the concept selection the remaining concepts were assessed in a new selection matrix with different selection criteria based on the second list of product requirements, table 8.2.The weights of the different criteria's were decided by the authors and based on the criteria's made for the AHP in chapter 4. Each concept was given a score between 1-5 and a total score for each concept was calculated.

Table 8.2 Concept scoring

Requirement / concept	**Weight**	**Concept 3**	**Concept 11**	**Concept 12**	**Concept 14**	**Concept 15**
Camera angle, face recognition	**0.09**	4	3	4	5	4
Camera angle, overview	**0.09**	5	3	3	2	4
Simple installation	**0.12**	3	1	3	4	3
Camera image in bad weather	**0.06**	2	2	2	4	4
Installation, wall	**0.02**	1	1	2	1	2
Installation in snow, rain, etc.	**0.03**	1	1	1	1	2
Facilitate repair work	**0.12**	4	2	4	4	3
Design, aesthetics	**0.10**	2	4	4	3	4
Even light distribution	**0.10**	2	3	4	4	4
Avoid light pollution	**0.04**	4	2	4	4	4
Recyclable	**0.05**	4	3	2	3	2
Minimize glare	**0.10**	2	2	2	3	3
Enable variety of camera inst.	**0.05**	1	1	1	4	1
Prevent insect nesting	**0.03**	4	3	3	3	3
Total score	**1.00**	**2.95**	**2.34**	**3.06**	**3.48**	**3.28**

Two concepts scored somewhat higher than the other three and the authors had difficulty to determine which of the concepts that were most promising out of the two based on the existing factors. A decision was made to further explore both concepts before a final decision was made.

8.3 Further exploration and selection of concept

The focus of the exploration was different ways of installation of the camera, placement of the cameras and light source, room and positioning of components and the field of view from the cameras. The most of the exploration was made through sketching and more developed CAD models, figure 8.7.

Figure 8.7 Exploration of the two concepts.

One of the main advantages of concept 15 was the 360 degree viewpoint because of the possibility to install up to four cameras in the cylinder contrary to concept 14 where a dome camera only has the possibility to look in one direction at the time and with two bars blocking a part of the view. As a test a math lab code was scripted to get more certain numbers on the field of view of concept 15, figure 8.8.

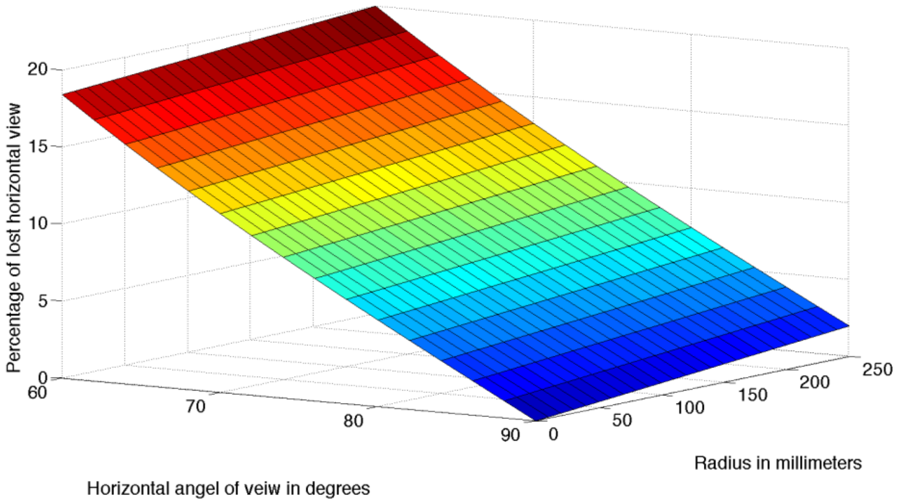

Figure 8.8 Field of view of concept 15.

The figure shows a diagram with three axis's, on the z axis is the *percentage of horizontal view lost in an 8 meters radius*, the y axis describe the *radius the cameras are positioned in* and the x axis the *horizontal angle of view of the camera*. Even with the P1214-E camera from Axis with a horizontal angle of view of 81°, the widest of the small covert cameras, an installation radius of 10 mm would mean a 5.8% loss of view per quadrant, figure 8.9. [27]

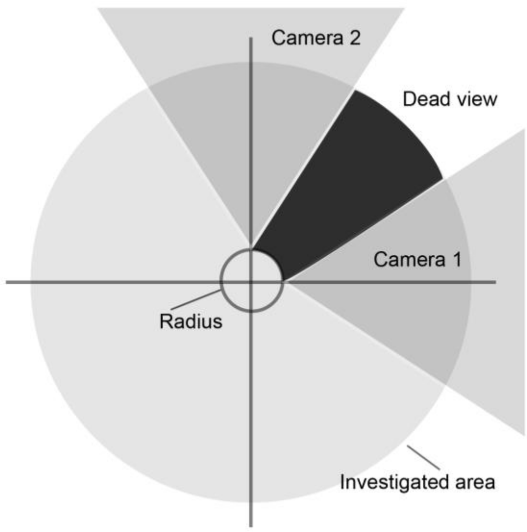

Figure 8.9 Schematic view of the cameras seen from above, illustrating the "dead view"

To identify how much field of view that will be lost because of the struts a mathematical model was constructed. The problem was simplified to two dimensions and can be seen in figure 8.10.

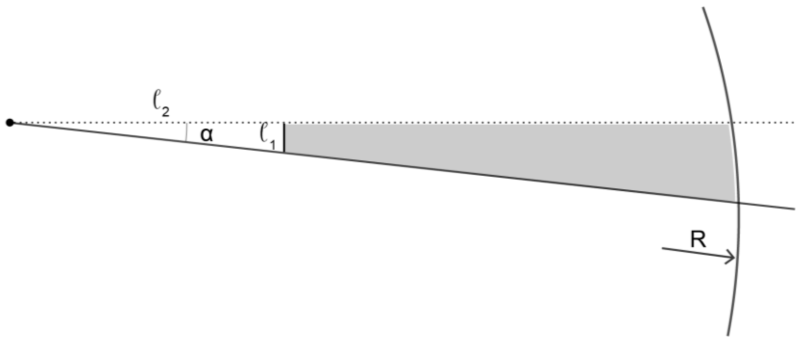

Figure 8.10 Schematic view of the cameras seen from above, illustrating the lost view caused by struts

Length L2 is dependent on the tilt of the camera but were in the model simplified to be constant and is the distance from the camera to the struts, L1 is the dimension of the struts. Equation 1 shows how the angle of view is lost (α) as a result of the struts were calculated.

$$\alpha = \arctan \frac{l_1/2}{l_2} \qquad (1)$$

Table 8.3 shows the percentage of area of view lost in full circle. The distance L2 was set to 300 millimeter and 230 millimeter and L1 10 to 30 millimeters.

Table 8.3 Percentage of view lost in a full circle

Length l2	***Length l1***	
	10	**30**
300	1.98 %	6.36%
230	2.60%	8.58%

The outcome of the calculations shows that there will be a loss of view in both concepts, and are not significant for the choice of concept.

A similar construction of that from concept 15, a cylinder with four covert cameras, could easily be incorporated in concept 14. This in combination with the possibility to install a wide portfolio of cameras and an easier, more straight forward way to install the camera, concept 14 was selected as the concept to further develop.

8.4 Chosen concept

The chosen concept consists of two main parts, the struts that support the construction and the assembly ring that contains the camera, the light source and other technology. The camera is placed in the middle of the assembly ring and around the camera are openings for the light source to be assembled in.

9 Concept refinement

The selected concept will in this chapter be refined. This will be done by dividing the design into sub problems and then combine them to a finished concept.

9.1 Dividing the design

The complexity of the concept requires it to be divided into sub problems resolved separately. The concept was divided into struts, assembly ring and a top part. On the assembly ring the LEDs, driver for the LEDs, the “motherboard” and camera or other sensors will be attached. The attachment of these parts needs to be solved. When these components need to be repaired it is necessary that the top part can be easily removed. The struts needs to be strong enough to support the assembly ring and attachable to a pole.

9.2 Benchmark

A Philips StreetSaver LED luminaire was acquired; this was to examine how a leading brand company solved some of the difficulties about designing a luminaire, figure 9.1 [28].

Figure 9.1 Philips StreetSaver LED luminaire

Replacing the LED surfaces is not possible according to the product manual, which becomes obvious examining the construction. 37 screws holds together the two parts where the LED surfaces are mounted, the cables from the driver unit to the LED surfaces are also soldered and sealed with a sealing paste, figure 9.2.

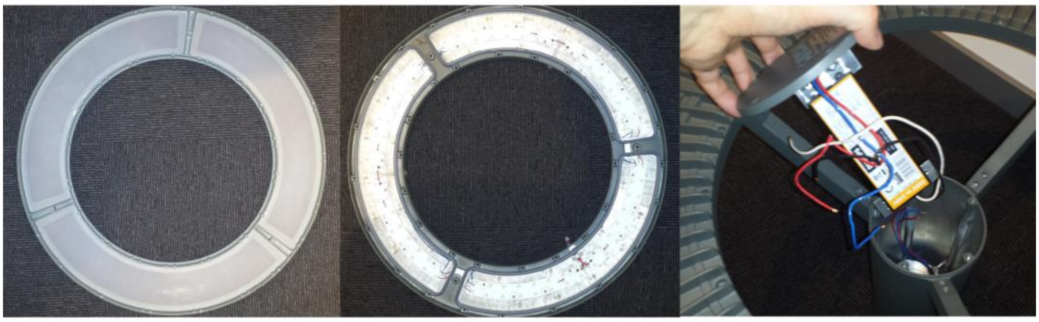

Figure 9.2 Left: The bottom plate of the construction. Center: Top plate of the construction. Right: The cylinder construction containing the driver.

Another aspect is that the LEDs are attached to the top construction of the luminaire, while the optical cover rests on the bottom part of the construction and are squeezed together by the two parts when screwed together. This means that at an impact from an object at the optical covers is distributed to the entire construction, rendering good resistance to vandalism.

The driver is placed in a cylinder construction that is assembled on the pole, which opens up on the top with just a few screws enabling easy access to the driver unit, figure 9.2. These two factors fortify the conception that the driver is the fragile part in a LED lamp, and the manufacturer considers the actual LED to last the entire luminaire lifetime.

The circular LED construction consists of three identical lighting compartments, and these contain three LED surfaces each, figure 9.3. In total 16 LED dies are mounted on each LED surface, this leads to a low heat concentration and an even lighting distribution.

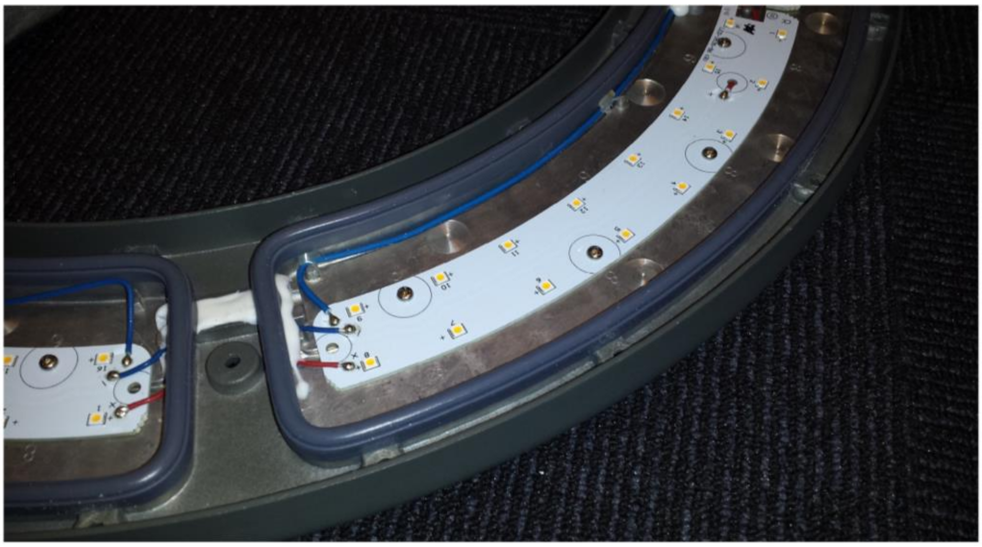

Figure 9.3 Lighting compartments

9.3 Tests

Some questions and concerns were raised considering the design concept, especially how much field of view the struts would cover in the camera view, how much glare would they reflect as well how much glare the camera would get directly from the LED light, figure 9.4.

Figure 9.4 Illustration of light from the LED hitting the dome

The luminaire that was benchmarked was therefore used as a test rig and with a few modifications a PTZ camera could be installed in the center of the luminaire. The test rig was installed in the ceiling of the office and a few simple tests were conducted to test the concept and answer some of the raised concerns, figure 9.5.

Figure 9.5 The Philips luminaire modified to a test rig with a P55 camera installed

9.3.1 Glare

To test the glare from the LED lighting the test rig was set up in open space within the office and during dark conditions to eliminate factors that could influence the test. The camera was mounted in level with the LED light to see if glare appeared and propagated in the dome, it did. Three different ways were considered to remedy the problem, figure 9.6:

- The camera need to be raised upwards to avoid the light dispersion
- The LED need to be angled away from the camera, out towards the periphery
- A brim need to be placed between the light and the camera to shield the dome

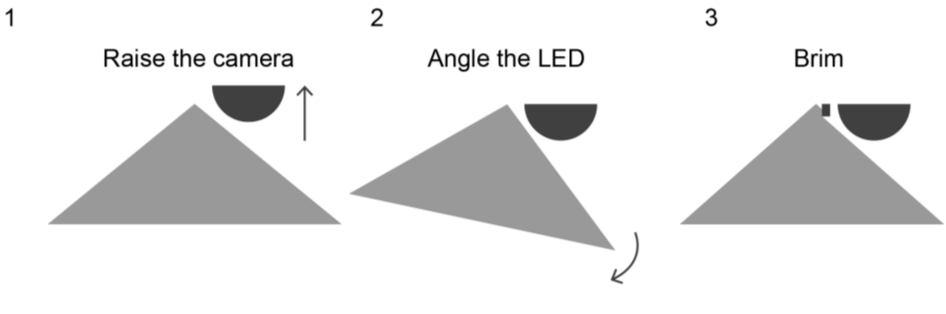

Figure 9.6 Different ways to eliminate glare in the dome.

The two first alternatives were deemed problematic right away. If the LED is angled, the light will be projected towards people instead and create discomfort. If the camera is raised upwards, the sight of the camera will be highly affected. Remaining is the third alternative where a brim is placed between the light source and the camera. A brim was made out of Styrofoam and placed between the LED and the camera for further testing, figure 9.7.

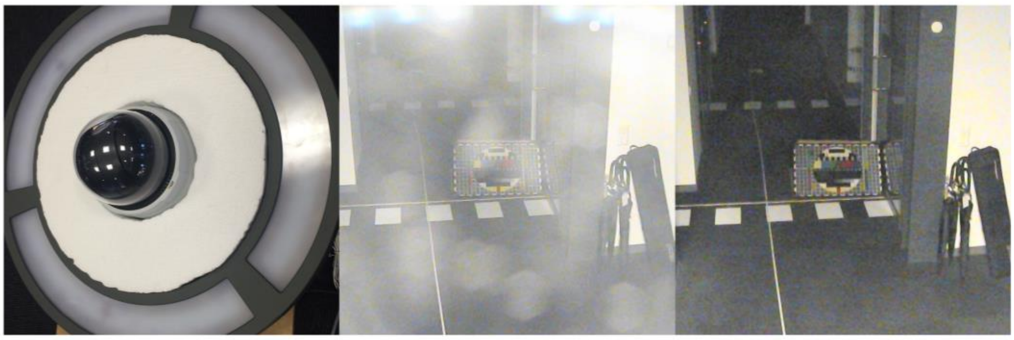

Figure 9.7 Left: The test rig prepared with a Styrofoam brim. Center: Picture without the brim. Right: Picture with the brim

The difference in the cameras video quality is substantial, a brim reflecting the light should be introduced to the design concept for a better result.

The second issue tested was glare from the struts, mock up struts were created and installed on the test rig. Problem with glare arose in this situation too, three different ways were considered to solve the issue:

- The struts are positioned on the inside of the LED source
- The surface of the struts need to be matte
- The surface of the struts need to be colored dark

Mock up struts in different material, cross sections and colors were tested and installed on the test rig. The first test conducted was struts positioned on the inside and the outside of the light source, and colored/matte texture versus a shiny surface, figure 9.8.

Figure 9.8 Top left & right: Shiny versus matte strut on the outside of the light source
Bottom left & right: Shiny versus matte strut on the inside of the light source

The most significant difference is with the black/matte strut contra the shiny when placed on the outside of the light source. The glare in the picture with the unpainted surface is substantial, whereas the colored strut placed on the outside of the lighting source cause glare but not as significant. The difference in glare between an uncolored strut and a matte strut is not as significant but a difference can be seen.

9.4 Design

From the tests that were done and earlier findings, some factors in the design needed to be considered. A brim on the inside of the LED was deemed necessary, while the decision of struts on the outside or inside of the LED, as well as the design of the top was more difficult to decide. A workshop was arranged with Morten Bergström, design consultant at Axis to get some aid and guidance.

9.4.1 Image board

An image board was created with inspiration from products with association to the intended environment, appendix I. This was helpful partly to convey the intended expression of the product and inspire some new thoughts.

9.4.2 Mockups and sketching

Some rough mock ups were made out of ordinary foamcore and paper to get an understanding of perspectives and shapes of different design alternatives that is difficult to achieve from CAD models, figure 9.9.

Figure 9.9 Rough models of shapes

The mockups made with three struts felt bulky or tight, and two struts attached to the outer rim made the construction feel thin and weak. A design with two struts attached on the inside of the light source was the one that was most appealing and chosen to elaborate further. The struts need to be hollow and wide enough to fit two cables through, a power cable and an Ethernet cable. A wide strut will also make the design feel sturdier and more homogeneous, which infringe upon the field of view. A trade-off between a wide strut for the design and a narrow strut for the field of view needed to be done. Sketches were made trying to identify a width of the struts and an angle of the struts that conveyed a composed impression, figure 9.10.

Figure 9.10 Rough sketches of different struts

9.5 Struts

The struts were designed as one bent piece of material that is attached to the inside of the LED lighting and are clamped by a cylindrical attachment to the pole, figure 9.11.

Figure 9.11 Attachment of pole and struts

The attachment of the struts to the assembly ring can be seen in figure 9.12.

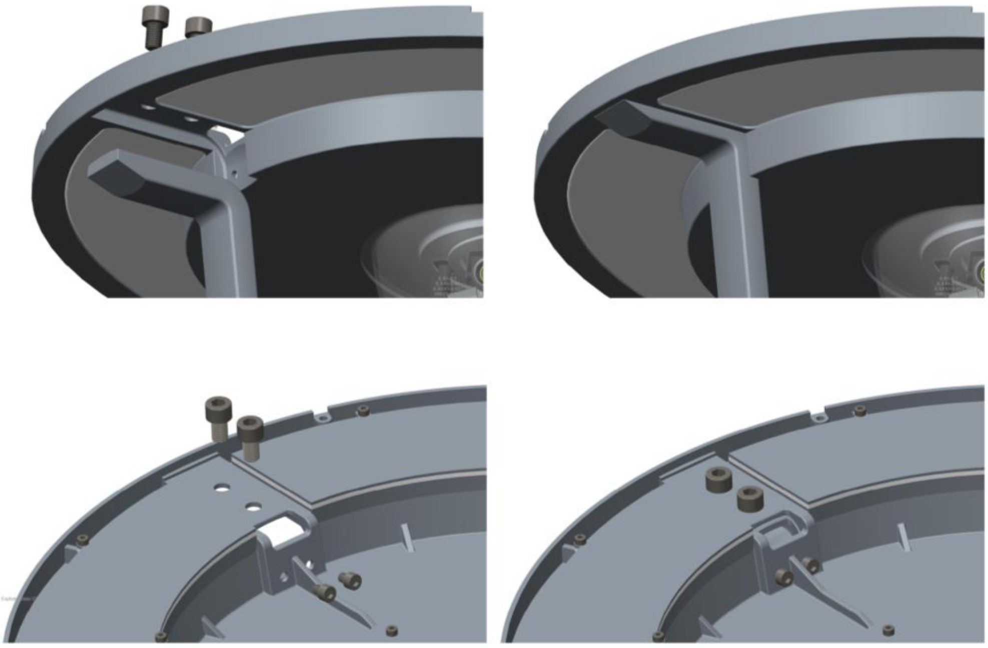

Figure 9.12 Attachment of struts to assembly ring

9.6 The top

The top or the lid of the luminaire needed to be as streamlined as possible it was decided within the group, partly because of the windbreak but especially to avoid making the design look top heavy. The size of the largest camera decided to be incorporated in the design was the P55 PTZ. CAD drawings of the camera were printed and sketches made based on the drawings were used to get a concept of scale and dimensions, figure 9.10.

The most important feature identified was that the outer brim of the lid needed to be as thin as possible considering that the luminaire is assembled about four meters in the air. The design preferred were a concept of levels that got higher towards the center of the lid. This would allow space for the camera but not produce a top heavy expression when seen from ground level, figure 9.13. The top part is assembled to the assembly ring with screws.

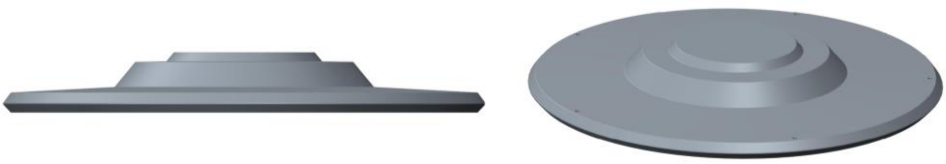

Figure 9.13 The top part

9.7 Assembly ring

The assembly ring can be seen as the main part in the concept, this is where the technology as camera and lighting is fitted, see figure 9.14. The compartment between the assembly ring and the top is not considered to be IP classed, but all the components within will have its own IP classed cover.

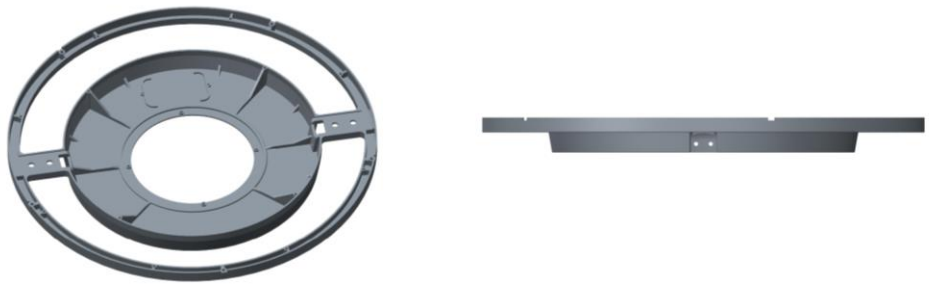

Figure 9.14 The assembly ring

9.7.1 Camera installation

The chosen concept allows the product to be designed to install different kind of cameras. The largest of the axis dome cameras is Q60 but it was considered to be too bulky for the design. The second largest dome camera is the P55 and is considerably smaller and by making space for the P55, a lot of other smaller dome cameras e.g. M30-series, P33-series etc. can be installed. A design to install the much smaller P12 cameras will also be developed.

Two approaches to install the camera were identified, by removing the top and access the installation point or gain access from underneath. When a camera will be retrofitted in a luminaire the dummy needs to be removed and a cover plate attached in the gap between the dome of the camera and the assembly ring. After discussing the two approaches the installation from underneath were considered to be impractical. The accessibility will be restricted because of the struts and the size of the luminaire. The working position for the installer will not be ergonomic and since it will require a number of steps; remove the dummy, install the camera and attach the cover, it is a major factor to consider. The top were already specified to be removable so an installation from the top seems to be the natural option.

The easiest way to install the camera from the top that was identified is to let the camera be held up by either surface A or B, see Figure 9.15

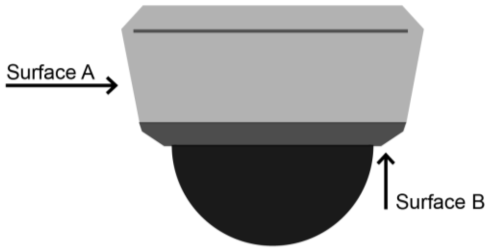

Figure 9.15 Different surfaces for installation

Using surface A were considered being problematic since the slope of the surface is small, it is not rotationally symmetrical and small for the other camera series being considered. Surface B is more promising from this point of view. In both cases the camera needs to be held in place by some supporting structure so it can't be pushed out of place from below. This can be accomplished by either a spring placed in the top that applies a force when the top is mounted or some structure attached to the assembly ring that holds the camera in place. The concept with a spring would make it difficult to attach the top since it needs to be pushed down and overcome the spring force. It also needs to be long enough to support cameras that are not as high as the P55 or different springs for different cameras. An advantage with this is that the spring can absorb energy from an impact on the camera. Another method for fixing the camera is to create a holder attached to the assembly ring and the camera. The idea was to either use elastic straps or a bracket. Two experienced engineers were consulted and they both preferred the bracket solution.

Another way to attach the camera would have been to use the existing mounting plate and cover it with a case according to Figure 9.16.

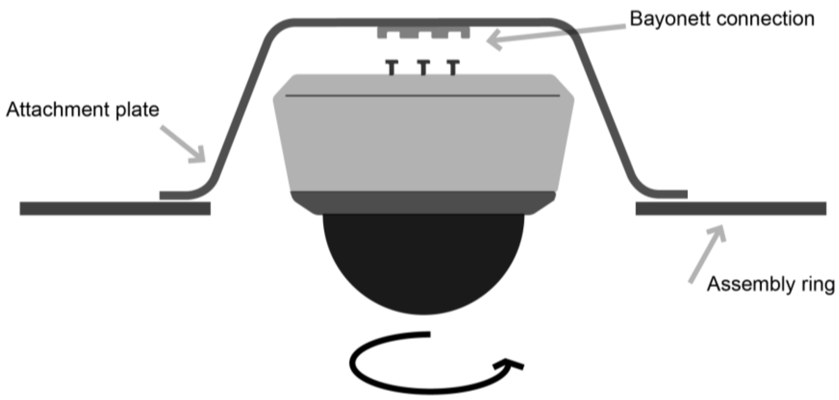

Figure 9.16 Installation using bayonet connection

This would give access to the camera from both the top and the bottom but would leave a gap between the assembly ring and the camera especially when a smaller camera is installed. If the gap is covered the camera will only be accessible from the top and the concept has no advantages compared with the other alternative.

In Figure 9.17 and 9.18 the selected concept to enable camera installation can be seen. Both the bracket and the cover ring need to be specially designed for each camera model.

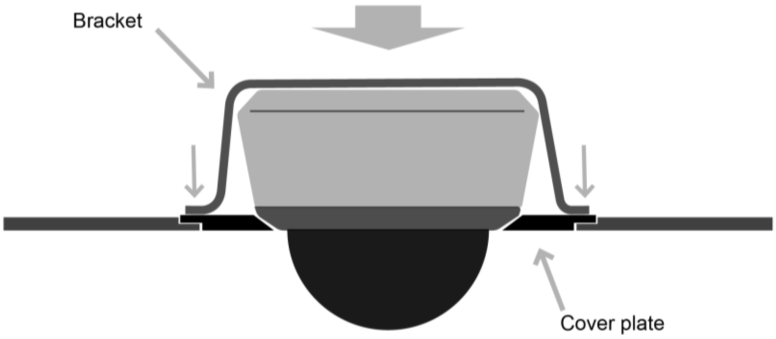

Figure 9.17 The chosen concept of installation

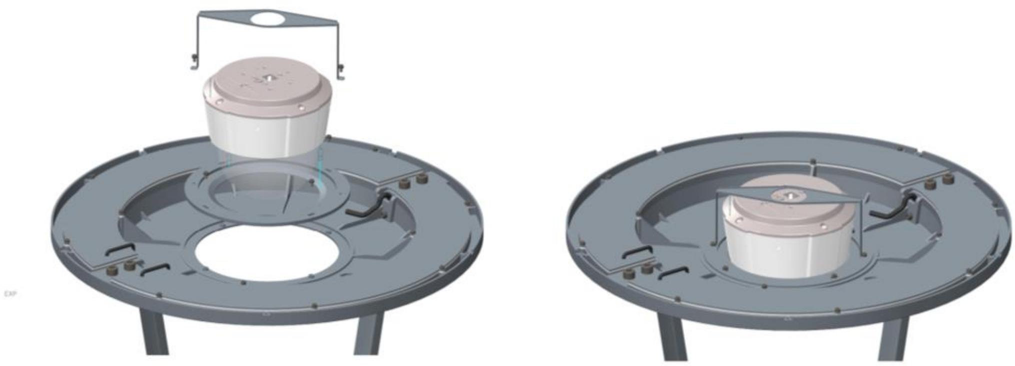

Figure 9.18 A P55 camera installed to the assembly ring

To install the P12 cameras a housing that fits in the assembly ring needs to be designed where the P12 can be attached. This housing will be designed to be similar to a standard dome camera so that uniformity can be achieved. In Figure 9.19 the design of the housing can be seen.

Figure 9.19 Installation of up to four P12 cameras.

9.7.2 Dummy/sensor installation

One feature that needs to be considered is the fact that not all luminaires in a system need to be installed with a camera. In a park or on a street not every luminaire needs to be equipped with a camera, this call for a dummy or a platform for another sensor that can be installed in its place. The dummy is just an object to cover the opening for the camera. Other sensors could be pretty much anything that supports an Ethernet connection, PIR sensor, loud speaker, warning light, etc. The dummy plate can be seen in figure 9.20.

Figure 9.20 Dummy plate with PIR sensor.

The dummy and the sensor plate will be installed in the same way as the cover plate.

9.7.3 Driver/motherboard installation

The motherboard will be enclosed in a box that needs to be IP classified, figure 9.21. This box will then be attached to the assembly ring with screws. The attachment of the driver needs to be more flexible to ensure that it can be replaced with drivers with different measurements. This was achieved by applying the same principles as for the camera installation, using brackets that will clamp the driver to the assembly ring.

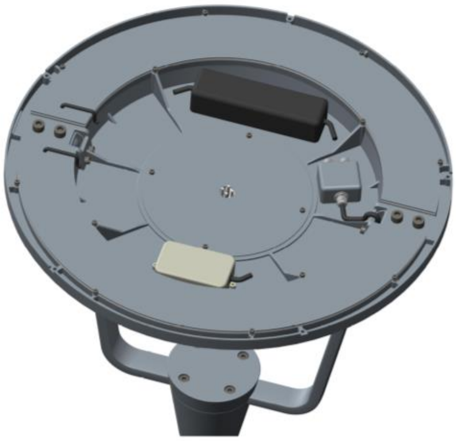

Figure 9.21 The driver and motherboard installed in the assembly ring

9.7.4 LED

Two main factors from the product requirements were considered with the LED lighting, IK class and recyclability. The optical covers of the LED lighting are the most fragile part in the product and need to be able to take a direct hit from a thrown object or other vandalism. Exchangeability in LED luminaires on the market is almost none existing and would be an interesting problem to solve. Four different ways to incorporate the LED were elaborated, figure 9.22.

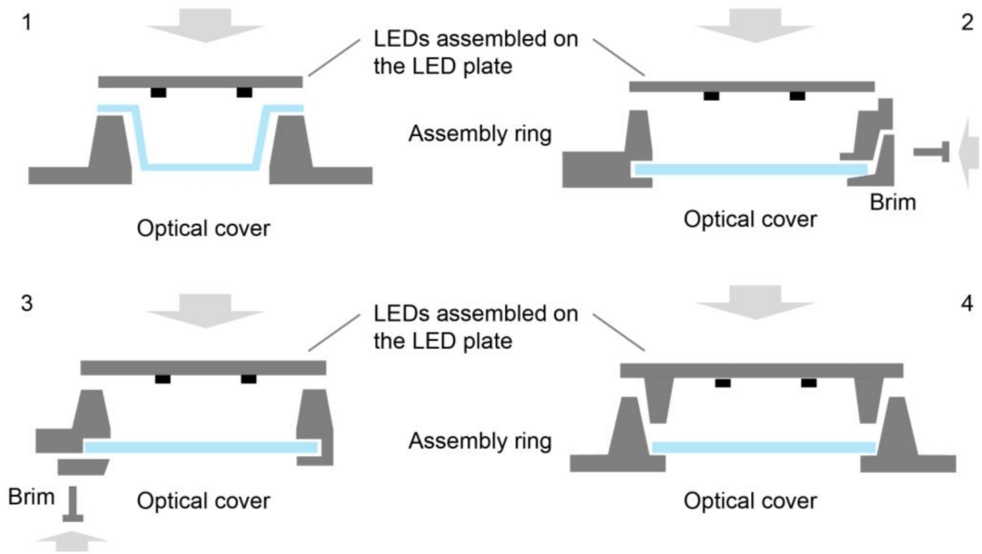

Figure 9.22 Four ways to install the LED and optical cover

The first alternative involves an optical cover in the shape of a container that is positioned in the openings of the assembly ring. The container will rest on a brim that follows the opening on the assembly ring, as can be seen as concept 1 in a simplified cross section drawing in figure 9.22. The LEDs are assembled on a LED plate and the compartment is sealed shut by glue, with a membrane for pressure equalization and to minimize condensation. The LED plate is fixed to the assembly ring by screws or snap fits.

The second one consists of an optical cover that is wedged into the inner opening of the assembly ring and a brim that wedge the cover from the outside. The LED plate is attached on the assembly ring from above, concept 2 in figure 9.22.

Alternative three is similar to the second one but a circular brim is attached on the inner edge of the opening on the assembly ring - fixating the optical cover, concept 3 in figure 9.22.

In the last alternative the LED plate has two borders that encapsulate the LEDs, the two borders press down on the optical covers that rest on the assembly ring, concept 4 in figure 9.22.

Alternative two and three were ways to install the optical cover from beneath allowing the assembly ring to take up the force at an impact instead of a bolted joint or similar. Both alternatives would involve problems on how to seal the LED compartment and disrupt the thought that installation on the assembly ring would occur from above.

Alternative four would mean that the LED plate had to be molded in a fairly complex way, leading to more difficult manufacturing and higher costs. Leaving alternative one that shows the most prospects, and was chosen as the one to develop and implement.

Two ways were considered as attachment to the assembly ring, bolted joints and snap fits. Snap fits would have the advantage that it would be a quick way to assemble and remove the LED package, but it would be weak against outer force. Another aspect to consider is the rate the LED would be replaced, with an expected lifetime of at least five to ten years replacement can't be considered frequent. Bolted joints would be an almost as easy and quick way to attach the plate as well as it would strengthen the resilience to outer force and was therefore chosen as the way to attach the LED plate to the assembly ring, figure 9.23.

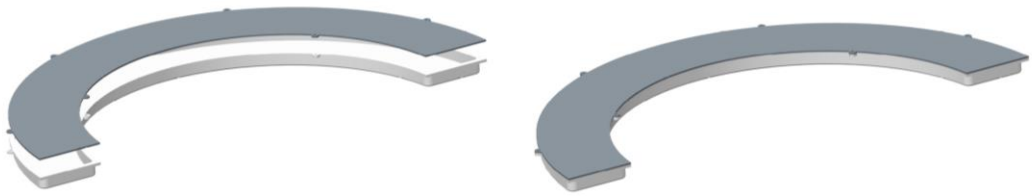

Figure 9.23 LED container

9.8 Structure analysis

A simplified model was constructed in ANSYS to analyze the stress that arises when the luminaire is exposed to wind. The force from the drag were calculated with equation 2

$$F_d = \frac{1}{2}\rho v^2 C_d A \qquad (2)$$

Where F_d is the drag force, ρ is the density of air, v is the wind speed, C_d is the drag coefficient and A is the cross section area. The density of air was approximated to 1.2 kg/m3, the drag coefficient to 0.5 because of its spherical shape and the cross section area to 0.6*0.15 m2. The wind speed that the luminaire needs to withstand is approximated to 30 m/s. This resulted in a wind force of 24.3 N and a safety coefficient of 4 were applied because of the uncertainties in the variables that were used to calculate the force and the fact that the gust can be higher than 30 m/s. The consequence of a breakdown could result in harm to people and the safety coefficient ensures that the luminaire won't fall down even at greater winds than 30 m/s. The force that was calculated was similar to what the transport administration recommends. When calculating the force from wind according to *vägutrustning* 94

[29.pp, 3-5] the result was 90 N. So the calculated force of 97.2 N is a good approximation.

9.8.1 Static analysis

The element for the FEM analysis were a *4 node shell 181* with a thickness of 3 millimeter. The material was assumed to be aluminum with a Young's modulus of 70,000 N/mm2 and a Poisson's ratio of 0.34. The cross section of the two struts were set to 15 by 30 millimeter, the height of the outer flange to 15 millimeter and the height of the support flange for the LED were set to 10 millimeter. The top part of the luminaire was not included in the analysis because of the assumption that it will not be loadbearing. The meshed model can be seen in Figure 9.24.

Figure 9.24 The meshed FEM model

The lower part of the struts where it will be clamped by the "pole attachment part" (see Figure 9.11) were locked in all directions. Two load cases were analyzed and in both cases the force were applied to the outer flange. In the first case the force were applied in X-direction and the second in Y-direction. Figure 9.25 shows the Von Mises stress from the first load case.

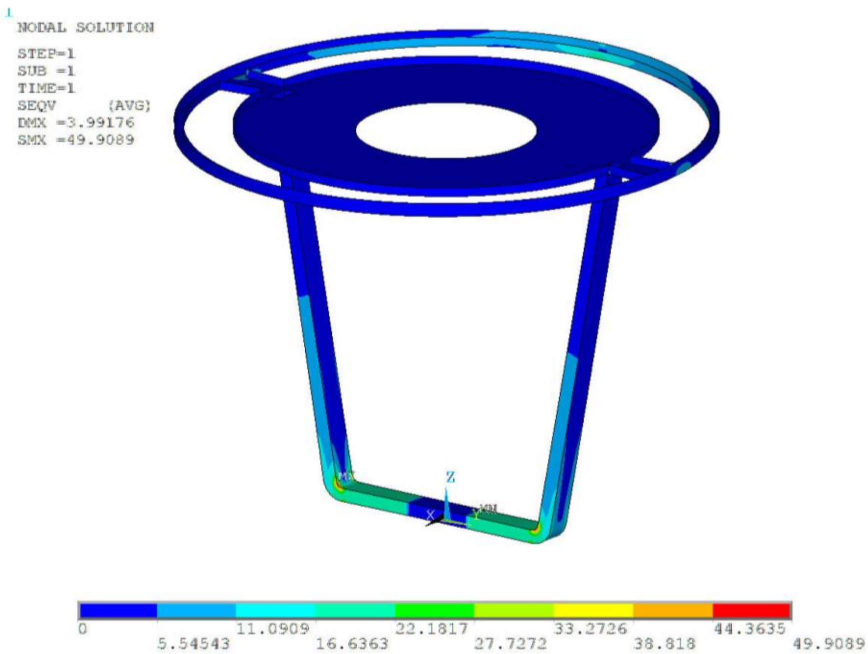

Figure 9.25 Von Mises stress in the structure for load case 1.

The maximum stress in the structure occurred where the struts are rounded and was 49.9 MPa. The maximum deflection was 3.99 mm located where the force was applied. Some stress concentrations occurred on the assembly ring were the LED container is supposed to be attached. In Figure 9.26 the Von Mises stress for the second load case where the force is applied in the Y-direction can be seen.

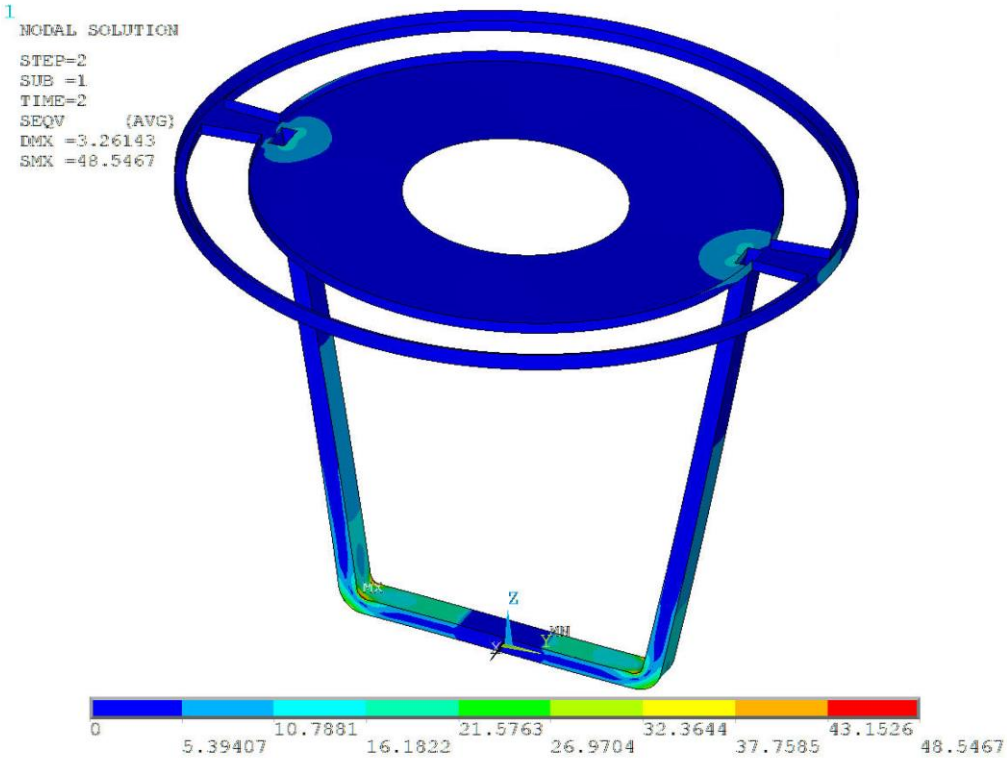

Figure 9.26 Von Mises stress in the structure for load case 2.

The maximum stress in this case appeared on the same place as for load case one. The maximum deflection was 3.26 mm. In this case some stress concentration occurred where the struts is attached to the assembly ring.

The deflections for the structure was assessed to be acceptable considering the rather large force that were applied. For aluminum alloys the tensile strength varies from 200-600 MPa, a stress concentration of 49 MPa is in the limit even considering fatigue. The fatigue limit for aluminum alloys cannot be defined [30.p,223], but considering the high safety coefficient applied on the force and the high wind speed to achieve that force the design were at this point in the judged to be strong enough.

9.8.2 Modal analysis

The force from the wind will not be static and therefore a modal analysis was conducted to identify the all the Eigen frequencies for the structure from 0-5 Hz. In the analysis 12 Eigen frequencies were identified and can be seen in appendix J. Out of those twelve four significant frequencies were identified: set 1, set 2, set 3 and set 4. In set 1 the whole structure swayed around the Y axis, set 2 it swayed around the X axis, set 3 the assembly ring waggled around the attachment points and in set 4 the assembly ring rotated around the Z axis. The other frequencies the inner ring and/or the outer ring deflected relative to each other. This motion will be stabilized by the LED container and the forces to achieve such motion are not realistic.

9.9 Prototype

A 3D printed prototype of the finished concept was made in scale 1:2, figure 9.27.

Figure 9.27 3D printed prototype of the finished concept

10 Result

The final product concept is a lamp platform that primarily provides the ability to install different types of axis cameras, figure 10.1. The platform also allows installation of other sensors or accessories which is powered and communicates with PoE. The platform is developed to install on poles in outdoor environments and appeal to municipality that wants to follow the smart/safe city trend.

Figure 10.1 Renderings of the final result with a PTZ camera installed

Figure 10.2 Exploded view of the concept

All of the installations and repairs of the luminaire will be performed from the top for easy access, figure 10.2. The camera is attached in the center of a ring by using a cover plate that is screwed on to the assembly ring and the camera then rest on this and is clamped down with a bracket. This installation method applies to fixed dome and Pan-Tilt-Zoom cameras.

The cover plates hole where the dome will be lowered down and the height of the bracket needs to be different for different camera models. The P12 cameras will be installed by attaching housing to the assembly ring the same way as the cover ring is attached. In this housing the P12 cameras are mounted on adjustable holders that allow the camera view to be configured to meet the demands. When there is no need for a camera a dummy plate will replace the camera and in this other accessories can be installed.

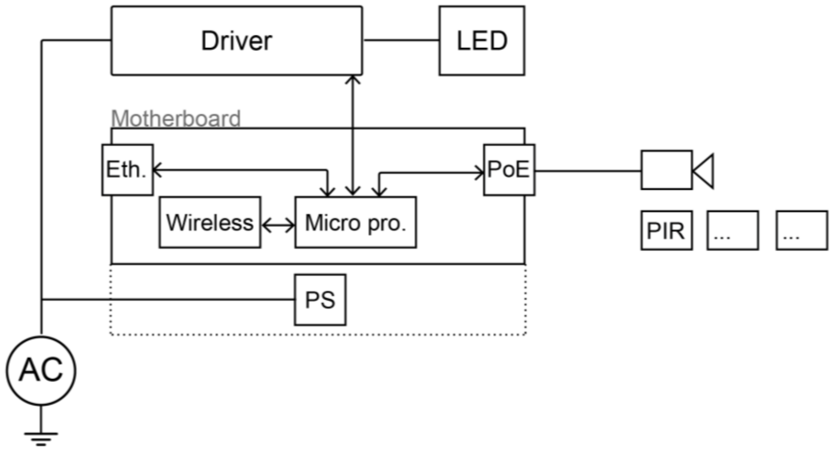

Figure 10.3 The system architecture

All luminaries will include the motherboard which is the brain of the luminaire and allows communication from luminaire to luminaire and from the luminaire to a management system. The motherboard will control the driver which is dimmable. This makes it possible to control the light and by doing so reduce the energy consumption. The reduction will come from the cameras ability to identify motion and illumination levels or a PIR sensor that identifies motion. By doing so the light output will not be higher than necessary. The luminaire to luminaire communication allows one sensor equipped luminaire to control the non-equipped. This possibility to create a meshed network with intelligent sensor equipped platforms adds value to the product concept and makes it fit into the safe/smart city concept. The system architecture can be seen in figure 10.3.

The final concept design is shown in a rendering it one of the intended environments in figure 10.4.

Figure 10.4 Rendering in environment

11 Further development

The presented concept is in an early prototype state and not all aspects of it have been investigated. The reflector and diffuser design is important for the light distribution and has to be considered for future work. A consortium called Zhaga is working on standardization for LEDs that will define an interface between luminaires, LEDs and driver. At the point of this development process the book defining the standard for the outdoor segment were not finished. The authors recommend that in a further development follow this standard to increase the substitutability of the lighting components.

The product will be installed in environments where it might be exposed to vandalism and because of this it needs to be IK classified. How high the classification needs to be must be investigated and tested and suitable materials must be chosen for the design. No cost analysis were conducted for the material and manufacturing of the product.

One of the aims with the product was to make it adaptable to the existing infrastructure. To achieve this goal wireless communication were demanded. In the future development the wireless communication might be considered not to be included and only focus on new installations where an Ethernet cable is drawn to each pole.

Axis has a video management system that controls its cameras. For the concept to work the management system needs to be extended or a new system developed to also include lightning control for the luminaire.

12 Discussion

Considering the broad brief of the project given by Axis at the start up, with only a directive to develop a product combining a lamp and a camera rendered it difficult to develop a suitable methodology. But we believe we found a method that suited this project quite well. Early in the project it was determined with Nina and Michaela from technology management that we should cooperate in the beginning for our projects to make sure we found an appropriate market and application for the product, although we knew that this would render less time for development and design. But we all felt that this would produce a better result for Axis considering both projects would have the same prerequisites.

The parts that we cooperated in were the pre-study and ideation of different environments and applications. The ideation together with Nina and Michaela was a very exciting and interesting part of the thesis, it was very efficient with four people from four different educations working together and contributing with different expertise. The ideation yielded many ideas, some more plausible than others. The criteria's from the ideation was something we used throughout the entire project and tried to incorporate in all parts of the concept.

The pre-study that was conducted feel very thorough and it is our strong belief that we found a suitable market and application were a camera and a lamp can be combined. After this phase was concluded we should probably have had a review of the result and put up a new list of requirements and especially delimitations because of the time spent with the pre-study and deciding an environment was very time consuming.

During the collection of information in the pre-study but also in later phases of the thesis, people at Axis were very helpful. All took time in their schedule to meet us which we appreciate highly. This is probably something we could and should have utilized further throughout the project.

Exploring the decided segment and its customers were a tricky part, partly because municipalities are a complex area with many stakeholders and different conditions with infrastructure. But also because of the confidentiality of the project, we couldn't speak as freely with all people outside of Axis as we would have wanted. Although at large we think we managed to collect a good set of customer needs and requirements for the product which helped us in the concept generation, selection and refinement.

Dividing the concept generation in two parts with technology and design felt natural, partly because of the nature of the product but also considering our different backgrounds in education. During the concept generation considering design a lot of different concepts were produced, what we had problem with was the opportunity to develop some of the concepts further considering the time aspect. Some of the concepts rejected might have advantages towards the selected concept we haven't considered. In the beginning of the concept generation we worked with the perception that the incorporated camera should be a small bullet camera. The concept generation and the open attitude towards different concepts helped free our attitude.

We did not get at all as far as planned from the beginning of the project. In part because it is a very big project with many different aspects and partially because we had problems during this part and changed a number of aspects of the design very late in the process. We did not have time to look at some of the technical solutions when it comes to attachment between different parts in the construction nor look as deep into material and manufacturing that was given as a brief from Axis and an intention from our part. Initially the idea was to create a fully functional "mother board" for the prototype, and be able to control the lamp and camera. At this stage it is unfortunately left in a concept stage.

As a whole we believe that this project has been very rewarding for our part and we have learned a lot about how things work at an industry leading company and how a product development of this dignity works. Hopefully this project can inspire and function as a foundation for further development of this or other projects in Axis future.

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Image References

Figure 1.1 Fox6 News tour Tutwiler prison (Electronic)

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Figure 1.2 Axis P1214-E Network camera (Electronic)

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Figure 7.2 Driving LEDs: How to Choose the Right Power Supply (Electronic)

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Figure 7.3 Driving LEDs: How to Choose the Right Power Supply (Electronic) http://www.digikey.com/en/articles/techzone/2011/may/driving-leds-how-to-choose-the-right-power-supply, 2014-06-01

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Figure 9.1 Philips StreetSaver LED (Electronic)

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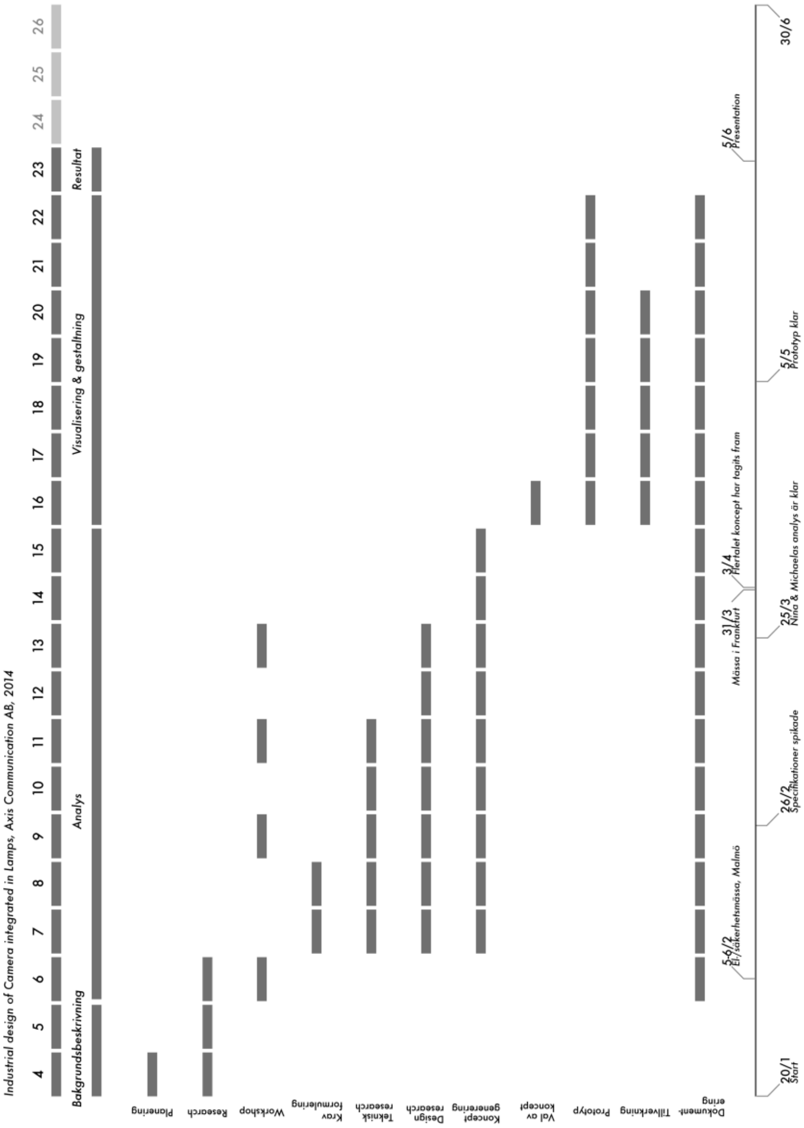
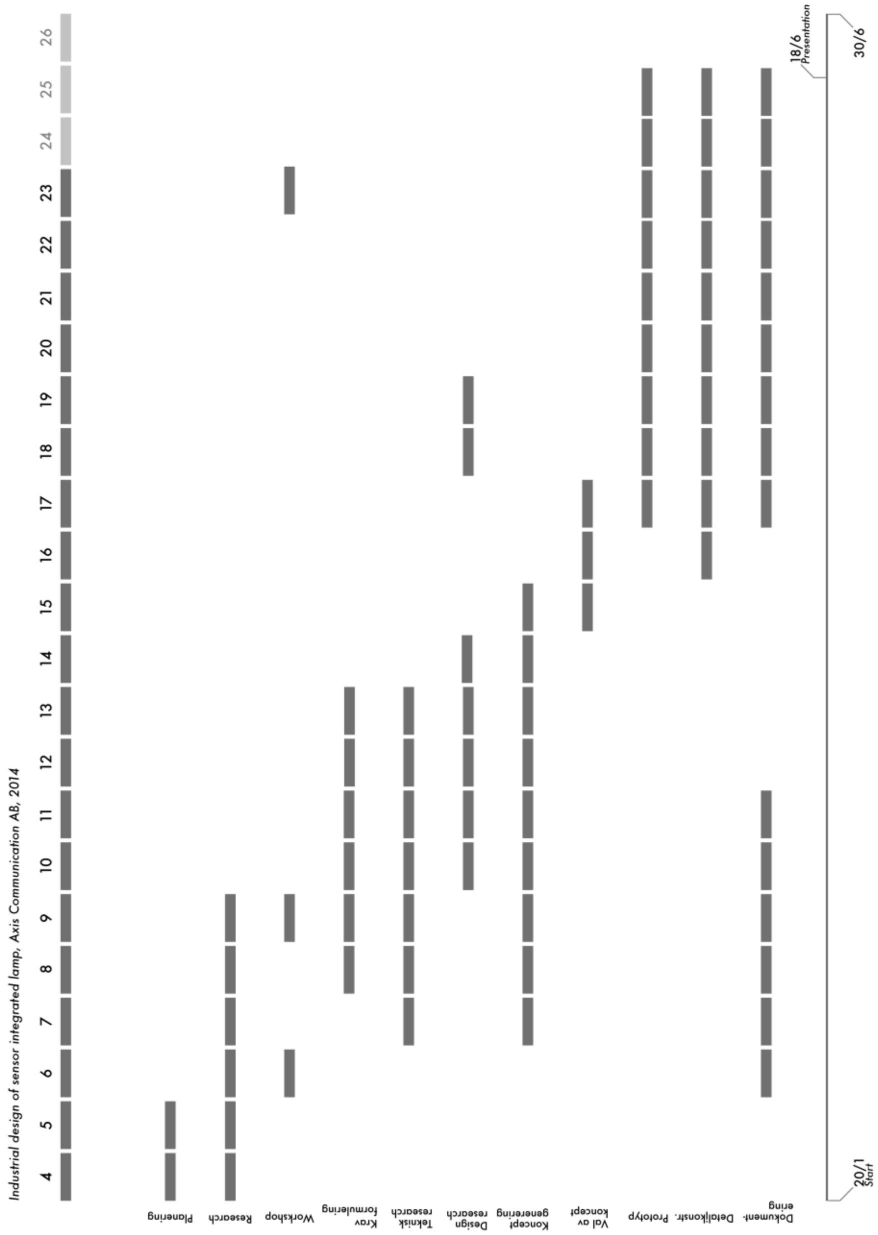
Appendix A: Project plan

The intended project plan from the beginning of the project.



The outcome of the project.



The most part of the Master thesis is written in collaboration between the two authors, but in the technology chapter Anton Östberg has had a leading role. Whereas in the design part of the Master thesis Henrik Lundgren had more responsibility.

Appendix B: Interview guide, Axis personnel

The interview guide used when interviewing Axis employees within three different segments; retail, transportation and city surveillance.

1. Vad är din roll inom Axis?

2. Hur ser du på trenderna inom ditt segment och marknaden.

2b. Finns det särskilda i trender i de olika länderna/marknaderna?

2c. Hur såg ditt segment ut för några år sedan? Hur har utvecklingen sett ut?

3. Hur ser försäljningsstatistiken ut inom ditt segment? Har du någon data på det?

4. Vad finns det för konkurrenter inom ditt segment?

5. Vad ser du för problem med övervakning inom ditt segment?

6. Vilka är de viktigaste länderna inom ditt område?

7. Finns det särskilda regler/bestämmelser inom ditt område som är viktigt att tänka på?

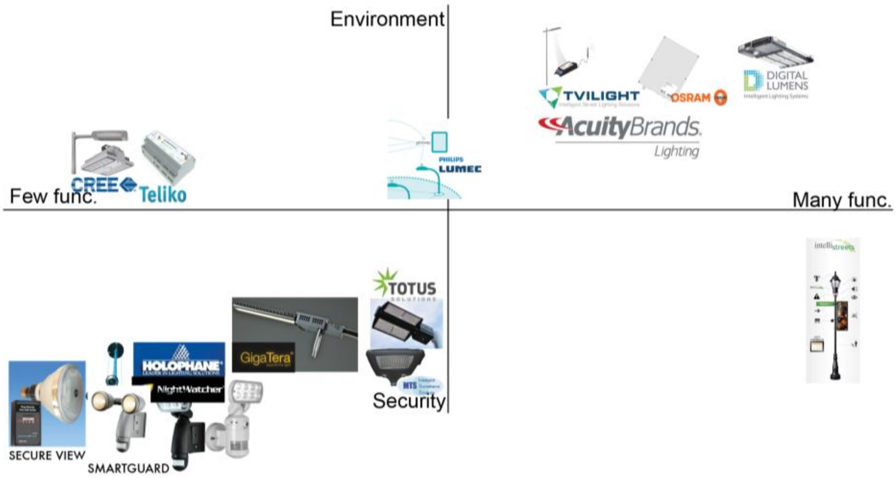
8. Vad är det primära syftet med övervakning inom ditt segment?

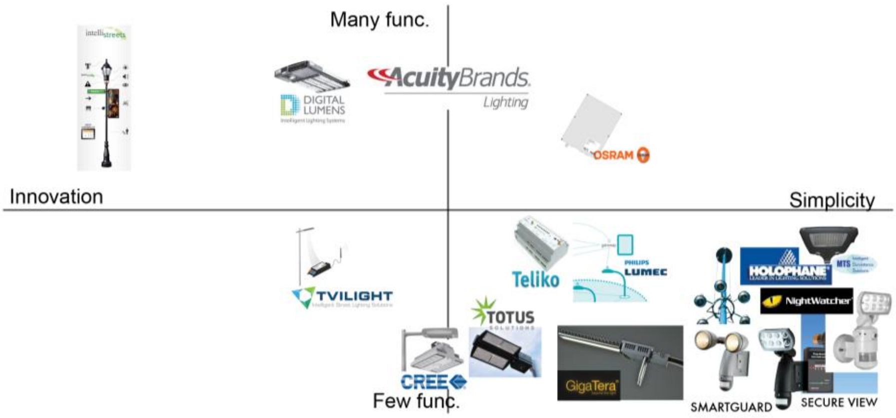
9. Hur tror du framtiden för övervakning inom ditt segment ser ut?

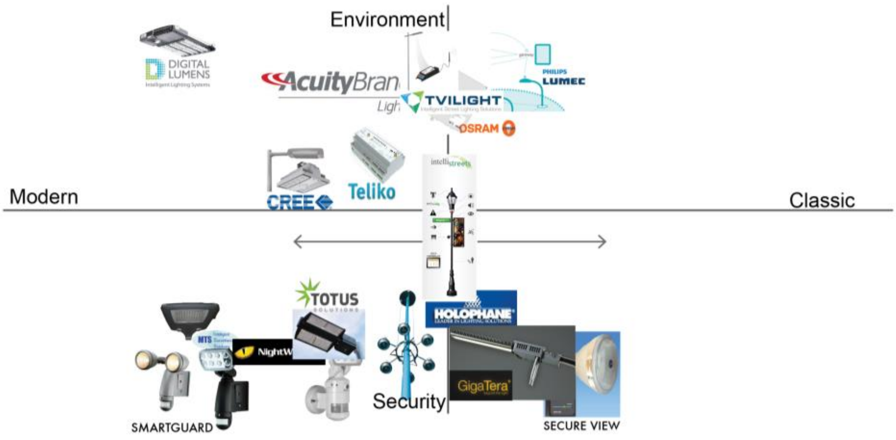
10. Vad tror du det finns för möjligheter med lamp/kamera-produkten inom ditt segment (banking, retail, transportation)

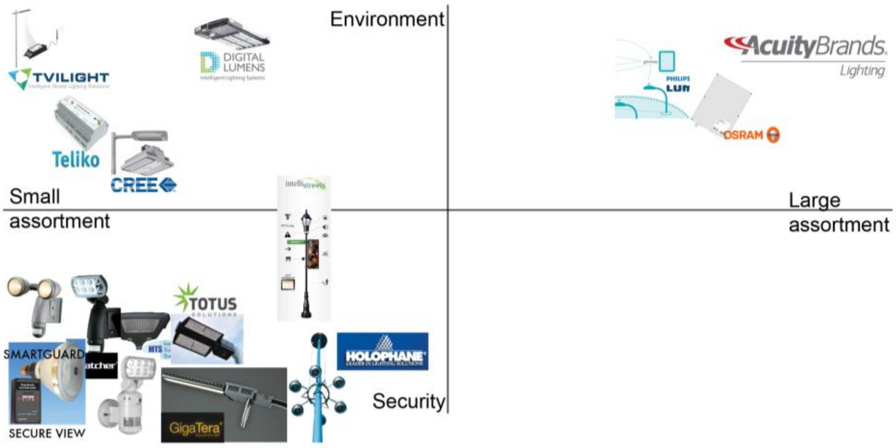
Appendix C: Product matrices

Product matrices used to find sweet spots in the market.






Environment
DIGITAL LUMENS
AcuityBran
TVILIGHT
LUMEC
OSRAM
Teliko
CREE
Modern
Classic
TOTUS
HOLOPHANE
Security
GigaTera
SMARTGUARD
SECURE VIEW


Environment
TVILIGHT
DIGITAL LUMENS
AcuityBrands
Lighting
OSRAM
Teliko
CREE
Small
assortment
Large
assortment
TOTUS
SMARTGUARD
HOLOPHANE
SECURE VIEW
GigaTera
Security

Appendix D: Function analysis

Funktion	Klass	Anteckning
Erbjuda ljus	HF	
Medge kamerainstallation	N	
Äga design	N	
Vara nytänkande	Ö	
Skapa mervärde	N	
Vara robust	N	
Vara integrerad	N	
Underlätta inställningar	Ö	
Skapa trygghet	Ö	
Möjliggöra kontroll	Ö	
Vara miljövänlig	Ö	
Efteranpassa infrastruktur	N	
Säkerställa ljuskvalitet	N	
Säkerställa bildkvalitet	N	
Erbjuda helhetslösning	N	
Skapa stämning	Ö	
Utstråla kvalitet	Ö	
Vara modulär	Ö	
Användbar kameravinkel	N	
Lösa behov	N	
Skydda innehåll	N	
Medge placering	N	
Vara återvinningsbar	Ö	
Erbjuda dimring	Ö	
Tåla väder	N	
Tåla omgivning	N	
Tåla temperaturintervall	N	
Undvika bländning	N	
Medge distansinställning	Ö	
Uttrycka trygghet	Ö	

Uttrycka säkerhet	Ö
Äga täthet	N
Medge rengöring	N
Medge öppning	Ö
Underlätta rengöring	Ö
Motstå nedsmutsning	Ö

Appendix E: AHP

The full AHP generated excel files.

	1	2	3	4	5	6	7
1. Ökad faktisk säkerhet	1.00	0.13	3.00	1.00	0.20	1.00	0.33
2. Ökad upplevd trygghet	8.00	1.00	6.50	2.00	0.33	3.00	1.00
3. Återvinningsbar	0.33	0.15	1.00	0.20	0.20	0.33	0.33
4. Energibesparing	1.00	0.50	5.00	1.00	0.50	0.33	0.33
5. Förenkla kamerainstallation	5.00	3.00	5.00	2.00	1.00	0.50	1.00
6. Möjlighet att kontrollera	1.00	0.33	3.00	3.00	2.00	1.00	3.00
7. Design/Estestik	3.00	1.00	3.00	3.00	1.00	0.33	1.00
Summa	19.33	6.11	26.50	12.20	5.23	6.50	7.00

Weighted	1	2	3	4	5	6	7	Weight	PRIO
1. Ökad faktisk säkerhet	0.05	0.02	0.11	0.08	0.04	0.15	0.05	0.07	6
2. Ökad upplevd trygghet	0.41	0.16	0.25	0.16	0.06	0.46	0.14	0.24	1
3. Återvinningsbar	0.02	0.03	0.04	0.02	0.04	0.05	0.05	0.03	7
4. Energibesparing	0.05	0.08	0.19	0.08	0.10	0.05	0.05	0.09	5
5. Förenkla kamerainstallation	0.26	0.49	0.19	0.16	0.19	0.08	0.14	0.22	2
6. Möjlighet att kontrollera	0.05	0.05	0.11	0.25	0.38	0.15	0.43	0.20	3
7. Design/Estestik	0.16	0.16	0.11	0.25	0.19	0.05	0.14	0.15	4
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

Appendix E: AHP

Ökad faktiskt säkerhet	Gator &	Universit	Privathem	Parkering	Mobil-lösning
Gator & Torg	1,00	5,00	0,50	1,00	0,14
Universitet & Skola	0,20	1,00	0,20	0,33	0,13
Privathem	2,00	5,00	1,00	1,00	0,14
Parkering	1,00	3,00	1,00	1,00	0,15
Mobil-lösning	7,00	8,00	7,00	6,50	1,00
Totalt	11,20	22,00	9,70	9,83	1,56

Ökad upplevd trygghet	Gator &	Universit	Privathem	Parkering	Mobil-lösning
Gator & Torg	1,00	0,25	1,00	1,00	5,00
Universitet & Skola	4,00	1,00	3,00	0,33	4,00
Privathem	1,00	0,33	1,00	0,33	4,00
Parkering	1,00	3,00	3,00	1,00	4,00
Mobil-lösning	0,20	0,25	0,25	0,25	1,00
Totalt	7,20	4,83	8,25	2,92	18,00

Återviningsbar	Gator &	Universit	Privathem	Parkering	Mobil-lösning
Gator & Torg	1,00	2,00	4,50	1,00	0,25
Universitet & Skola	0,50	1,00	4,00	0,50	0,20
Privathem	0,22	0,25	1,00	0,33	0,14
Parkering	1,00	2,00	3,00	1,00	0,20
Mobil-lösning	4,00	5,00	7,00	5,00	1,00
Totalt	6,72	10,25	19,50	7,83	1,79

Energibesparingspotenti al	Gator & Torg	Universit et & Skola	Privathem	Parkering	Mobil-lösning
Gator & Torg	1,00	4,	7,	2,	7,00
Universitet & Skola	0,25	1,	5,	0,5	4,50
Privathem	0,14	0,2	1,	0,25	4,00
Parkering	0,50	2,	4,	1,	5,00
Mobil-lösning	0,14	0,22	0,25	0,2	1,00
Totalt	2,04	7,42	17,25	3,95	21,50

Förenkla kamerainstallation	Gator & Torg	Universit et & Skola	Privathem	Parkering	Mobil-lösning
Gator & Torg	1,00	4,00	0,50	1,00	0,17
Universitet & Skola	0,25	1,00	0,33	0,33	0,14
Privathem	2,00	3,00	1,00	3,00	0,25
Parkering	1,00	3,00	0,33	1,00	0,17
Mobil-lösning	6,00	7,00	4,00	6,00	1,00
Totalt	10,25	18,00	6,17	11,33	1,73

Möjlighet att kontrollera	Gator & Torg	Universit et & Skola	Privathem	Parkering	Mobil-lösning
Gator & Torg	1,00	5,00	3,00	3,00	1,00
Universitet & Skola	0,20	1,00	2,00	1,00	0,50
Privathem	0,33	0,50	1,00	0,50	0,33
Parkering	0,33	1,00	2,00	1,00	0,50
Mobil-lösning	1,00	2,00	3,00	2,00	1,00
Totalt	2,87	9,50	11,00	7,50	3,33

Design/estetik	Gator & Torg	Universit et & Skola	Privathem	Parkering	Mobil-lösning
Gator & Torg	1,00	1,00	0,17	5,00	5,00
Universitet & Skola	1,00	1,00	0,20	6,00	5,00
Privathem	6,00	5,00	1,00	8,00	9,00
Parkering	0,20	0,17	0,13	1,00	3,00
Mobil-lösning	0,20	0,20	0,11	0,33	1,00
Totalt	8,40	7,37	1,60	20,33	23,00

Ökad faktiskt	Gator & Torg	Universitet & Skola	Privathem	Parkering	Mobil-lösning	Weight
Gator & Torg	0,09	0,23	0,05	0,10	0,09	0,11
Universitet &	0,02	0,05	0,02	0,03	0,08	0,04
Privathem	0,18	0,23	0,10	0,10	0,09	0,14
Parkering	0,09	0,14	0,10	0,10	0,10	0,11
Mobil-lösning	0,63	0,36	0,72	0,66	0,64	0,60
Totalt	1	1	1	1	1	1,00

Ökad upplevd	Gator & Torg	Universitet & Skola	Privathem	Parkering	Mobil-lösning	Weight
Gator & Torg	0,14	0,05	0,12	0,34	0,28	0,19
Universitet &	0,56	0,21	0,36	0,11	0,22	0,29
Privathem	0,14	0,07	0,12	0,11	0,22	0,13
Parkering	0,14	0,62	0,36	0,34	0,22	0,34
Mobil-lösning	0,03	0,05	0,03	0,09	0,06	0,05
Totalt	1,00	1,00	1,00	1,00	1,00	1,00

Återviningsbar	Gator & Torg	Universitet & Skola	Privathem	Parkering	Mobil-lösning	Weight
Gator & Torg	0,15	0,20	0,23	0,13	0,14	0,17
Universitet &	0,07	0,10	0,21	0,06	0,11	0,11
Privathem	0,03	0,02	0,05	0,04	0,08	0,05
Parkering	0,15	0,20	0,15	0,13	0,11	0,15
Mobil-lösning	0,60	0,49	0,36	0,64	0,56	0,53
Totalt	1,00	1,00	1,00	1,00	1,00	1,00

Energibesparingspotential	Gator & Torg	Universitet & Skola	Privathem	Parkering	Mobil-lösning	Weight
Gator & Torg	0,49	0,54	0,41	0,51	0,33	0,45
Universitet & Skola	0,12	0,13	0,29	0,13	0,21	0,18
Privathem	0,07	0,03	0,06	0,06	0,19	0,08
Parkering	0,25	0,27	0,23	0,25	0,23	0,25
Mobil-lösning	0,07	0,03	0,01	0,05	0,05	0,04
Totalt	1,00	1,00	1,00	1,00	1,00	1,00

Förenkla kamerainstallation	Gator & Torg	Universitet & Skola	Privathem	Parkering	Mobil-lösning	Weight
Gator & Torg	0,10	0,22	0,08	0,09	0,10	0,12
Universitet & Skola	0,02	0,06	0,05	0,03	0,08	0,05
Privathem	0,20	0,17	0,16	0,26	0,14	0,19
Parkering	0,10	0,17	0,05	0,09	0,10	0,10
Mobil-lösning	0,59	0,39	0,65	0,53	0,58	0,55
Totalt	1,00	1,00	1,00	1,00	1,00	1,00

Möjlighet att kontrollera	Gator & Torg	Universitet & Skola	Privathem	Parkering	Mobil-lösning	Weight
Gator & Torg	0,35	0,53	0,27	0,40	0,30	0,37
Universitet & Skola	0,07	0,11	0,18	0,13	0,15	0,13
Privathem	0,12	0,05	0,09	0,07	0,10	0,09
Parkering	0,12	0,11	0,18	0,13	0,15	0,14
Mobil-lösning	0,35	0,21	0,27	0,27	0,30	0,28
Totalt	1,00	1,00	1,00	1,00	1,00	1,00

Design/estetik	Gator & Torg	Universitet & Skola	Privathem	Parkering	Mobil-lösning	Weight
Gator & Torg	0,12	0,14	0,10	0,25	0,22	0,16
Universitet & Skola	0,12	0,14	0,12	0,30	0,22	0,18
Privathem	0,71	0,68	0,62	0,39	0,39	0,56
Parkering	0,02	0,02	0,08	0,05	0,13	0,06
Mobil-lösning	0,02	0,03	0,07	0,02	0,04	0,04
Totalt	1,00	1,00	1,00	1,00	1,00	1,00

	Säkerhet	*Trygghet*	*Återvinningsbar*	*Energibesparings potential*	*Förenkla kamerainstallation*	*Möjlighet att kontrollera*	*Design/Estetik*	**Total**	PRIO
Gator & Torg	0,01	0,04	0,01	0,04	0,08	0,08	0,02	**0,28**	1
Universitet & Skola	0,00	0,07	0,00	0,02	0,01	0,03	0,03	**0,15**	5
Privathem	0,01	0,03	0,00	0,01	0,04	0,02	0,08	**0,19**	3
Parkering	0,01	0,08	0,00	0,02	0,02	0,03	0,01	**0,17**	4
Mobil-lösning	0,04	0,01	0,02	0,00	0,12	0,06	0,01	**0,26**	2

Appendix F: Interview - municipalities

Interview guide, used for interviews with municipalities.

Berätta gärna lite fritt om dig själv och vilken roll du har på _______________ kommun.

- Hur fungerar processen vid inköp av belysning och annan utrustning inom ditt segment?
  - Hur skiljer sig inköpen av själva belysningen och annan utrustning?

- Vilka trender ser du inom belysning?

- Vad är dina egna visioner för belysning?

- Hur ser du på styrning av belysning på olika sätt?

- Vilka är nyckelfunktionerna hos produkterna när beslut av inköp tas? (Inom gatubelysning, parkbelysning och fasadbelysning)

- Hur ser du på användningen av belysning för att öka trygghet och säkerhet?

- Vilken är din syn på andra medel för trygghet/säkerhet, så som videoövervakning och liknande?
  - Skulle inköp av sådan utrustning landa på en annan avdelningoch på så sätt försvåra inköpen?

- Vilka andra sätt finns för att öka trygghet/säkerhet tror du?

- Hur ser reglementet ut inom belysning inom kommunen, är den begränsade för din eller er vision av belysningen?

Appendix G: Survey

Survey questions to the 20 largest municipalities in Sweden.

Questions:

1. Vilka är de största kostnaderna när det gäller utomhusbelysning?
2. Vilka är de största kostnadsposterna när det gäller övrig utomhusförvaltning?
3. Är det något underhåll som tar extra stort tidsutrymme i anspråk?
4. Finns det något i underhållet i komunen som skulle kunna underlättas genom automatiserad övervakning?

Answer from the municipalities:

Göteborg (Magnus Eklund, planeringsledare trafikkontoret):

1. Cirka 60 % av kostnaden är underhåll av ljuspunkten.
2. –
3. –
4. –

Helsingborg (Anna Henningsson, Stadsbyggnadsförvaltningen drift och underhåll) :

1. Förhållandet energi-drift är att energin kostade förra året 11,7 milj. Kr. och underhållet 9,1 milj. Kr, och där är allt med typ påkörningar, vandalisering, kabelfel, byte av ljuskällor m.m. Staden har drygt 28.000 st ljuspunkter.
2. Det beror på vad som ni anser innefattas av utomhusförvaltning. Gäller det både drift och underhåll och både gata och park?Gällande driftskostnader på park så är skötsel av bruksgräsmatta en stor post då det handlar om så stora ytor, likaså underhållet av stadens gator i form av beläggningsprogrammet.
3. Det som jag kan komma på där det finns möjligheter till automatiserad övervakning är gällande papperskorgar som är fulla eller trasig gatubelysning. När det gäller papperskorgar så kan automatiseringen leda till att man får lägga om sina rutter eftersom olika papperskorgar blir fulla olika snabbt, idag töms papperskorgarna regelbundet på bestämda tider vilket såklart gör att vi tömmer papperskorgar som kanske inte är helt fulla. Frågan är dock om det skulle bli billigare och mer effektivt, men risken för överfulla papperskorgar skulle minimeras. Automatiserad

övervakning på gatubelysnigen kan vara en bra lösning då vi idag förlitar oss på felanmälning från invånarna när en lampa är trasig, eller att vi själva eller entreprenören upptäcker det.Hör gärna av er om ni har fler frågor och lycka till med ert examensarbete!

Huddinge (Lars Lantz, Chef gatu- och parkdriftsavdelningen):

1. För Huddinges del är elkostnaden den största kostnaden på belysningssidan.
2. För övrig drift och underhållsverksamhet är vinterväghållning, städning och asfaltsbeläggning det i särklass mest kostsamma drift och underhållsåtgärderna.
3. Tidsmässigt är nog städning det mest tidsödande arbetet.
4. Allt drift och underhållsarbete underlättas av bra meoder för övervakning, felrapportering och uppföljning.

Södertälje (Kurt Ackerblad, Planerings ingengör) :

1. 75% el, 25% övriga driftåtgärder
2. 22% beläggningsunderhåll, 34% gatubelysning. 24% barmarksrenhållning (gröna ytor (slåtter vägdiken), trafikanordningarm trafiksignaler, konstbyggnader (broar) och dagvatten)
3. Gatubelysning tar mycket tid hela året med avseende på anmälningar av trasiga ljuskällor.
   Beträffande det övriga så är mycket fördelat per säsong.
4. Det vi idag har är driftövervakning av trafiksignaler så när det blir något fel så går larmet till entreprenören för åtgärd av felet.

The municipalities that did not answer:

- Stockholm
- Malmö
- Uppsala
- Linköping
- Västerås
- Örebro
- Norrköping
- Jönköping
- Umeå
- Lund
- Borås
- Sundsvall
- Eskilstuna
- Gävle
- Halmstad
- Nacka

Appendix H: Customer statement

Customer statement or pre-study findings	Interpreted need
• Customers has high demands on certification, interview with Patrik Andersson, transportation • Procurement within lighting is a thorough process, which can be widely different from case to case. It could be a matter of technical matters that the luminaire need to achieve; e.g. IP class, interview with Martin Hadmyr - Helsingborg stad • In Malmö stad all luminaires and lights are thoroughly tested in a 3-4 year process, Johan Moritz - Malmö Stad.	• The product need to be vandal resistant • The product need to withstand weather conditions.
• Insects are attracted to light, maintenance of the product is a problem. Interview with Timo Sachse at Axis	• Prevent insect nesting • The product need to be resistant to cleaning and cleansing agent
Requirement	Resistant to external and internal temperature
To reside in an environment where colors become clear can improve the feeling of safety, contrary to environments with low color rendering index where difficulty to distinguish faces and color of clothes will feel unsafe, from the report Trygghetsprogram Malmö Stad.	High Color Rendering Index
• Procurement within lighting is a thorough process, which can be widely different from case to case. It could be a matter of technical matters that the luminaire need to achieve; e.g. distribution of light. *“Alot of light on the walking path but none around the path will counteract safety. Spotlights on surroundings are important”,* interview with Martin Hadmyr.	• Good distribution of light • The product has an even distribution of light

• Light quality is an important factor in procurement of lighting, interview with Martin Hadmyr.	Satisfying illuminance
One of the master thesis objectives	Enable camera installation
When it comes to a product combining a lamp and a camera, cameras should be placed where the infrastructure is, if the target is light poles - use existing poles. In the future, poles will be the main support for cameras, Andrea Sorri pre-study interview	• Enable pole installation • Fit existing infrastructure, voltage • Fit existing infrastructure, software • Fit existing infrastructure, communication
In the city surveillance segment it is important with a side angle from the camera, not just a top down view, itnerview with Andrea	• Camera angle for face recognition • Overview camera angle
• Installers could be a problem for such a product, they need to be trained or scaled up to install a camera and not just lighting equipment. • Installation is one of the important factors regarding procurement of lighting in Jönköpings kommun report - Upphandling gatubelysning.	Simple installation
Report broken light fixtures is one of the tasks that could be simplified according to the survey sent out to municipality.	• The product could identify lighting out of function • The product could identify cameras out of function • The product could identify if the lamp post is out of function
Talk with Viktor Gustafsson, PCNI	The product can record in snow or rain
Intelligent or smart lighting is a trend that is noticeable within the lighting market .The idea is that a sensor, software or a combination of them control the lighting conditions based on daylight or occupancy and heightens the efficiency, pre-study.	• The product should measure energy consumption • The product can be guided remotely
When more and more cameras are being deployed the amount of information gather has created a need for	The product should offer video analysis

video analytics, pre study - surveillance market.	
Martin expects energy consumption to go down and lifetime of the light source will go up and that tests have been made with dimmer switches to lower the energy consumption but that they have had problems with maintenance of the equipment. Interview Martin Hadmyr	The product can adjust the light
Talk with Viktor Gustafsson, PCNI.	The product can be installed during rain
Talk with Carl-Axel Alm, PCNI	The product supports a panic button. Featuring a button placed on the pole for emergency situations. Pressing it could increase the light flow, contact emergency telephone numbers etc.
There is no present standard when it comes to replacing broken LED equipment, leading to the entire light fixture being replaced, interview with Johan Moritz.	• The product facilitate repair work • The product can be recycled
Brief from Axis	The product is aesthetic
	The product should avoid light pollution
Ideation process	The product should use low power
	The product minimize glare
Talk with Carl-Axel Alm, PCNI	Enable possibility to install multiple different cameras

Appendix I Image board

Image board of products and surroundings.

Appendix J Modal analysis

Identified Eigen frequencies for the structure.

```
*****  INDEX OF DATA SETS ON RESULTS FILE  *****

   SET   TIME/FREQ    LOAD STEP   SUBSTEP  CUMULATIVE
     1 0.64014           1          1          1
     2 0.65063           1          2          2
     3 0.87840           1          3          3
     4  1.0790           1          4          4
     5  1.5180           1          5          5
     6  1.6120           1          6          6
     7  1.6762           1          7          7
     8  2.1916           1          8          8
     9  4.1576           1          9          9
    10  4.7135           1         10         10
    11  4.7962           1         11         11
    12  4.8206           1         12         12
```