**Semester:** 10th, Spring 2017, LID 4

**Title**: Liquid Light

**Project Period:** 01/02/2017 – 02/06/2017

**Semester Theme:** Master Thesis

Aalborg University Copenhagen
Frederikskaj 12,
DK-2450 Copenhagen SV

Semester Coordinator:
Geogrios Triantafyllidis
gt@create.aau.dk

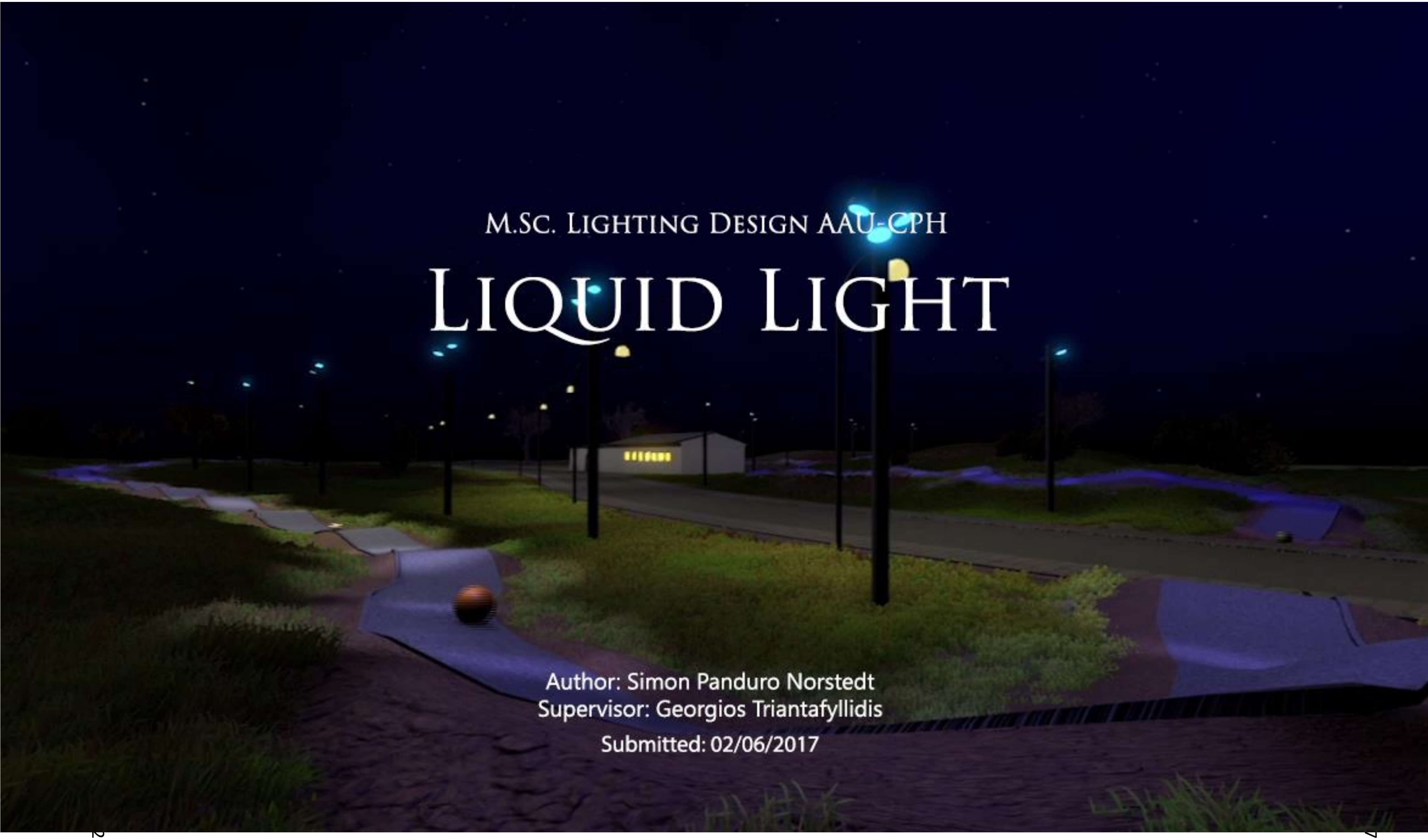
Secretary:
Lisbeth Nykjær

**Supervisor(s):** Georgios Triantafyllidis

**Project group no.:** N/A

**Members:**
Simon Panduro Norstedt
# 20113453

**Abstract:**
The main emphasis of this master thesis project is to provide a qualified answer to the problem statement: *"How can we use lighting to simulate the movement of, and physical interaction with, water on a public pump track, while ensure sufficient visibility?"*. As part of a Lighting Metropolis project centered around creating playful interactions between users of a pump track in Roskilde and the lighting, the thesis serves to support the realization of the project in two aspects: the selection of appropriate components (primarily lighting system, fixtures and sensors), and the development towards using light to simulate the movement of, and interaction with water on a pump track. The solution consists of two main elements; *Visual Expression* and *Layers*. The *visual expression* describes the basic representation of water through pixels. The layers consist of a *functional layer*-responsible for sufficient visibility of the riders, an *aesthetic layer* responsible for the general appearance of the area, and a *behavioural layer*, responsible for the playful direct interaction and indirect interaction on the pump track. Different water codes were developed and tested in Unity. From observations, three characteristics were necessary for simulating the movement of water: smooth and continuous intensity transitions, large variations of intensities, and unpredictability.
Through thorough analysis the different components for the project were selected. The performance of the selected sensor for the project (2D laser scanner) was evaluated based on a test setup imitating the real


M.Sc. Lighting Design AAU-CPH
Liquid Light
Author: Simon Panduro Norstedt
Supervisor: Georgios Triantafyllidis
Submitted: 02/06/2017

# Table of Contents

# 1. Introduction

## 1.1 Project Background

### 1.1.1: Lighting Metropolis

With the goal of becoming the world's leading living lab for smart urban lighting, Greater Copenhagen (eastern Denmark and Skåne) has initiated the EU-funded project - Lighting Metropolis. Regions, municipalities, private businesses and universities are collaborating to develop and showcase innovate lighting solutions, to attract and retain international investments, companies and tourism. The overall aim of Lighting Metropolis is to strengthen the important role lighting can play in promoting safety, accessibility, identity, health, and education for people in cities.

### 1.1.2: Musicon Path

Amongst the approximately 20 projects that is currently undergoing in Lighting Metropolis, one of the projects, *Musicon Path*, was initiated by the interest of Roskilde Municipality to create a *attractive, direct and eventful* biking- and pedestrian path between Roskilde Station and the new district of *Musicon*, Roskilde. The 1km long path between Musicon and Roskilde Station is currently used by a large segment of the people at Musicon.

The *Musicon Path* project was initiated in august 2016, and is as composed of three main partners: Roskilde Municipality - By, Kultur og Miljø, DONG Energy - City Light and the Lighting Design master program at Aalborg University Copenhagen.
I did my internship in the period from August 2016-december 2016, and has since January 2017 been involved in the realization of the project in coherence with the three above-mentioned partners and electrical and lighting engineer Frederik Waneck Borello from ÅF Lighting.

## 1.2 Goals

One of the visions of Musicon is to promote environmentally friendly traffic by prioritizing "soft" road users: people on bikes, pedestrians, skaters etc. By constructing the *Musicon Path*, the aim is to invite people to bike or walk between Roskilde Station and Musicon, instead of taking the car.

As the Musicon-path project is part of the Lighting Metropolis Project with Roskilde Municipality as the main client and project leaders, it is important to understand their intention, visions and expectations for the project.

The lighting design project was initialized with a couple of meetings in September 2016 with the goal of conveying and defining the scope of the project and to share expectations between the main project partners, Roskilde Municipality (Gunilla Rasmussen - project leader), DONG Energy (Tine Byskov Søndergaard - outdoor lighting consultant), and AAU CPH - Lighting Design (me and Esben

Oxholm Bonde - students). The individual objectives along with the shared objectives agreed upon from the meetings, were gathered in a collaboration agreement document. See Appendix 11.1 Collaboration Agreement Document.

Along with the collaboration agreement, information and thoughts about the project was gathered during a walk through the path to Musicon (soon to-be *Musicon Path*) by the project leader Gunilla Rasmussen from Roskilde Municipality. This walk provided a broader perspective of the context of the path and the objectives from the previous mentioned collaboration agreement.
Based on the collaboration agreement and the walk with Gunilla Rasmussen, the information relevant to the development of a lighting design for the path was narrowed down to three main goals and a number of sub-goals:

The lighting design on the Musicon-path needs to:

1. **Invite people to use the path**
   a. Invite people to use the path
   b. Guide people along the path
   c. Invite people to stay and play at the squares
   d. Give the path an identity
2. **Be innovative**
   a. Be able to notify users on the path about events at Musicon
   b. Function as a Living Lab
3. **Be sustainable**

The list below will cover the sub-goals required for accommodating the above mentioned main goals:

**Invite people to use the path**

- The lighting design needs to invite people to use the path. This concerns particularly the segment of users who tend to drive by car or take the bus. The lighting needs to have qualities that can change the minds of this segment.

**Guide people along the path**

- The path to Musicon from Roskilde Station has several turns and it not intuitive for people the first time they walk the route. The lighting design needs to guide the users by signifying directionality and to stress the turns to ensure that no users walk or bikes in the wrong direction

**Invite people to stay and play at the squares**

- Half way through the path, the path crosses through the park - Raadhusparken. In this area, the municipality has planned to build several installations for different activities. With the main theme being *bike play and learning*, multiple biking tracks will be built, including a pump track and a bike track for learning traffic. The lighting design needs to promote these activities and help make people interested to stop and use or observe the activities. A common interest among the project members was that the lighting should be directly interactive with the users in this area.

**Give the path its own identity**

- By providing the path with a clear identity, it is predicted that the knowledge of the path is spread more extensively, and will become more unique. The lighting design along the entire path and at the seven squares needs to be identified as a common theme, creating a coherent identity to the entire path.

**Be innovative**

- As a prerequisite for any Lighting Metropolis Project, the lighting solutions have to be innovative. To keep the budget low, it is however necessary to make the lighting design innovative by combining existing technologies in a new way. An example of this could be to use existing luminaires and sensors in a way that has not been done before - creating a new type of interaction.

**Be able to function as a Living Lab**

- The purpose of Lighting Metropolis is not only to develop new and innovative lighting solutions, but the level at which we can observe and learn from these new solutions, is just as important. This way, the lighting solution should be constructed with the purpose of becoming a kind of Living Lab at which citizens can provide valuable feedback.

**Be able to notify users on the path about events at Musicon**

- The lighting design needs to have the capability of changing when certain events are happening in Musicon. This way, people walking through the path, will be better informed, helping to bridge the gap between Roskilde Station and Musicon.

**Be sustainable**

- For the sake of the environment and to keep the budget at a minimum, the lighting design needs to have low energy consumption.

## 1.3 Initial Problem Statement

During my internship at Lighting Metropolis, the main objective was to come up with an overall lighting design concept for the Musicon-path, accommodating the goals mentioned above. Thus, the initial problem statement serves as the overall guideline for the project, defined as;

*"How can a playful, innovative, interactive and sustainable lighting design concept, invite people to use the Musicon-path?"*

# 1.4 Context Analysis

Prior to engaging in the design process, it is essential to understand the underlying context of the project. Thus, the following section will discuss the project in relation to its larger context and the plans for the Musicon path, along with its users.

## 1.4.1 Larger Context

The municipality of Roskilde is planning to create a path running from Roskilde Fjord (in the northern part of the city), through the city center, continuing through the Musicon area and Dyrskuepladsen to Viby, south of Roskilde. The Musicon Path is the second stage of this larger path project. The main objective of the Musicon Path is to provide a direct, safe, aesthetic and interesting connection for the “soft” road users (pedestrians, bikers, skaters etc.), between the Musicon-area and Roskilde train station (figure 1).

### 1.4.1.1 Musicon

Musicon is a new city district, south of the center of Roskilde, which have been under development since the end of 2007 and is expected to be fully developed in 2030. Prior to the emergence of Musicon, the area has since 1890 been used for agriculture, as an industrial area and a junkyard. The primary industrial usage of the area has revolved around gravel pit and production of concrete.

The main vision of Musicon is to shape a community that allows a great diversity of different cultures, residential and cultural-and leisure activities, in order to create a vibrant environment. With an emphasis on promoting a creative and environmental-friendly community, the area enables visitors and citizens to engage in a large variety of different activities such as dance, theater, music, museums, art and indoor/outdoor skating. While founded under the terms of; *creativity, play and learning,* the vision of Musicon is to shape a community that is densely used, during most hours of the day. The vision is further described in “*Musicon Handleplan 16-19 (Plan og Udvikling, 2015)”*, where five overall goals are formulated as;

**A musical and creative district**

- *Musicon must be based on the growing human and must make space for the district’s actors to collaboration and merge ideas and knowledge.*

**Life before the city - and the city with life**

- *Musicon must have activity throughout most of the day. Different applications should be mixed and temporary activities should create variability, ideas and knowledge through experiments.*

**Experimental construction and industrial traces**

- *Buildings and urban spaces in Musicon should be eventful and challenge the visitors. Musicon has a raw and industrial expression, and projects will build further on the traces in the area.*

**A laboratory for sustainable traffic**

- *Musicon must be a laboratory for sustainable traffic. Musicon must offer the best conditions for pedestrians, cyclists, skaters, and bus and car parking must be the least prominent in the urban environment.*

**An environment-friendly district**

- *Musicon must focus on innovative and sustainable solutions. Impacts of undesirable substances and greenhouse gases must be limited through the usage of new and experimental knowledge.*

When the final plans for Musicon has been established (expected in 2030), it is expected to contain 650 residences, 5.500 m2 detail, minimum of 2000 creative workplaces, 33.000 m2 for culture, 32.750 m2 for education, 15.000 m2 for hotels. 6.000 daily cyclists and 9.000 pedestrians are expected to use the path between Roskilde train station and Musicon. (Plan og Udvikling, 2015)

An important signifier for Musicon is the way in which the area has utilized water during the years. In the early years it was used for industrial purpose in the process of creating concrete, and in 2008, the area implemented a very innovative system for rainwater (Roskilde: Storm Water Skate Park, 2017). The system was built to lead local drainage from Rabalderstræde to a nearby human-made lake. The innovative part of the system is that it is constructed for two purposes: firstly, to lead the water down the street and further on to the lake, and secondly, to allow local users to use the pipe as a half pipe for skating utility when water is not present. This way of combining a water system with a skating utility, is a very unique feature of Musicon.

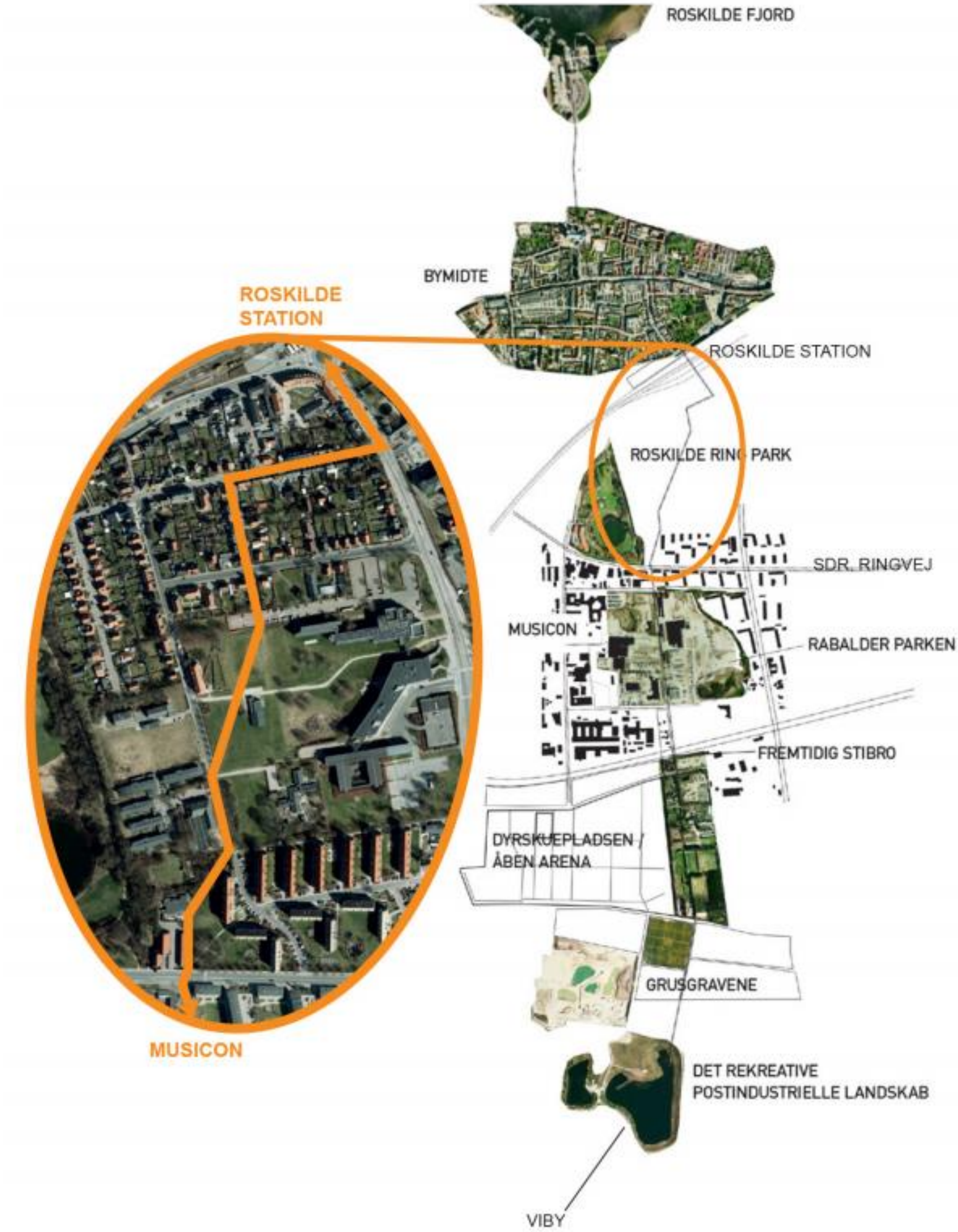



**Figure 1: Overview of the context of the path. The Musicon Path is part of a greater path from Roskilde Ringpark to Viby.**

### 1.4.2 Musicon Path

With the broader perspective on the project, acquired through the section above, the following section will look further into the plans for the path and the different users that will use it.

### 1.4.2.1 Path

As a means of guiding the users through the Musicon Path, the route and squares with different activities have been identified and presented by Roskilde Municipality. The route of the path and the location of squares can be seen in figure 2.
The path runs from its starting point at Roskilde Station. As it continues down Køgevej (a road of high level of traffic), it turns and runs along Knudsvej( a residential street). As it reaches halfway down Knudsvej, it turns left and continues along Thorasvej (also a residential street). As it crosses Gormsvej (residential street), it runs through a small passage of green area which leads to the park - Raadhusparken. Further down the park it merges with Eriksvej (residential street) and goes through a small green passage until it reaches and crosses Søndre Ringvej (a road of high level of traffic) and ends in the Musicon area. (see appendix 11.2).

### 1.4.2.2 Spots

The spots are mainly located at intersections:

- Spot 1: intersection between Køgevej and Knudsvej
- Spot 2: intersection between Knudsvej and Thyrasvej
- Spot 3: small green passage leading up to Raadhusparken
- Spot 4: near the wrestling-club building in the middle of Raadhusparken
- Spot 5: intersection between Raadhusparken and the small passage leading up to Søndre Ringvej
- Spot 6: in the middle of the small passage and leading up to Sønde Ringvej
- Spot 7: intersection of the path and Søndre Ringvej.

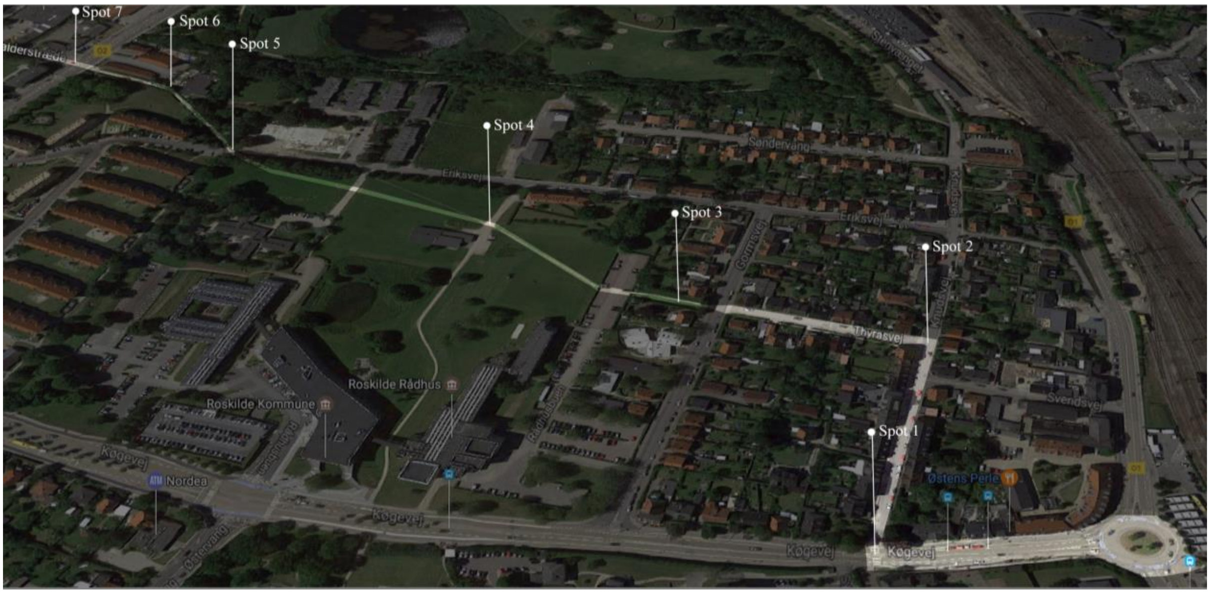



Figure 2: overview of the Musicon Path and the 7 spots along its course

### 1.4.2.3 Spatial context

To get a better understanding of the spatial perception of the path as it stands today, thoughts and observations were written down, assembled and formulated from a series of site observations in figure 3. The site observations were conducted with the purpose of identifying spatial conditions that affect the perception of the space for the users. This entails elements such as traffic interference, width of the passage, directionality of the passage, level of nature vs level of concrete. With a reference to figure 3, there seem to be a drastic change going from spot 1 and spot 7 with high-traffic roads to spot 2,3 and 6 with residential areas, with narrow passages, to spot 4 and 5 at Raadhusparken, which offer a wide open green space with low levels of interfering traffic.

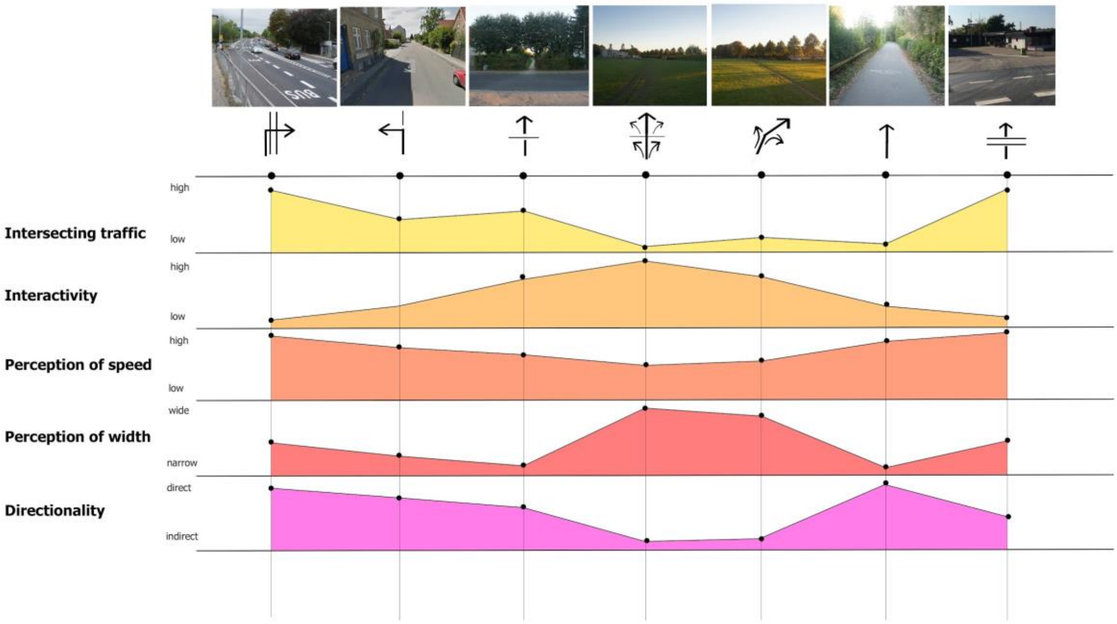



**Figure 3: the figure above illustrates the 7 chosen spots along the Musicon Path. Based on the different charts, it is visible that there seem to be a varying degree of intersecting traffic. As most of the spots have interfering traffic and high directionality, spot 4 and 5, which are located in Raadhusparken changes character and becomes a much more open and inviting space.**

### 1.4.2.4 Users

In the process of developing a meaningful lighting design for the path, it is crucial to get insights as to which kind of users are using it, when are they using it, and why.

Based on the assumption that most people who will use the path is travelling to or from the Musicon area, the type of users can be narrowed down to four different categories (musicon.dk).

### Work

With a large variety of companies situated in Musicon, this group of people utilize the path to go to and from work. This entails two segments:
the people who work in Musicon, and the people how lives in Musicon and are working in another city

### Education

The two main educational systems, Roskilde Tekniske Skole and HTX, situated in the soutern part of Musicon, draws students to the Musicon area.

### Culture

This segment of users involve people who come to the area for cultural events such as exhitions at RAGNAROCK, concerts at Paramount, theater performances and other events in geneal

### Leisure

Being a significant part of the Musicon area, leisure activities draws a large variety of users to the area for skating, dancing, playing music, performing all types of arts, climbing, acting and so on.

**Table 1: Four overall user groups in the area of Musicon were identified.**

The illustration below (figure 4) shows the estimated hours that the respective user-groups will use the path. The hours of interest for this project are the late hours, so it seems that the people that will be most exposed to the lighting will be people who come there for leisure activities or for cultural activities.

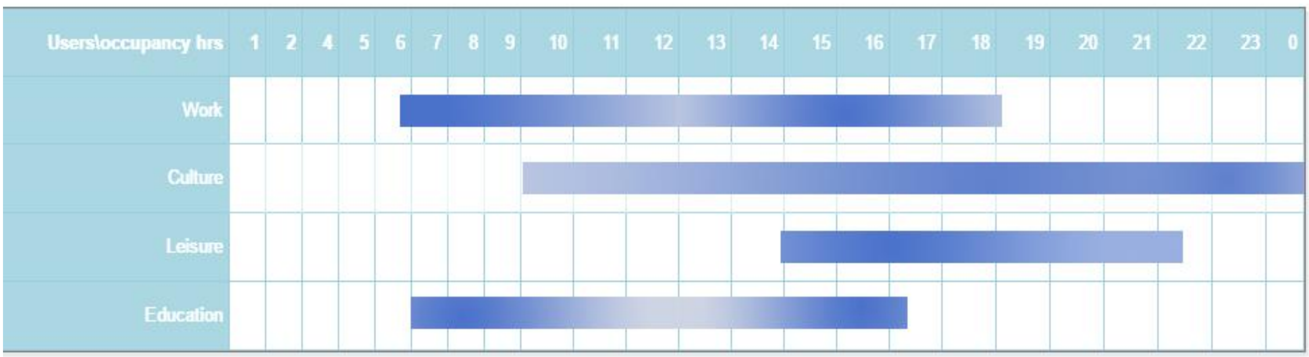



**Figure 3: User occupancy hours, estimated based on information on musicon.dk**

#### 1.4.2.5 Context Summary

The Musicon path is part of a bigger path project which will lead citizens from Roskilde Fjord to Viby. It will be responsible for a direct and safe, but also an interesting and eventful path between Roskilde Station and Musicon. To understand the greater vision of Musicon, key visions and characteristics were also mapped out and presented. In essence, Musicon is a community that is genuinely interested in shaping a district of creativity, diversity, growth, collaborations across different fields, arts, sports and education. Another essential signifier for Musicon is the environment-friendly mindset and the long history of utilizing the water in the area.
The initial plans for the Musicon path project were also covered, giving insight into the route of the path and the designated spots. A series of field observations of the path revealed a graduate change in level of interfering traffic, width of the path, nature and directionality along the path.
Along with the construction plans, offering numerous activities, and the theme of the park *Bike-play and learning*, Raadhusparken seems to be the appropriate place to invite people to stay and play. Four types of users were recognized, involving people who work in Musicon, the people who come there for cultural events, the people who come to Musicon for leisure activities, and the people who come there for educational purposes. A user-occupancy time table was established based on estimated hours for each activity (leisure, work, education and culture). Results indicate that the two user groups (leisure and culture) have the most relevance to this project, as people of these respective groups tend to be around the Musicon area during the afternoons and night - thus being more exposed to the lighting.

## 1.5 Expectations

During the first meetings with the Musicon-path member in September 2016, my position as an AAU-lighting design student was discussed. Since we were two students on the task, it was agreed upon, that our individual work should be synchronizable and not interfere with and overlap each other. Due to my media-technical background, my primary interest was within the field of interactive lighting. Thus, while there was a common consensus amongst the project member that the level of interactivity should be centered on Raadhusparken, I received the task of coming up with an interactive lighting concept for spot 4 or spot 5 in Raadhusparken(figure 2), while the other student had to come up with an overall concept for the whole path. It was, as mentioned above, essential that we were on the same page, ensuring clear coherence between the two concepts.

## 1.6 Idea generation and concept development

A significant insight into the nature of the overall project, from the perspective of both Musicon, Roskilde Municipality and the users, gave valuable data to help narrowing down the initial problem statement to a more specific problem statement. With an emphasis on directly interactive lighting in Raadhusparken, the middle of the Musicon Path, the potentials for this were further investigated.

## 1.6.1 Raadhusparken

The previous mentioned sub-goal for Raadhusparken, *bike-play and learning* became an important inspirational factor for developing a lighting concept. Despite having yet to be built, the park is expected to be an attraction for all users who wish to use their bike for more than just transportation, along with users who find it pleasurable to observe them.

## 1.6.2 Pump track

Among the five different bike lanes that will be built in Raadhusparken, a 200m long pump track in the middle of the park is expected to be the main attraction due to its position in the middle of the park and due to its proximity to the Musicon Path - enabling users to easily take a detour on their way to or from Musicon. With the large segment of young people "on wheel" (skaters, BMX riders, roller-skaters etc.) in the Musicon area, this pump track is estimated to get a lot of attention from this user group in particular. As figure 4 shows, these users - who use the area for leisure activities, will be more likely to stay in the area in the afternoon/night hours.
With proper lighting, this pump track could potentially be a useful place for these users and the general public to hang out and skate/bike after in the later hours. Due to the above mentioned observations and the big potential in the area, the pump track became my main focus.

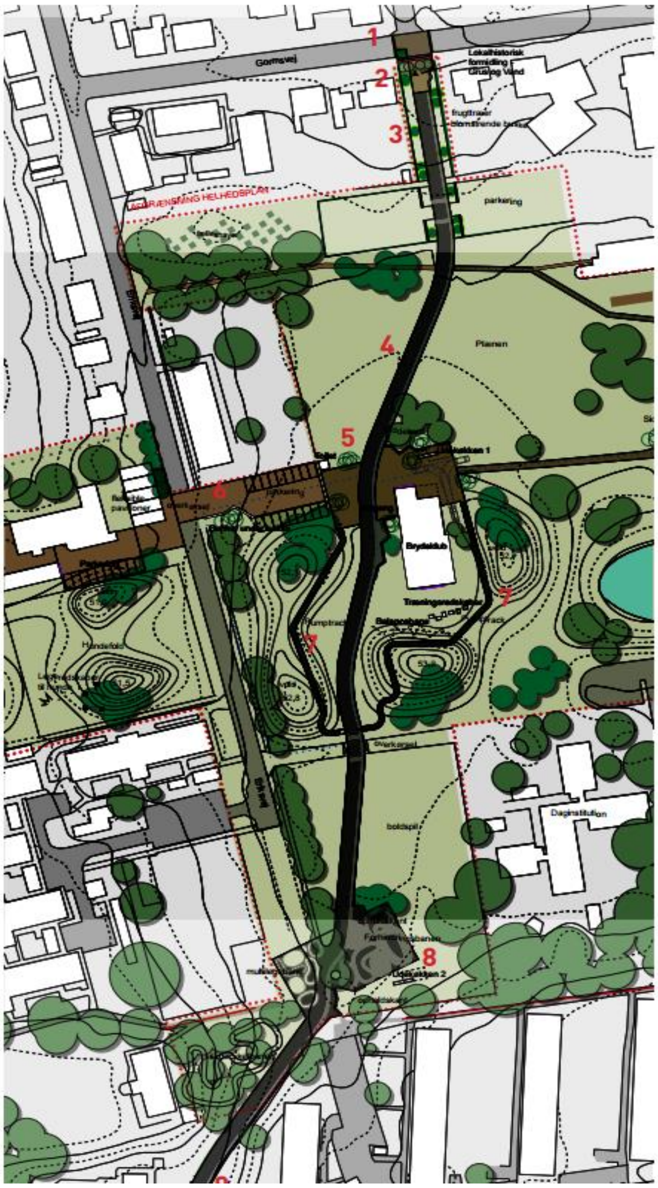


Figure 4 (sti til Musicon n.d)

## 1.6.3 Water

The theme that was developed for this particular part of the overall project, was inspired by Musicon's long history of utilizing water - first for industrial purposes as a means of producing concrete, and later as a means of developing a smart and innovative water drainage system built in a shape which allows local skaters/bmx to use it as a half-pipe.

### 1.6.3.1 Symbolism

In a symbolic sense, water can in many ways be associated with the spirit of Musicon: dynamic, diverse, adjusting and every-changing - unless no force/energy is applied to it. It is the energy that is put into the community of Musicon which makes it alive and vibrant. Each user of Musicon affects the community in one way or another.
This is essentially the effect that the symbolism should have on the users - to make them feel, not only as a part of the community, but also as an important contribution to the community.
The symbolic links are illustrated below (figure 6).

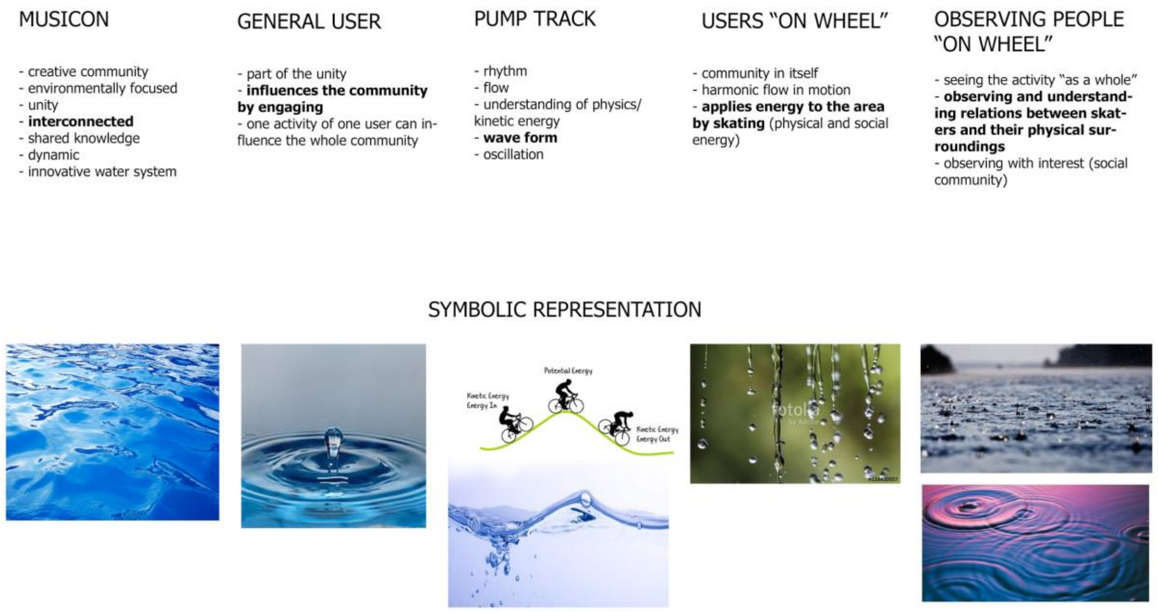



**Figure 5: The symbolic link between water and the community of Musicon, its users and the pump track.**

### 1.6.3.2 Interactivity

Another important reason for choosing water as a concept for the lighting design was that water is highly interactive and responds in different ways to different forces. This was deemed to be an important element of the lighting in Raadhusparken, to allow interaction between users of the area, and the lighting - and in that way "*invite people to stay and play*"**.**
An additional layer that potentially could add value to the interaction is if different speeds of the users on the pump track could be traced. Higher speed on the pump track would create more "force

on the water", which would result in a greater visual effect in the lighting. This would ideally enable a way for users to play with different speeds, or even compete with each other by comparing visual effect.

## 1.7 Final problem statement

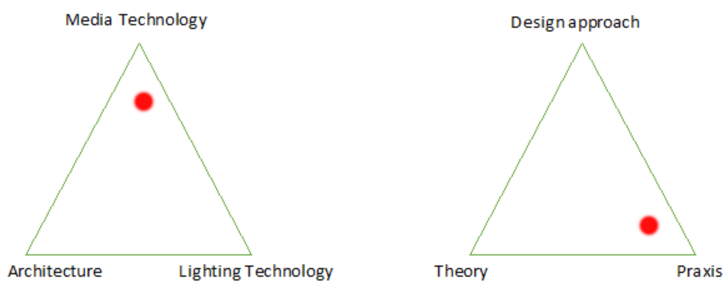
Based on substantial research within the context of the project and the different visions and goals for the path and Raadhusparken, a lighting concept for the pump track in the middle of the Musicon Path and Raadhusparken was developed, narrowed down to the final problem statement, as follows;

*"How can we use lighting to simulate the movement of, and physical interaction with, water on a public pump track, while ensuring sufficient visibility?"*

# 2. Thesis approach/methodology

The approach of this thesis is to apply a "praxis/media technical" methodology. The work will mainly consist of two parts; a practical part, and a "simulation" part. The practical part will serve the purpose of identifying the proper components for the project. Since the interactivity planned for this project (detecting positions of users on the pump track) is new in the field of interactive lighting, thoroughly examining and evaluating the potential components (primarily sensors, but also luminaires) is a necessity.
The "simulation" part of the project will largely involve the physical and technical aspect of reaching a "fluid" behavior in the light. The physical aspect will involve analysis of water motion and how water reacts to different forces, while the technical aspect will involve how to program this behavior through lighting. By applying this "praxis/media technical" methodology, the purpose is to get experience in the practical approach of executing a project like this.

Beneath is an illustration of how I see my thesis is balanced between "architecture, lighting technology and media technology" and "design approach, theory and praxis".



# 3. Problem analysis

In an attempt to answer the final problem statement "*how can we use lighting to simulate the movement of, and interaction with, water on a public pump track, while ensuring sufficient visibility?"* the problem analysis will thoroughly examine the underlying topics that has an influence on the problem.
The analysis will be approach by first presenting some inspiring projects that has worked with water simulations and position detection of users in public. Subsequently, the analysis will present the project specifications, including drawings of Raadhusparken and the pump track.
The next step in the analysis will examine the human relation to water in terms of health and well-being. Subsequently it will investigate the natural characteristics of water behavior along with references to known water phenomena. With an emphasis on human perception, the analysis will then examine the perception of blue (for water), to gather knowledge on the potentials and risk of using this color. This will entail both emotional responses, physical responses and the effect it can have on our perception of space. A closer look at the skating community in Musicon, BMX cycling and the characteristics of pump tracks will then be conducted, to get a better understanding of the context behind pump tracks and the people involved with them. For the practical element of the project, the analysis will also investigate which types of luminaires can be used to simulate the motion of water, along with which kind of sensors technologies have the capacity to detect exact positions of users on a pump track.

## 3.1 Project specifications:

This section will provide a brief overview of the plans for Raadhusparken and the pump track, along with general specification for the project.

### 3.1.1 Plans for the pump track:

Figure 7 shows the course of the pump track. The estimated start of the construction of the pump track is august 2017. The course of the path will have different curves and bumps (which will be further elaborated in *pump track)*.  Around the pump will be built small grassy hills along with some of the equipment for activities mentioned above (balance course). The track will be 200m long, 2.5m wide and will be built in asphalt. The exact course and shape of the path might change, as dirt builders (the company that will build it), will build it on the spot without official drawings. See appendix for additional drawings (11.6)

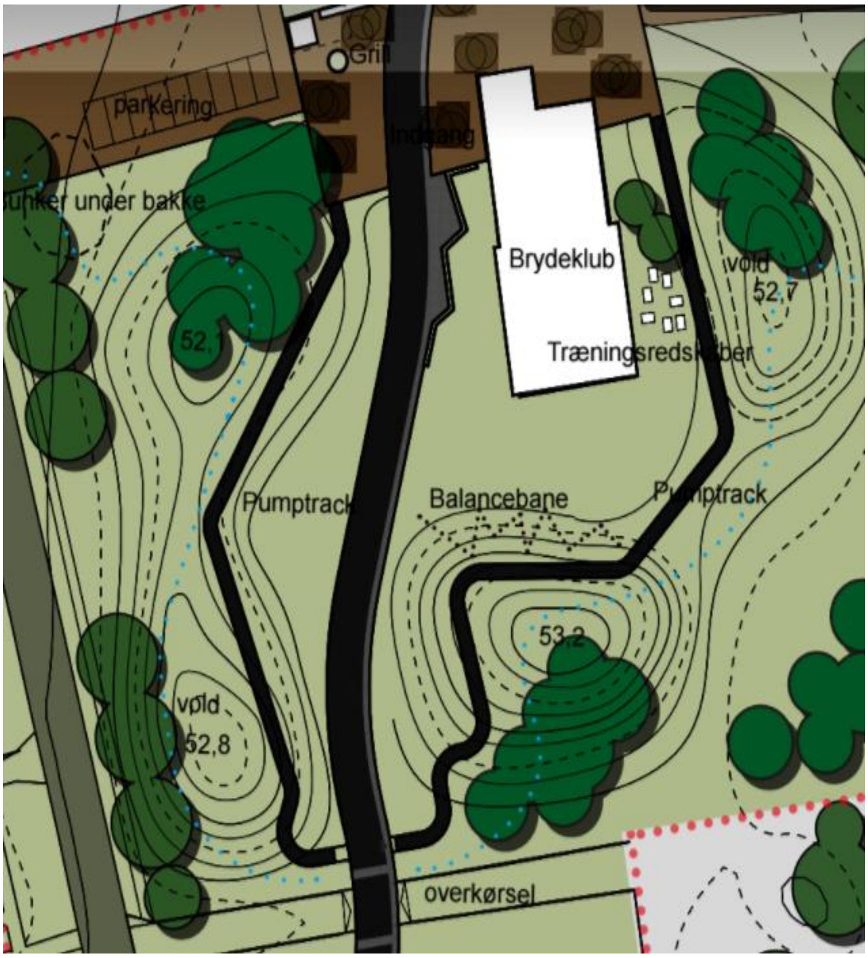



Figure 6 (Raadhusparken, in the middle of Musicon Path. The pump track can be seen curving around the Wrestling Club.

### 3.1.2 Lighting on the pump track:

The lighting on the pump track will be installed after the pump track has been built. To save money, Roskilde municipality has decided to cut half of the budget off for the lighting - meaning, instead of lighting the whole pump track as initially planned, the lighting installation will only concern the left part of the track(from picture above) - which is estimated to be 80m long. The budget for the installation is 300.000 kr.

## 3.2 Related Projects/inspiration:

After extensive research, it became evident, that no current research has been done regarding lighting on a pump track, or how to simulate water through lighting. That being said, a variety of lighting projects have been involved with the simulation of water.  This section will investigate some of these projects to provide a basis for the lighting potentials in simulating flow of water.

***"Efeito Agua"*** *- Piso Interactivo*

Projection mapping on floors is now a relatively common technique in the realm of interactive lighting technologies. The advantage of projection mapping is the great amount of details that can be conveyed through the projected pixels, allowing complex scenarios to unfold. This project - Efeito Agua (water effect), by Brazilian company Piso Interactivo, applies codes for projecting the movement of water. The projection is interactive, so as people walk pass it, the water will react in accordance.

***"Universe of Water Particles on a Rock in which Resides a God"*** *- TeamLab, Japan 2017*

With the purpose of enhancing the experience of nature, the digital art collective, *teamLab*, will during the summer season of 2017 transform trees, lakes and rocks into interactive art pieces in the *Inari Daimyojin Shrine nature park*. Among various pieces is the *Universe of Water Particles on Rock in which Resides a God*, which is an installation that projects a waterfall, controller by an algorithm that imitates water flow.

***"Walk the Light"*** *- Inimod Studio*

In *Walk the Light,* visitor of the Museum's Exhibition Road tunnel, control the light by how they move through the tunnel. A band of white light follows the visitor. As one person passes, the white light jumps to the next visitor. On both sides of the white band, strong colors are pushed and pulled along the tunnel, forming an ambient lighting effect that is associated with the overall ebb and flow of the day's visitors. During the day, there will be a shift in hue and saturation of these colors, as they respond to the flow of directionality among the visitors.

***"Lungs"*** *- Loop.pH.*

For the Velo-City Global 2016 cycling conference in Taipei, the London-based studio aimed to show the relationship between air quality and mobility by combining a pump track with a lighting installation. Loop.pH's two looping wooden pump tracks illuminate with LEDs as riders pass them, while the large lights at both ends - simulating human lungs and the branching structure of trees - change color according to the quality of air around them.

## 3.3 Human response to water

Most of us can relate to the calming sensation of walking along a coastline or by a river, observing the ever changing picture and listening to the characteristic sounds. The human attraction to water is a well-known phenomenon. While we are very aware of the feeling, not much research has been done to know why water has such an incredible effect on us. A recent study by marine biologist Wallace J. Nichols, (Wallace 2014) researches the neurological, psychological and emotional changes our brains experience in the presence of water. Nichols explores the sensory appeal of water, giving us an indication of how sight, sound, feel and even smell and taste of water affect us on an incredible deep and raw level.

While health benefits of green spaces are well known from research of Roger Ulrich and the Kaplans (Ulrich 1991) amongst others, there seem to be a lack of research regarding “blue spaces” - the effect that rivers, lakes, the sea and urban water installations have on our health and wellbeing. Professor Michael Depledge and his team attempted to dig further into this topic in 2012. After funding the European Centre for Environment and Human Health (ECEHH), the team launched the *Blue Gym* project, with the purpose of studying health and wellbeing benefits of aquatic environments. (Depledge 2012)

They approached the topic by repeating one of Roger Ulrich’s early studies, by showing a group of test participants photos of different landscapes. By assessing the level of stress at each picture, Roger Ulrik was able to demonstrate that the stress level was lowered proportionally with the amount of greenery in the image. By introducing water into 2the images, Michael Depledge found that people showed a strong preference for more and more water. Michael Depledge then repeated the study with urban spaces “*from fountains in squares to canals running through the city, and once again people hugely preferred the urban environments with more water in them*” (Depledge 2012). Images with green spaces received positive response, but images of both green and blue got the most favorable response of all. The team did a second study which was even more conclusive. They used data from *Natural England*, where they examined anonymous self-reported health data by area in England, to see if the health varied with proximity to water. The research revealed that the closer people lived to the coast of England, the healthier they were. There were also links between level of health and other aquatic environments like lakes and rivers.

Ph. D. student and lead researcher at the *National Marine Aquarium*, Deborah Cracknell, has studied the health effects on Alzheimer’s patients and elderlies who are watching fish in aquariums and tanks (Cracknell 2013). Despite having her main emphasis on the biodiversity aspect, which is the level of marine biota in the water, she found that people showed an increased level of wellbeing (based on positive effects on mood, heart rate and blood pressure) from just watching the aquarium without fish. This all leads to the question: what is it about water that affects us in such a significant way, that it improves our wellbeing and health?

Marine Biologist Sir Alister Hardy suggested that the answer lies in our instinctive nature, as human beings have evolved in close contact with nature up until 200 years ago. It is only since then that people have been increasingly removed from oceans and forests (Hardy 1960).

## 3.4 Water characteristics

In order to understand how to simulate water, the initial part of the analysis will look into the characteristics of water behavior.

### 3.4.1 Basics of waves

As a basis for understanding water behavior, it is necessary to understand the basis for waves in general. A wave, in any type of shape (sound, electromagnetic, radio, wind, water etc.) consists of parameters such as:

- wavelength (the length of one oscillation),
- amplitude (the distance from equilibrium to crest/trough),
- wave period (the time of one oscillation),
- wave speed (the speed in which the wave is travelling),
- Crest (the top of the wave),
- Trough (the bottom of the wave),
- Wave height (the distance from trough to crest)
- Frequency (number of oscillations per unit time)

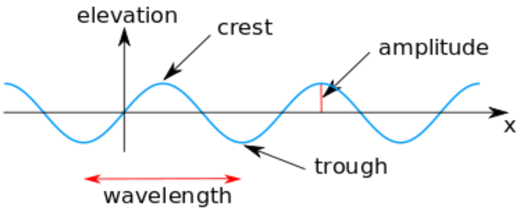



Figure 7 (Amplitude n.d.) The illustration presents the basic characteristics of waves.

In the two pictures below it is shown how these parameters differ, depending on the scenario. In figure 9, a mild wind is causing waves (capillary waves, explained further down) of low amplitude and small wavelengths. In figure 10 the amplitude of the wave is much higher, along with the wavelength.

Figure 9: Low amplitude and small wavelength capillary waves

Figure 10: High amplitude and long wavelength gravity waves

The behavior of water waves is fully dependent on external forces such as wind, ships and rain etc., but to understand how these forces can trigger different types of waves, it is essential to grasp the continuous forces that are applied to the water molecules.

## 3.4.2 Continuous forces on water

### 3.4.2.1 Surface tension

A water-molecule which is in contact with a neighboring water-molecule is in a lower state of energy than if it were alone (Perlman). The water molecules inside the ocean, for instance, have the maximum amount of neighbors as it can have, but at the surface of the water, the boundary molecules are lacking neighbors (compared to the interior molecules) and will thus contain more energy. This energy is what makes the molecules stick together at the surface - referred to as *cohesion* (as depicted in Figure 11). This phenomenon is known as *Capillary waves* (figure 12) - a certain type of wave that is influenced by the surface tension. A mild wind or water droplets can trigger such waves - causing *ripples* on the surface of the water.

**Figure 11: Surface Tension**

**Figure 12: Capillary Waves**

### 3.4.2.2 Gravity

Similar to all other objects on earth, gravity pulls on water as well. When enough energy is applied to water, causing wavelengths beyond 10 cm, the type of wave triggered is referred to as *gravity-waves*. For oscillations to exist and to propagate, gravity forces any displacements of the surface to be pushed back towards the mean surface level - equilibrium. What causes the oscillation is the kinetic energy gained by the fluid on its path back to its rest position - causing it to overshoot, and thus being displaced again (Perlman, 1985).

While this is somewhat intuitive to comprehend, understanding why this forces the gravity wave to move horizontally is a bit more challenging. To grasp this, one needs to understand the horizontal forces at play. When a wave of water rises above the surface, the added weight of this wave creates a pressure that is locally higher than normal, which as a result accelerates/pushes the fluid away from the place, piling it up at the nearby trough, which generate a new surface some distance away - pushing the wave forward. (Ruisin, 2005)

In most cases, the types of wave that we see when observing the ocean, is a mixture of *gravity-waves* and *capillary-waves*, referred to as *gravity-capillary waves* as illustrated below:

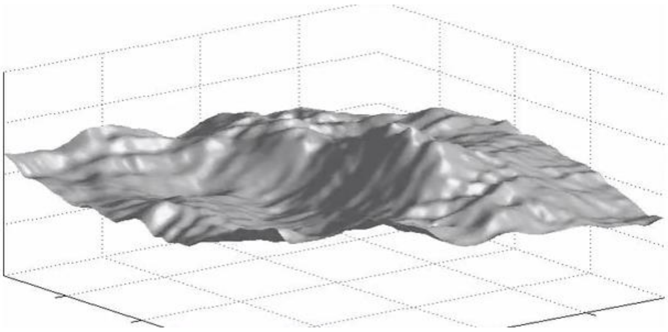


Figure 13: Gravity-capillary waves

### 3.4.3 Loss of energy:

The amplitude of waves gradually becomes lower as energy is lost due to factors such as, internal friction, air resistance and by energy dissipation due to the divergence of the direction of propagation. Shorter wavelengths are losing energy more rapidly over distances than longer wavelengths. As a consequence, the dominant wavelengths of the spectrum are centered around the long wavelengths, capable of lasting far longer and over greater distances (Ruisin, 2005).

### 3.4.4 Group waves

Figure 14: Group waves: A water drop creates a wave formation outwards.

An interesting aspect of wave propagation is that the energy carried by waves does not always travel at the same speed as crests and troughs. For gravity waves, for instance, the accumulated energy velocity is half the wave speed of each wave (Ruisin, 2005). In a wave consisting of multiple components, different wavelengths are present at different locations, altering energy distribution and speed for each wave. In the example in figure 14, a force on the water triggers a gravity wave outward. Since longer wavelengths have a higher velocity (for gravity waves), these waves "catches" up with the group velocity, since the group velocity has a lower rate.

### 3.4.5 Wave Interference:

When two or more correlated waves of the same type are present at the same point, the waves are referred as being *superposed,* and are forming an interference pattern. This is the effect you can observe from rain drops on the water surface as depicted in figure 16. When this occurs, the resultant amplitude at that particular point is equal to the vector sum of the amplitudes of the individual waves (figure 15) (Ockenga, 2011).

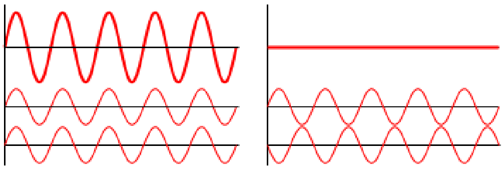


**Figure 15(interference n.d): Wave interference.**

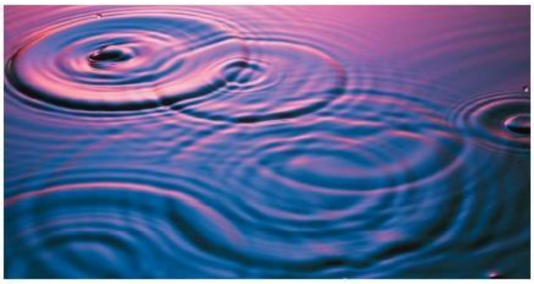


**Figure 16: Group waves from multiple water drops interfere and form an interference pattern**

### 3.4.6 Water scenarios:

As an inspiration for simulating water, this section will look further into different water scenarios. By "water scenarios", meaning depicting situations in which water behaves in different ways as a result of different forces.  One water scenario which has already been described is the behavior of water that unfolds when a water drop hits the surface of the water.

*Rain*

Going from the details of one water drop, to observing rain hitting the surface of a lake, the appearance of the water changes as the waves interfere with each other, as visualized in the above section *wave interference.*

**Figure 17 (Temblor 2012): Rain Scenario**

*Boat*

Another water scenario that we can all relate to is the result of a boat sailing through the water. As the boat applies pressure on the surface of the water, the pressure distributes outward around the boat and forms foams due to air being entrained in the water. Depending on the weight and speed of the objects sailing through the water, the amount of foam and the amount of time the foam lasts will change in accordance. The more energy applied, the more foam and the longer the foam will last, leaving a longer trail.

**Figure 18 (Luxuo 2016): Boat Scenario**

*Current*

Water currents are usually a result of gravity, solar heat or wind. [1] Currents in water can be seen from the ocean coasts as a results of solar heat and wind, whereas water in floods is influenced by gravity. A commonality is that the force is dragging the water in one direction. An interesting fact about the speed of the travelling current and the speed of wind, is that, in the wide oceans where winds have can reach high speed, the speed of the travelling water current will accelerate until it reaches the same speed as the wind. The moment it reaches similar speed, the water can no longer retrieve energy from the wind, and will thus stop accelerating. In floods, the current of the water is influenced by the width of the passage. The current seem to slow down and diffuse in many directions as it reaches open areas, whereas it accelerates when the passage becomes more narrow (Ruisin).

Figure 18 (Gangajal n.d.): Water current.

## 3.5 Human perception of blue:

Along with the water-concept, comes the discussion of using blue light in the public sphere. What do we associate with the color blue? How do we physically/emotionally respond to it? How well do we see the world and each other under blue light?

On an emotional level, blue is the most universally favored color in the visual spectrum. Due to the ocean and sky, it is perceived as a constant in our lives, and has a balancing calming effect (Cerrato, 2012)).Though the perception of blue (and any other color) is largely influenced by culture and prior experiences, there are some common associations to the color blue, which is widely agreed upon. The color is used for clear communication and often represents intelligence and efficiency (Cerrato, 2012). This is why offices often are colored blue - to raise the productivity. It also often represents quality, tradition, trust and responsibility, which explains why politicians often choose to wear the color.  Opposed to red which stimulate a physical reaction in people, blue has little physical influence on us(Cerrato, 2012).. Strong blue will excite clear thought whereas lighter softer blue will calm the mind and aid concentration. (Wright, A. 2015).

The wavelengths in the visual spectrum range from the smaller wavelengths of higher energy (blue) to the longer wavelengths of lower energy (red). This difference in energy results in one-third of all visible light being considered *high-energy visible* (HEV), or “blue” light (toc). A large variety of research have studied the effect from receiving light rays in the *HEV* spectrum, and these researches have for instance shown that the blue light has a positive effect on concentration, alertness, memory and cognitive function. HEV rays have also been discussed rigorously in the topic of circadian

[1] https://earth.usc.edu/~stott/Catalina/Oceans.html

rhythm. Harvard researchers conducted an experiment comparing the effect of 6.5 hours of exposure to blue light to exposure of green light. The blue light turned out to suppress the melatonin level for about twice as long as the green light, shifting the circadian rhythm by twice as much(Wright, A. 2015). Light rays in the HEV spectra are beneficial during daytime to maintain a healthy circadian rhythm, but as the research indicate the light can also have a negative effect on a person's circadian rhythm if being subject to too much exposure during dark hours, preventing a biological fatigue. Constant exposure to blue light at night, through TV and cellphones is part of the reason so many people don't get enough sleep (Sack, 2007). The consequences of lack of sleep has been linked to increased risk for depression, as well as diabetes and cardiovascular problems(Sack, 2007).

Because blue light, which has a short-wavelength and high energy, scatter more easily than other visible light, it can be harder to focus under blue light. This is due to *chromatic aberration,* which describes the processes in which light rays refract differently in the eye depending on wavelength, causing them to converge before others in the eye and to be placed on non-corresponding locations of the two eyes. This phenomenon is typically evident as *blue haze (Faulbert)* around objects in bright light (snow and sun e.g). When you are looking at a computer screen or other digital devices that emit significant amounts of blue light, this unfocused visual "noise" can reduce contrast compared to other colors.

However, in terms of energy consumption, blue light is very beneficial. This is because light sources that have greater power at the short-wavelength end of the visible spectrum *produce a perception of higher brightness at the same illuminance* (Boyce, 2004 – p 434).

## 3.6 Perception of depth:

It was first noted by Goethe in his *Fabenlehre* (Theory of Colors), how colors influence on our perception of depth that we encounter in our daily lives - our ability to understand the three-dimensional space around us, and our ability to differentiate close objects from objects farther away. In *Fabenlehren* Goethe recognized blue as a receding color and yellow/red as a protruding color (Faubert, 1994). The study of chromostereopsis , in which the perception of depth is conveyed in two-dimensional color images (comparing pairs of colors), has later confirmed this theory of short wavelengths (blue-turquoise) as being perceived as further away.

## 3.7 Pump track users

Since the purpose of this project is to design a lighting solution for a public pump track - this section will take a closer look into the kind of users who would be most inclined to use the pump track.

### 3.7.1 Street sport Community of Musicon

Pump tracks are often an integrated part of skating parks, and is thus an attraction to the street sport community as it provides similar curved concrete surfaces as halfpipes etc. The street sport community in Musicon is strong, as the area contains great facilities for BMX riders and skaters. This entails an outdoor skate park (Rabalderparken - as visualized in figure 13), an indoor skate Hal (Hal 12), and an indoor BMX race track.

**Figure 20: Based on information gathered on the official Musicon Website[2], along with early observations, age seems to be a determining factors for the level of motivation to exercise street sports in Musicon, and seems to range from early childhood to early adulthood.**

### 3.7.2 Field observations and street interviews

In order to identify essential characteristics of the street sport community in Musicon, street interviews and observations were conducted on-site in Rabalderparken and Hal 11 (BMX racing hal).
With an open-ended approach trying to identifying characteristic behavioral patterns of a group of skaters/BMX racers, skaters were observed over a time period of 1 hour in Hal 11. During the observation period, field notes were written down, and subsequently assessed through *content analysis (*Krippendorff 2004) Semi-structured interviews were subsequently conducted, emphasizing the participants' experience of skating/cycling and which factors they consider most important for their motivation to skate.

**Figure 21: BMX hal in Musicon**

Based on the interviews, it seems that the motivation for this group of people to skate/ride, can be assembled down to two main reasons:

- the sensation they get from the act itself (explained as feeling of "*joy, freedom, flow, independence"*) and

[2] www.musicon.dk

- the social aspect of being a part of larger community with shared interests.

The social aspect was likewise very evident through the observations, showing a very coherent, friendly and positive atmosphere. Common traits among the skaters/riders was that they expressed sheer joyfulness during, but especially after they had been on the pump track. While on the track, they seemed to be fully occupied by what is in front of them. Their engagement was very visible in their facial expression while riding/skating - expressing a strong concentration, but also a sense of determination. The determination to continue a process of trial and error was seen in many instances during the 1 hour observation session. This seemed to be fueled by positive comments from other riders, especially the older, more experienced riders. From the observations, it was also learned, that there is a certain degree of competitiveness in the community as well. While most of the riders seemed to find joy in just “cruising” through the track, some of the riders tried to push their level to the highest, almost falling in some cases. A common tendency for the “determined” riders, were that they checked their time after each ride - to assess and compare their performance with themselves and their fellow riders.

### 3.7.3 BMX racing

From a professional aspect, pump tracks are originally made for BMX cyclists. The sport - BMX racing - is the sport associated with pump track. In essence, BMX racing is all about speed - being the fastest over a designated distance. Athletes target to achieve and reproduce a perfect movement pattern. This is experienced as a sensation of *flow*, at which the athlete is able to transfer all energy via the bike into the forward direction, a sensation of a technique where the whole body becomes one with the bike (Nakamura, 2001). The sensation of *flow* is often associated with the act of cycling, skateboarding or other types of “wheel tools”.

While the BMX/skateboarding experience often revolves around learning tricks, the purpose of a pump track is instead to see how much speed you can generate without using the pedals. As an expert BMX rider said in an early interview: *“An experienced pump track rider, who is only using his/her momentum to generate speed, can at any time beat an unexperienced rider who IS using the pedals”*. The motion which keeps the momentum going throughout the track is called the *pump motion*, a *“technically challenging and physically exhausting motion”,* which is performed by pushing the bike downward during the lower curve of the pump track (figure 22), and pulling the bike upward during the higher curve of the pump track (figure 23). The upper body maintains somewhat the same height throughout both motions.

**Figure 22: At the trough of the pump track, the rider pushed the bike downward**

**Figure 23: At the crest of the pump track, the rider pulls the bike upward**

### 2.8.4 Pump track

The shape of a pump track is designed to utilize as much of the kinesthetic energy and gravity from the bike as possible, to generate a forward motion. Despite having numerous different shapes, there are some basic principles as to what constitutes a good pump track. Good dirt jumps (crest of the shape) will be close together with smooth, curved transitions between each jump. The slope at the launch stage should accelerate in steepness to help push the bike in the air. The landing should be situated somewhat high and the slope should be steep to keep the pump and rhythm for the next jump. Figure 24 shows how the pump track can enable the rider to gradually reach higher speeds throughout the track until the rider reaches his/her top speed which is accompanied by the "main jump", which is the steepest and tallest jump. To make it easier to land tricks, this main jump is often accompanied by a mellower landing.

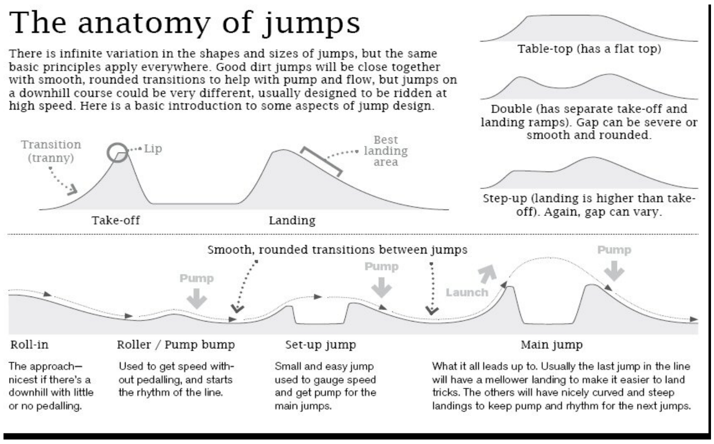



Figure 24: The shape of the pump track (Rora, 2009)

The pump track that will be built in Raadhusparken, will however, likely not contain completely similar shapes as the above mentioned. The reason for this is that the pump track should be applicable to the general public - allowing people of no prior experience and with different "wheel tools", such as rollerblades or skateboards, to ride the track. Thus, the pump will contain far less steep curves and will not be as challenging. The image below illustrates how the pump track is likely going to look like (despite not having any official drawings of it).

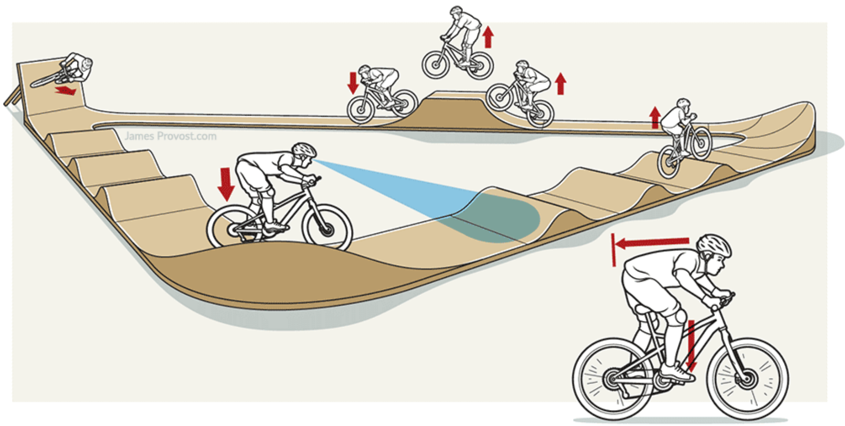


Figure 25 (pump 2015): As visualized in the illustration above, the position of the back is particularly important for riding the pump track properly

## 3.8 Luminaire analysis:

To get more insight into possible ways of illuminating a pump track, this section will illustrate possible light scenarios and explain the pros and cons of each. The analysis of the solutions are heavily influenced by feedback from the project members, entailing parameters such as prior experience, vulnerability towards vandalism and price. The section will conclude on the luminaire to use for the project.

### 3.8.1 Ground-recessed LED strip:

Figure 26: Ground recessed LED strips

The initial idea for lighting the pump track was to use ground-recessed LED strip along both sides of the track. With the purpose of simulating water behavior, this was deemed as a useful solution, as it would allow for a large variety of different visual expressions, due to its magnitude of pixels. With 60 pixels per meter, this would enable 960 pixels in all (60 x 80 x 2) throughout the 80 meter pump track.

Figure 27: Experiment with addressable LED strip on mock-up of pump track.

During my internship period, I was working on addressing LED pixels on a mock-up of the pump track. The experimentations became a tool for inspiration, and gave meaningful feedback as to possible interactions and visual expressions. In the figure 27, I experimented with the idea that the lights would be dragged down towards the troughs of the pump track - similar to how water would act.

**Evaluation:**

Pros: The solution would provide the pump track with a large variety of possible expressions, with the help of 960 pixels. The lights would stress a clear border between the pump track and the rest of the park - creating intimacy.

Cons: For the LED strips to illuminate the pavement of the pump track, they would have to be placed above ground level to enable the right angle. This would require an additional construction alongside the pump track. With the main criteria for the lighting being that it should not interfere with the user’s ability to ride it, a solution like this was deemed insufficient, as it could become an obstacle for the riders. An additional note from the project members was that aligning an LED strip alongside such a curved surface could become too big of a challenge.

### 3.8.2 In-ground up light LED's

Another type of lighting solution that was assessed was LED-chips mounted in the asphalt.


Figure 28: In-ground up lights

**Evaluation:**
*Pros:* Aesthetically, and from a programming perspective, this is the solution that could get closest to the appearance of water movement, as it adds a second dimension to the previous solution. This would allow the movement of water (light) to not only be directed alongside the pump track, but also in perpendicular direction.

*Cons:* It can be discussed, whether the scarce illuminance on the pavement that these LED up-light would provide, is adequate for safe and secure movement on the track. Additionally, from a distance, the effect of the lighting would be minimal. In a correspondence with Frederik Borello (ÅF Lighting), Frederik pointed out that the solution would likely be too expensive to execute.

### 3.8.3 Pullert lights

Another type of luminaire that was looked into was pullert lights.

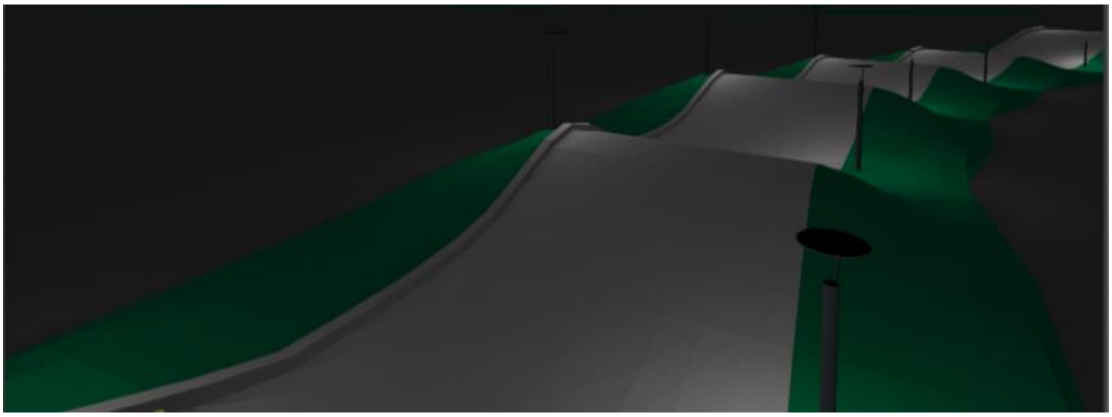


Figure 29: Dialux experiment with pullert lights on the pump track

**Evaluation:**
*Pros*: Using pullert light would easily enable sufficient visibility of the users, and could, if placed close enough to each other, provide a decent variety of visual expressions.
*Cons*: During a meeting with the project member, SEAS-NVE and Stig Nielsen (road engineer, Roskilde Municipality) pointed out an important point for the area of the Musicon Path: vandalism is a common thing. Stig

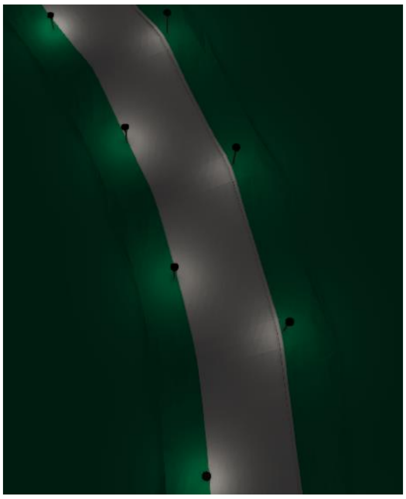


Figure 30: Dialux experiment with pullert lights on the pump track.

expressed his experience with public luminaires in Roskilde which have been accessible from ground level: They get vandalized by a number of young groups in the area.

### 3.8.4 Spotlights

The last lighting type that was assessed was spotlights.

Figure 31: Possibility of spot lights for the pump track

*Pros:* Amongst the above mentioned lighting solutions, this solution is the most secure one for ensuring sufficient visibility and safe movement of the riders on the pump track. Additionally, spotlights would be mounted high up in the air, making them far less accessible to the people committing vandalism. Another important consideration was that the lamp post holding the spotlight would also be able to be placed at a distance to the pump track - preventing it from becoming a possible obstacle for the rider. In one of the project meetings, it was also stressed by Tine Byskov Søndergaard that this solution would also be the cheapest one - allowing for a bigger budget for the sensors and system.

*Cons:* A less attractive part of this solution is that spotlights are fairly common in the public, so its visual appearance (in static state) has certainly been seen before. Additionally, due to the rather far distance from the pavement which the spotlights require, the resolution (amount of lights) throughout the pump track would be quite restricted, allowing for a very limited amount of “pixels” to work with compared to e.g. solution 1 or 2.

### 3.8.5 Summary

As it turns out, according to prior experience of Stig Nielsen (the road engineer of Roskilde Municipality - responsible for public lighting in Roskilde), vandalism is a widespread issue in the Musicon area. He stressed, during multiple meetings that he recommends mounting city light beyond three meters, to ensure that they are not accessible to the public. In other words; he strongly suggested not to mount lights near the ground. Acknowledging this issue, there was a common agreement amongst the project members, that spotlights were the right solution - a solution that would also prioritize sufficient illumination on the pump track, and a safe movement without physical obstacles (luminaires) close to the track.

## 3.8.6 Sensor analysis

With the pursuit of identifying the proper sensor technology for detecting positions of multiple people on the track, this section will go further in depth with which relevant technologies are available to this day, followed by an assessment of their advantages and disadvantages.

The technologies that will be examined entail pir sensors, regular and thermal cameras, ultrasonic sensors, 2D laser scanner and LIDAR sensors. The sensors will be evaluated based on their range, precision, reaction time, power consumption, maintenance, sensitivity to environmental factors, vulnerability towards vandalism and price.

### 3.8.6.1 PIR (passive infrared)

The most commonly applied motion detection sensor is the pir-sensor. It is recognized in many applications in our daily lives, and serves as the trigger for opening doors and turning on lights when we enter its detection area. The way it works, is that constantly receives and interprets infrared radiation/ambient temperature. As all living objects emit infrared radiation, the sensor is able to sense a difference in radiation the moment a person walks in, which will then send a signal onto the light or door or some other application.

Figure 32: pir-sensor

- Pros: The sensor is very cheap and is generally very compact, which makes it possible to fit into virtually any device. The lenses of outdoor versions of pir sensors can accommodate the harsh ultraviolet rays of the sun. The sensor is very energy efficient, as it absorbs energy from the incoming infrared radiation. It responds aptly to human motion and can get adjusted to body temperature.
- Cons: As the pir-sensor registers a *change* in infrared radiation, it doesn't really detect the presence of an object, but rather the motion. Though it can withstand sun rays, other environmental factors such as snow, dirt and heat can degrade its performance. The detection range of the pir sensor is not very long (up to 5m).

### 3.8.6.2 Cameras

An effective way of registering people can be through a camera. Cameras are often used for security purposes, due to the high amount of information that the camera provides. With the help of *image processing* [3]and software such as openCV[4], it is possible to analyse the activity in front of the camera, based on information of change in pixels. By defining the characteristics of size and shape of people in pixels, the program will automatically trigger when a person walks inside the scope of the camera.

Figure 33: Camera

- Pros: The advantages of cameras are vast in regards to detecting presence and motion of people. Through image processing, it is possible (as explained above), not only to detect a person, but to detect a large variety of people, their positions, speed and direction - simultaneously.
- Cons: While there are many technical advantages of using cameras for detection of presence and motion of people, there are just as many if not more disadvantages - in the context of

[3] image processing is processing of images using mathematical operations
[4] is a library of programming functions mainly aimed at real-time computer vision

public spaces. Cameras in public are often used for the purpose of surveillance - monitoring areas where crimes tend to occur. This could have a bad influence on the public perception of the space, along with the feeling of being observed - threatening the perception of privacy. From a technical viewpoint, cameras are also very sensitive towards sunlight and are computationally demanding.

### 3.8.6.3 Ultrasonic

Another sensor technology that will be evaluated is the ultrasonic sensor. As the word infers (sonic), the sensor uses soundwave to measure the distance to an object. It measures distances by sending out a sound wave at a certain frequency and listens for that sound wave to bounce back. By recording the elapsed time for the sound wave to bounce back, it is possible to calculate the distance between the sensor and the object. Ultrasonic sensors are applied in a wide range of indoor and outdoor applications, ranging from proximity sensing on cars to production lines.

Figure 34: Ultrasonic Sensor

- Pros: Ultrasonic technology is very accurate in measuring distances to objects. The sensors are resilient against environmental factors such as direct sunlight, dust, dirt, humidity, fog and material colors, making it a very robust sensor. Additionally, the sensor is relatively inexpensive.
- Cons: While the sensor is resilient against many environmental factors, it cannot completely abstract from interfering noises. On top of that, its ability to detect is affected by shape, density and texture of objects, resulting in some objects causing inaccurate readings. The detection range of the ultrasonic sensor is limited, due to the physics of sound waves travelling out in a cone shape (Massa 2010). Thus, most ultrasonic sensors operate within the range of maximum 10m.

### 3.8.6.4 2D laser scanners (2D LIDAR):

The possibility of using a 2D laser scanner was also examined. The way in which a 2D laser scanner works, is that it scans an area by steering a laser beam within a certain angle of interest and at a certain frequency (laser 2017). By measuring the time taken by the pulse to be reflected off the target and returned to the sender, the device is capable of measuring distances at every pointing direction. 2D laser scanners are widely applied for industrial purposes such as metal processes, mechanical-, civil- and electrical-engineering, or within the field of robotics - to constantly monitor objects and check for potential collisions etc.

Figure 35: 2D laser scanner

- Pros: 2D laser scanners have the capacity to detect distances far beyond the ultrasonic or pir sensors, and are able to detect multiple objects simultaneously - due to its capability of measuring distances at <u>every</u> pointing direction. Reaching scanning frequencies of up to 60 ms, the device has a very fast reaction time. In terms of its rigidness towards interfering environmental parameters, 2D laser scanners which are built for outdoor environments are able to withstand ambient illuminances of up to 80.000 lux, can withstand large temperature variations, and are resistant to shock and vibration.

- Cons: 2D laser scanners do not function well under direct sunlight. Though prices vary, 2D laser scanners are relatively expensive. The laser scanner will not be able to detect objects if they are occluded by another object.

### 3.8.6.5 Lidar (light detection and ranging)

Figure 36: Lidar sensor

A Lidar sensor works under the same principle as the 2D scanner - but scans areas in three dimensions instead. This technology has reached high popularity over the last years - with the acknowledgement of its high precision and incredibly long range (Arcmap, 2015). It is widely used to make high-resolution maps, with applications in agriculture, archeology, geography, geology, seismology, atmospherics physics, but also serves as a technology for control and navigation for some autonomous cars etc.

- Pros: The Lidar technology has the capability to create real-time high resolution distance calculations - with or without moving objects. Similar to the 2D scanner, it has the ability detect multiple moving objects simultaneously, and to differentiate them by size, shape, speed etc.
- Cons: Due to its long range, speed and precision, the Lidar technology is still quite expensive, and might extent the needs for this project.

### 3.8.6.6 Summary

In an attempt to identify the appropriate sensor solution for this project, the above-mentioned sensor technologies were taken into account. Considerations were made in terms of placement: Could a single sensor of long range, like the 2D laser scanner, pointing down the path of the pump track - be able to fulfill the task?  Or should there be multiple sensors, like pir or ultrasonic sensors, placed along the path - pointing across the path? Or should there be placed a sensor high up in the air, like the Lidar, pointing down at the path?

A general opinion amongst the project members was that the sensors should ideally be as “invisible” as possible, especially during daytime. They should not require a 10 m tall mast to point down, or be constructed on the pavement along the path. As pointed out in *analysis of luminaire type*, vandalism is a widespread issue in Roskilde, so the sensors should not be within reach of the general public. Integrating one long range sensor in one of the lamp post was also discussed, but due to the issue of occlusion - people being in the way of each other - it was decided that integrating the sensors in the lamp posts along the path was ideal. The pump track is only going to be 1.5 m wide, so the scenario of occlusion would happen rarely from that perspective.

When comparing the different types of sensors and their ability to detect people from the side of the path, it was clear that the best qualified sensor was the 2D laser scanner. The ultrasonic sensor would not be able to detect the position from that perspective (as it measured distances), the pir sensor would not provide enough information (as it only detect whether there is motion or not), and using a 3D Lidar sensor would be too expensive in cost and computation. With its ability to detect objects in the range of up to 270 degrees, and distances far beyond the ones required for this project, the 2D laser scanner was chosen as the appropriate solution.

## 3.9 Public lighting for pedestrians/cyclists

In the process of designing light for the public, it is essential to understand the basic needs for pedestrians and cyclists. While not much research has been done for lighting for cyclists, lighting for pedestrians is a well-documented topic, and should provide good guidelines. In the research, *Human factors in lighting* by Boyce et al. (Boyce 2014) it is described that the main objective, in lighting for pedestrians, is to make sure pedestrians can see where they are, can move safely over the ground, can assess the risk to personal security and avoid visual discomfort (Boyce, 2014 - p. 457). In order to accommodate these needs, Boyce et al. mentions spatial brightness as a critical factor. Spatial brightness is a measure of level and distribution of illuminance and light spectrum. While no current studies have yet concluded the effect of light *distribution* on pedestrians, the effect of illuminance and light spectrum has been studied.

It is commonly acknowledged that a high illuminance enhances the visibility and the ability to move safely around. However, for the sake of saving energy consumption, different international standards have been proposed to set a higher limit for the illuminance. While the standards for average horizontal illuminance for pedestrians vary from country to country (Australia: 0.5-7 lux and USA: 3-9 lux), the European Union has set the range from 2-15 lux. (Boyce, 2014-p.459) It is important to stress that these recommendation are minima, so the values are likely to exceed the upper limit in some areas (such as shopping malls).

A study of the speed and manner of movement through a large open-plan office under different illuminances showed that an average illuminance of 1 lux on the route was required for smooth and steady movement. This indicates, as Boyce et al. also addresses that the lighting standards might be setting the bar a little too high. While this is for pedestrians, it must be noted that, in the pursuit of identifying the proper light levels for cyclist, higher illuminance levels are required. Studies of car parks in urban areas examined the effect of illuminance on pedestrian, cyclists and cars, and concluded that an illuminance in the range of 10-30 lux is necessary and light sources with higher scotopic/photopic ratio were preferred (Boyce, 2014 - p. 457).

Another factor that is considered import for public lighting is the ability to recognize faces. Recognizing faces is associated with a higher sense of security (we will have the ability to assess threats at a distance), but is also associated with better visibility of other people in public. Semi-cylindrical illuminance is used to measure this. Semi-cylindrical illuminance is the average illuminance on the surface of an upright half cylinder. (Boyce,2014- 447). Rombauts et al. (1989) claimed that confident face recognition is not possible beyond 17m and that a semi-cylindrical illuminance on the face of 25 lx is sufficient to give confident identification at this distance. Boyce and Rea(1990) examined the effects of different security lighting installations on people’s ability to detect someone walking towards them, and then to recognize them between a selection of four b/w photographs. The results showed that the probability to detect someone approaching reached 90% at vertical illuminance of 4-10 lx on the person.

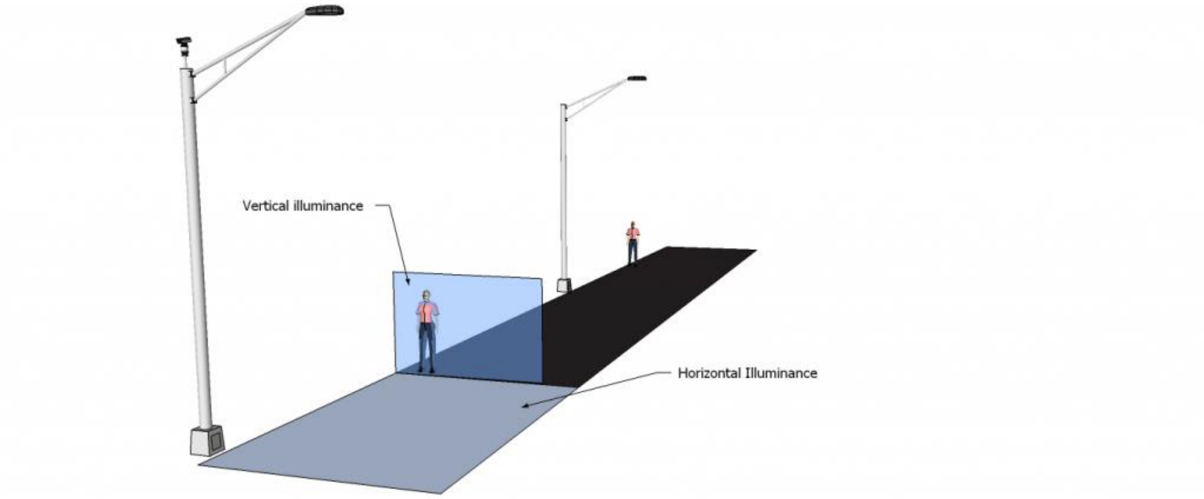



Figure 37: Illustration of the vertical and horizontal illuminance (Group EDF n.d.)

Despite guiding the lighting designer to achieve appropriate light levels for pedestrians and cyclists, Boyce et al. addresses that these recommendation often fail to meet many of the user' desires. "*They certainly provide a basis for ensuring safe movement along a road and provide some guidance about where the road goes, but they (recommendations) do not directly offer guidance on how to illuminate the surrounding environment and avoid discomfort glare"* (Boyce, 2014-p.480). Boyce et al. argue that it takes someone with an eye for the site and an aesthetic sense to create an attractive and comfortable installation which also meets the lighting criteria.

## 3.10 Interactive and Dynamic lighting in public:

The emergence of LED based lighting systems have during the past years revolutionized the way in which lighting designers can shape public spaces with lighting. This is due to the LED being digitally addressable, enabling immense possibilities for new types of interactions between users and the lighting through integration of sensors and smart environments (Kelley, 2007). The field of interactive lighting has been applied mostly to indoor lighting concept but with the development of more sustainable and robust LED fixtures and systems, the potential for interactive lighting in outdoor public environment have been largely increased (Jackson, 2015)

The outdoor lighting domain however has focused mostly on the LED's efficiency and low cost of ownership to save energy and money for local governments, due to its ability to be switched off when no-one is present. However, the use of the LED for providing interactive city lighting for entertainment is as still a fairly unexplored (Kelley, 2007). Interactivity in the public space can connect people to each other and to the space in which they are in. The effect of allowing such interactions is that the lighting changes from what we normally associate public lighting with - static and boring, to an interesting dynamic behavior.

Going from static lighting in the public, to the possible dynamism that the interactive lighting provides the notion of timing becomes increasingly important (Seitinger, 2013). Time dependent parameters for lighting has up until now focused on approximation of utility of the space in order to save energy by switching off in unused hours. With the integration of a large variety of sensors, detecting data such as wind, temperature, sound, human presence and humidity, it is now possible to enable far more adaptive and communicative scenarios that convey time dependent information back to its audience.

Additional to this, utilizing data from these sensors through Internet Of Things (IOT) and machine learning algorithms, the level of knowledge that can be learned from these installations reaches far beyond what we can imagine today (Jackson, 2015). One example of this could be that the level of activity detected through motion sensors is collected and analyzed - feeding the machine learning algorithms through a longer period of time. The more data the algorithm receives, the more it learns about the activity patterns on site. This knowledge can ideally be applied back to the system, enabling it to predict level of activity at what time during the day, week, and month.

**Interactive lighting as an aesthetic experience**

As a guideline for ensuring that future interactive lighting design installation attain the effect on the public as envisioned, Peeters et al. discusses in his paper *the aesthetic experience in interactive lighting design* (Peeters 2013) how he applies John Dewey's notion that *"the aesthetic experience, or quality, is something that comes from both a bodily sensed experience and an intellectual experience"*, (Dewey, 1934). Dewey argues that in order for an installation to have profound impact on the public, it must both have an impact on the immediate sensational level - achieved through an aesthetically pleasing design, and on an intellectual level - achieved through associations to earlier experience (memories, knowledge, and dreams). These two processes are *"interdependent and inseparable*", meaning that our experience of the aesthetic cannot be separated from its socio-historical context.

**Lighting responding to people's movements and presence:**

As this project is investigating potential ways in which people can affect the simulated flow of water, the interactive element largely revolves around the physical presence and movement of the users. As a reference to section *water characteristics* (section 3.4) the forces that the riders of a pump track would have on water, would be somewhat similar to that of a boat sailing through water, applying tension/pressure on the water along its path. A possible effect to replicate this scenario is to have light following the rider through the track, and gradually degrading behind him/her (*wave characteristics- loss of energy*). To understand the implications of such interaction - having light following people in the public - Poulsen et al. examined, in his paper *Full Scale Experiment with Interactive Urban Lighting* (Poulsen, 2011) how pedestrians' movements can be used for controlling the illumination of a town square. As people walked through the square, the general lighting was dimmed slightly, and a brighter circle of light would follow them as they walked. An interesting finding from this experiment was that most of the people who crossed the square did not notice the change of illumination, but the people who could see the square from a distance clearly noticed the effect. Poulsen et al. describes this phenomenon as a notion of *actor* and *observer*, in which the actor triggers an effect which is easier recognizable for the observers than the actor himself.

This phenomenon was similarly experienced in a field experiment carried out in November 2016 in Rabalderstræde, Musicon. The purpose of the experiment was to assess the potential of using

responsive lighting as a playful interactive element for people "*on wheel"* in the public. The playful part of the installation was that the lighting would respond to people's speed. In fact it did not, but was simulated by the test conductor, controlling eighth street lights real-time through a smartphone app. The eight street lights were set to decrease in intensity, from fully lit, to completely off, in 6 different intervals corresponding to the speed of: walking, slow running, running, fast running, cycling and fast cycling. As a person would approach the test area, the test conductor would estimate the corresponding speed to that of the above mentioned intervals. Every time a person, moving along the street, would pass a light post, the 8 street lights would be reset to fully lit. As he/she continued towards the next light post, the light intensities across the eight city lights would decrease again - but depending on the speed of the subject, the lights would either reach of point where it goes completely off (subject is too slow), or the subject succeeds in reaching the other light post, before the light goes completely off.
During the experiment it was recognized, as mentioned above, that most of the subjects did not even realize that they had an impact on the change of illumination. From observations during the experiment, it was learned that a possible reason for this could be that the subjects were inclined to fixate their eyes on the pavement right in front of them. This was especially the case for people who were walking, cycling slow, looking at their cellphone, or for people who walked in pairs. The lack of awareness of their impact on their surroundings can perhaps be characterized to be the result of; prioritized emphasis on safe movement and increased attention towards social interaction.
An additional factor that was deemed to have a big impact on the results of both the test in Rabalderstræde, and the test *Full Scale Experiment with Interactive Urban Lighting*, was the visual feedback that the citizens received. Was the interactions clear enough? For the test in Rabalderstræde it turned out that using street lights - which is mounted high up in the air, resulting in a wide beam spread and lower contrasts on the pavement, had difficulties conveying a clear enough interaction between cause (human movement) and effect (light). It seems that in order to provide clear enough feedback to cyclist/skaters/pedestrians for him/her to understand the interaction, the light must be restricted to smaller areas and higher intensity differences. With higher resolution (magnitude of sources), and with smaller distances between each source, it is possible to provide a larger variety of appearances, which as a consequence conveys the interaction more effectively.

## 3.11 Summary

The analysis examined relevant topics that apply to the final problem statement "*how can we use lighting to simulate the movement of, and physical interaction with, water on a public pump track, while ensuring sufficient visibility?*" This entailed an examination of the human relation to water, the characteristics of water behavior, identification of recognized water scenarios, human perception of blue from both an emotional, physical, spatial and electrical point of view, an examination of the skating community, the sport that is related to pump tracks - BMX cycling, and the structural character of pump tracks. For the practical part of the project, the analysis also investigated which types of luminaires and sensor could fulfill their respective tasks of simulating motion of water and detecting user positions on the pump track.

In the analysis, it was learned that the mere observation of water has more than a satisfactory effect on our mood - it can even have a positive impact on our health and wellbeing. Through the examination of water characteristics, a number of essential observations were made:

- water is influenced by both gravity and surface tension. Though water is often influenced by both forces, it is important to distinguish them from one another, since they shape waves differently. Gravity waves reach far longer distances, elicit longer wavelengths and higher speeds, whereas surface waves are more responsible for the “texture” of the water surface.
- Distribution and loss of energy was also identified an important element for simulation a realistic wave.
- Two interfering waves will either cancel each other out (if having similar wavelengths and if they are equally far away from equilibrium on both side), or will add up (if having similar wavelengths and are on the similar side of equilibrium).

To identify relatable water scenario as inspiration for themes and for the programming phase, three water scenarios were identified - *rain, boat and current*.
In the analysis of depth perception, it was learned that blue is the color in the visual spectrum that is perceived to be farthest away. For the sake of simulating water, this might actually be an advantage, as it could enable an additional perception of depth (between crest and trough) by adding white or turquoise color as the “crest of the wave”.
In the examination of human perception of blue, it was learned that blue can elicit alertness and concentration, but does also have the down effect of inhibiting our circadian rhythm (if exposed over a longer period) and our ability to visually focus. A possible way around these disadvantaged would be to occasionally add some green or white (red and green) to the light. In terms of circadian rhythm, it would be a big issue if the lighting was exposed consistently to a certain number of people. However, as this installation does not expose the light directly to nearby resident, this is not considered an issue.
During a field observation of BMX riders in an indoor skating hall in Musicon, it was learned that the level of concentration varied largely between the people who were riding the pump track and the people who did not. It seems that it requires full concentration to ride a pump track, so it might make more sense to focus on the observers and their experience of the lighting, rather than focusing on the experience of the riders - which is mostly centered on the mere act of riding the pump track.
Though no official standards for lighting for cyclists in Denmark were found, research suggests that a horizontal illuminance of 10-30 lux and fixtures of higher scotopic/photopic ratio is sufficient in ensuring visibility of the cyclists on the pump track. Vertical illuminances of 4-10 lux were found to be adequate in illuminating the riders, to ensure that they would not just be perceived as shadows.

In the process of designing interactive lighting in public spaces, examples of successful interactive designs along with recommendations from different researchers engaged in this topic, has been identified and analyzed. An essential finding from this analysis, is that, in order to succeed in capturing and maintain the general interest of the public, it is a prerequisite to affect the users of the space on two levels: *an aesthetic level* - the general intuitive respond people get from the installation, and *an intelligent level*, which links the installation to a deeper meaning involving memories, knowledge, associations etc. Additionally, it was deduced, that to use lighting to address an already existing activity, which in this case would be that act of riding a pump track, it is crucial to understand that the activity itself is enjoyable for the users. The lighting can accommodate or maybe even enhance the sensation of riding the track, but should at all times omit becoming an obstacle for them. The proper solution must then balance between a lighting design that ensures sufficient visibility, but at the same time can give an aesthetic and meaningful response to the activity on the pump track.

In the pursuit of identifying the best fit luminaires for the project, multiple solutions were presented and evaluated. However, one factor turned out to overrule most of the suggested solutions - the fact that vandalism is a rather common phenomenon in the area. Thus, having pullert light, ground recessed led strips or ground recessed led lights integrated in the pavement were not an option due to the high risk of being vandalized. Spotlight, however, were considered to be the appropriate solution, due to the above mentioned reason, but also because this solution would keep a distance to the pump track, to omit becoming an obstacle.

Through thorough analysis of possible sensor solutions, with an emphasis on factors such as range, price, response time, robustness etc., it was learned that 2D laser scanners were best fit to fulfill the task of detecting people along the track.

# 4. Component criteria

Prior to identifying the proper component for the project, it is essential to set a series of criteria for both the spotlight and for the 2D laser scanner. These criteria are formed on the basis of the analysis, and will ensure that the chosen component fulfills their purpose.

## 4.1 Spotlight

- The spotlight should:
    - Be addressable
    - Contain RGB(W) values
    - Provide a minimum horizontal illuminance of 10 lux on the pavement
    - Provide a minimum vertical illuminance of 4 lux
    - Have a high efficacy
    - Not cause glare (filter might be required)
    - Allow DMX control
    - Have a lifespan of more than 40.000 hours.

## 4.2 2D Laser Scanner

- The 2D laser scanner that that will qualify for the project, should:
    - React without significant delays (below 70ms)
    - Be able to function properly under outdoor environmental factors, such as:
        - Temperatures below -10 degrees and above 30 degrees

    - Rain/ high humidity
    - Ambient light above 60.000 lx
- Last for more than 15+ years
- Be easily installed and reinstalled: to ensure it is accessible if not functioning properly
- Provide a minimum of three detection fields

# 5. Design and implementation

After extensive examination of the underlying considerations, pitfalls and possibilities of this project, involving the aesthetic and interactive part of the project (water simulation), human factors (safe lighting for cyclists, perception of color) and the practical part of the project (examination of luminaires, sensors, system, placement), it is possible to draw an overall design for the pump track.

The design concept is developed to answer the final problem statement "*how can we use lighting to simulate the movement of, and interaction with, water on a public pump track, while ensuring sufficient visibility?"*, along with the three main goals and their respective sub-goals.

The *design and implementation* chapter will consist of three parts.

- The first part will explain the overall design concept, which will emphasize the aesthetic and interactive character of the lighting installation.
- The second part will explain why choosing this particular concept benefits the final problem statement and meets the goals of the project.
- The third part will explain the practical part of the design. Here, the different components that have been chosen for the project (in collaboration with DONG, ÅF, SEAS-NVE, Roskilde Municipality) will be presented, along with information on placement, height and direction.

## 5.1 Concept Design

The design concept will consist of four main elements: Visual expression, layers, behavior and timing.

### 5.1.1 Visual Expression

#### 5.1.1.1 Scenarios

Water physics and behavior was examined in the analysis, to strengthen the association to water. This gave inspiration to potential water scenarios that people could recognize and relate to. Inspired by this research, four main scenarios were chosen.

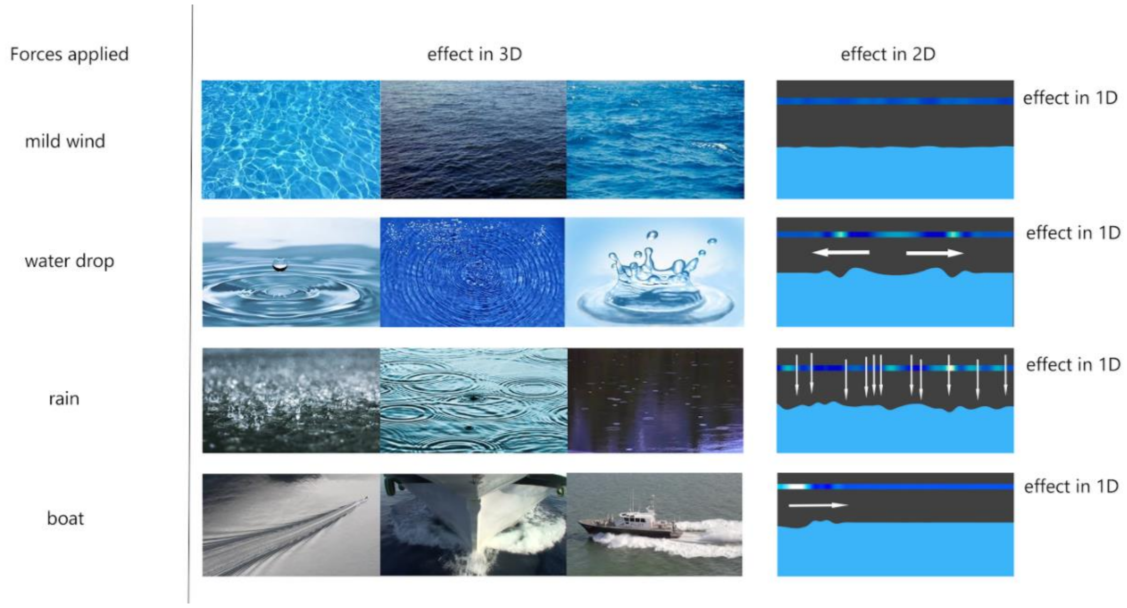


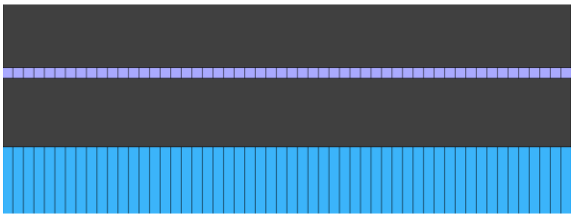

**Figure 38: Four scenarios are used as a guideline for how water behaves under different stimuli/forces. Associating these scenarios to how the surrounding area and people on the pump track can apply "forces" on the installation, the behavior of water in these specific scenarios will be simulated.**

The scenarios were chosen based on the different forces that are applied to the water. These forces can be related to the forces that will be applied to the pump track and the area around it. The scenarios will be further elaborated in *behavior* 5.1.6 and tested in the evaluation chapter (section 6.1.5).

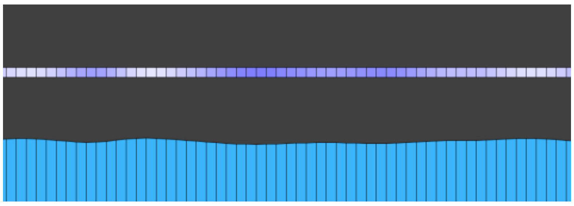
#### 5.1.1.2 Wave design

In the pursuit of simulating water through lighting, and being restricted to one dimension, the color information on each pixel (spotlight) is important for the "realism" of representing water. As first demonstrated by Goethe in his *Theory of Colors* and later supported by the study of the *chromostereoptic effect* (Faubert, 1994) the perception of depth is greatest at the short wavelengths (blue) of the visual spectrum. As an addition to this, it is also commonly acknowledged that dark objects appear farther away than light objects. In a 3-dimensional world, the lower curve of a water

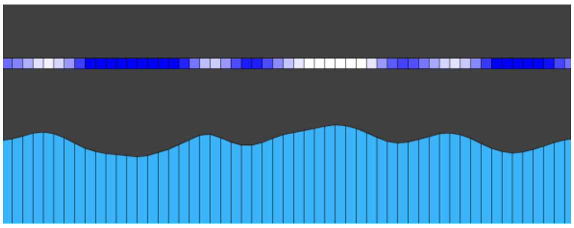
wave would be further away from the eye - suggesting a dark blue appearance, while the crest of the wave would be closer to the eye - suggesting a lighter appearance.
The images below illustrate the basic representations of waves through color. The first image shows the light wave's resting state - the state in which no energy is applied to the pump track, the second image show the light wave influenced by low amounts of energy, and the last image show the light wave influenced by high amounts of energy.



*No energy: RGB values = (110,110,256);*



*Low energy: RGB values = (90-130, 90-130,256);*



*High energy: RGB values = (0-200, 0-200,256);*

**Figure 38: The three illustrations above are screenshots from Processing 2.0. They show three variations of energy in the water.**

### 5.1.2 Layers

Inspired by John Dewey's notion that an interactive installation will only succeed, if it affects the audience on both an aesthetic and an intelligent level, the pump track will be divided into an aesthetic layer and an interactive layer. Additionally, a functional layer will ensure sufficient visibility. Each of them will have different responsibilities.

#### 5.1.2.1 Functional layer

The functional layer will be responsible for ensuring that the lighting provides enough illuminance to accommodate the functional needs of the users. In this case, the lighting needs to ensure that the users can actually ride the pump track. This entails providing sufficient illuminance for the riders to assess the spatial challenges ahead of them, such as obstacles or changes in directionality or curvature.

#### 5.1.2.2 Aesthetic layer

The aesthetic interactive layer will have the responsibility of conveying a general lively and fluent expression of the lighting installation. This is the layer responsible for sparking the initial interest of the users and creating and general ambient appearance.

#### 5.1.2.3 Behavior layer

The interactive layer will be responsible for instigating a playful interaction between the users of Raadhusparken, and the visual expression of the pump track. This layer goes beyond the aesthetic layer, in the sense that it requires the users to assess, experiment with and understand the interaction. How the interactive layer is designed will depend on the amount of activity on the pump track, time of the day and the amount of activity in Musicon, further explained in *Behavior* (Section 5.1.3)

### 5.1.3 Behavioral layer

In the same way that the behavior of water is always a result of external forces, the lighting installation of the pump track in Raadhusparken will be fully dependent on the amount of "energy" that is applied to the area. The types of *energies* that can have an influence on the installation can be divided into three categories:

- the amount of activity (events) in Musicon,
- the amount of activity on the pump track over time
- the current activity on the pump track

#### 5.1.3.1 Indirect interaction

The illustrations below attempts to clarify the approach to the interactive layer. Though it is in fact interactive, it does not explain how the light interacts directly with the users as they are riding it. This will be explained in the subsequent section.

The *Vibrancy State* scheme (figure 39) will be used as an indicator for how "vibrant" the lighting will be. The appearance of these states is inspired by the *Wind* and *Rain scenarios* explained in section 5.1.3. By calculating the amount of detections per hour, the *User Occupancy* parameter, visible on the left side, will keep track on how much activity there is on the pump track, from hour to hour, and will communicate this on to the next visitors. The *Musicon Event* parameter will keep track on the level of activity in the Music

on area. The more activity, the more vibrancy. By measuring the amount of activity in Musicon and amount of activity on the pump track – the lighting can have 5 overall *states of Vibrancy*. The *states of Vibrancy* is illustrated through the color codes, and further explained in figure 39.

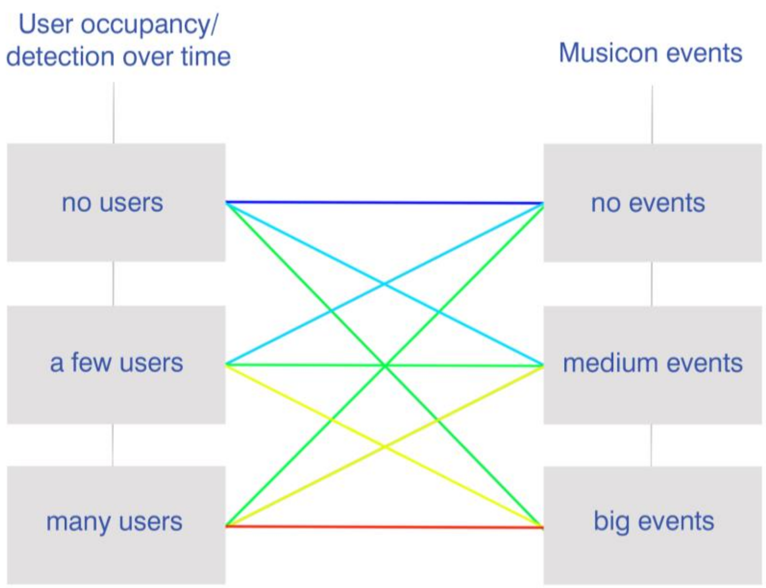



**Figure 39: *Vibrancy* Measurement: The cumulative level of activity/Vibrancy on the pump track and in Musicon is measured through the color codes represented above. The more used detected and the bigger events in Musicon – the higher the *Vibrancy***

Based on the average activity on the pump track and the general amount of activity on Musicon, different levels of light waves will be created. The blue wave in figure 40 indicates the lowest amount of activity, whereas the red wave indicates the highest amount of activity. (note; the color codes do not explain the color of the waves, just the vibrancy). All five states have an influence on the frequencies of the waves, their respective wavelengths and the amplitudes/intensities.

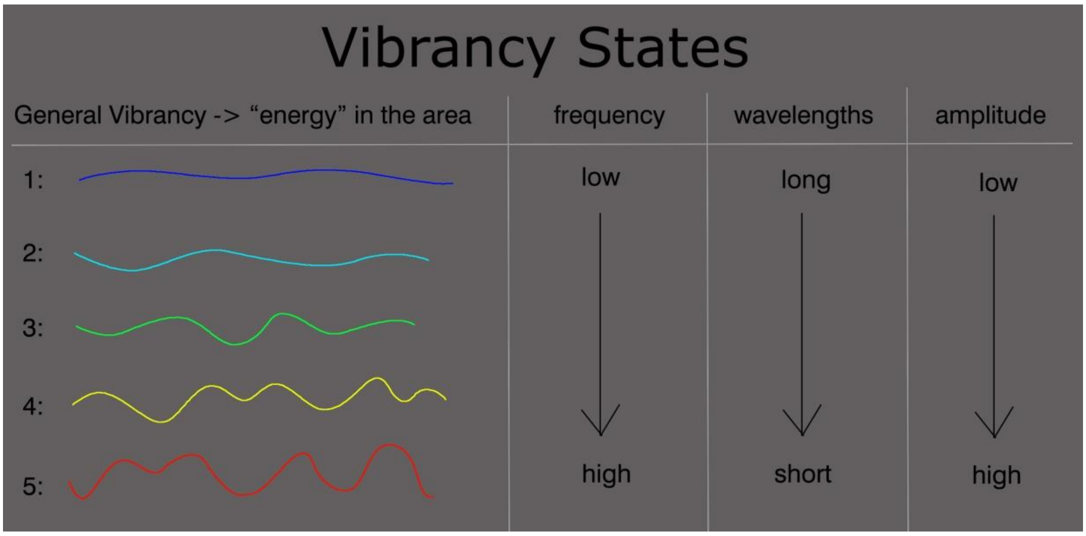



**Figure 40: Vibrancy states. The different vibrancy states are conveyed through a change in wavelengths, frequencies and amplitudes.**

#### 5.1.3.2 Direct Interaction

Light follows

With the intention of instigating a playful and experimental approach to riding the pump track in Raadhusparken, the lighting will respond directly to the presence of the users on the track. The interaction is meant as a reference to the *boat scenario* - which forces tension on the water surface around it and distributes the energy of the waves behind it. As the rider enters the pump track, light around him/her will increase in intensity. Continuing along the pump track, the wave of light will follow the rider and smoothly decrease in intensity behind him/her.

Lights responds

When the state of general *Vibrancy* is above 3 (few users + big event, many users + medium event or many users + big event), the light will begin to act a little differently. This can be thought of as an additional effect that only occurs when enough activity has happened in the area.

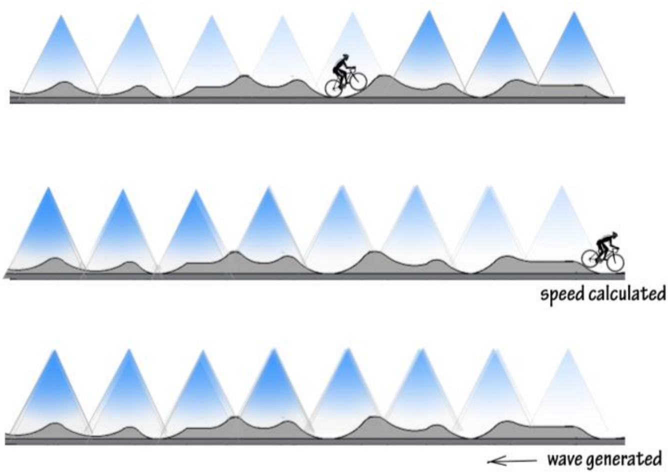



Figure 41: as the user reaches the end of the track, a wave of light will be generated and pushed back

As the rider reaches the end of the track, a wave of light will be pushed back (figure 41). The wave will respond by replicating the speed of the rider and will start at a high or medium intensity (depending on the speed) and gradually decrease until returning to its resting state. The higher the speed of the rider, the longer the responding wave will last, and the farther it will go. As higher speeds generate more energy, this will be visually apparent when comparing the responding wave from different users. Raadhusparken will be a place of many types of different users, with varying experiences with riding a pump track, and with various "wheel tools". The speed of the users on the pump track will thus vary a lot. The higher purpose of "rewarding" the better pump riders is that it should become a motivational factor for them to get better. The illustration below demonstrates the level of potential energy that different types of user can apply to the installation.

### 5.1.5 Timing

Timing is essential for a successful lighting design - without a well thought through timing of a lighting installation, the potential pitfalls would be that the installation will use an unnecessary amount of energy by illuminating during daytime when the sunrays will outshine the installation, or at times when the least amount of people are present (during night hours). Despite the obvious environmental issue in not timing an installation well, the well-being and comfort of nearby residents is also at risk. Thus, the lighting installation will follow a set of rules for how much it will lit and at what times throughout the day.

As a general rule, the installation will be turned on from civil twilight (right after sunset) until 1am, where the use of the path is expected to be at its minimum. Instead of the lighting turning completely off, it will remain at its lowest *Vibrancy state* (see section 5.1.3) dimmed down to 50%, ensuring just enough illuminance for people to see and navigate through the pump track. At 6 am the lighting will go back to 100%, and will again be affected by indirect and direct interaction until sunrise, where it will turn completely off. These set of rules work well for winter, spring and fall, but will not apply to the Danish summer. Here, the light will only be turned on between sunset and 1am.

## 5.2 Goals

To elaborate further on the reasoning behind the concept choices, the original goals and sub-goals will be presented again, with a subsequent explanation.

**1. INVITE PEOPLE TO USE THE PATH**

**Invite people to use the path**:
There are many ways to invite people to use a path. They can be "manipulated" by a lighting design that guides their attention, making them either follow the path without consciously knowing why, or they can be directly attracted by the lighting. However, as for this project, the way in which the lighting "invites" people, is directed at their prior experience of passing Raadhuspark and the pump track. The lighting will invite people based on their willingness to experiment with and interact with the installation.

**Invite people to stay and play at the squares**
The pump track itself is a playful element along the Musicon Path which will invite people to slow down or stay for a little. By adding a layer of lighting (*functional layer)*, the mere attraction for riding the pump track will increase because the lighting provides the sufficient visibility. On top of this, the *aesthetic layer (see section 5.1.2)* of the lighting design will create visual interest by conveying a sense of vibrant/dynamic appearance. By offering direct interaction between users of the pump track and the lighting, the *directly interactive layer* (see section 5.1.2.2) will promote a playful and experimental approach to riding a pump track.

**Give the path an identity**
The signified character of the path will be centered around the concept of *flow of water*, which will be conveyed through the lighting on the pump track. *Flow of water* will also be the concept of spot 3

and spot 5, which is currently being developed by former lighting design student, Esben Oxholm in collaboration with Frederik Borello.

**2. BE INNOVATIVE**

**Function as a Living Lab**

The lighting on the pump track will, on many levels, function as a Living Lab. There are many aspects of this project which are innovative, but the primary interest of using the area as a Living Lab, is to see how people react when they realize they can have an impact on the lighting. How do they react? Do they try it once, and never again? Do they stay and have play around? Since this has not been done before, we really do not know, and can most likely only learn from seeing the effect in real life.

**Be able to notify users on the path about events at Musicon**

The system that will be used in this project (section 5.3.4) have the capacity to be notified when certain events are happening at Musicon, and subsequently convey this information through a change in appearance of the lighting. In the *concept design* it was explained how the level of activity happening at Musicon (small event - medium event - big event) could affect the level of *Vibrancy*. To convey the message even clearer, a new color theme could overwrite the blue- water theme at special events, while still remaining its dynamic liquid-like appearance

**3. BE SUSTAINABLE**

As stressed in section 5.1.5 (Timing), timing is essential for keeping the energy usage and environmental impact low. Synchronizing the timing of the installation with the day/night cycle throughout the year will be the basis for ensuring a sustainable solution. On top of that, the lighting will also be influenced by the amount of activity on the pump track. The less activity, the lower state of *Vibrancy (*section 5.1.3*)* and the lower overall intensity. This will consequently also mean lower overall power consumption and environmental impact.

## 5.3 Implementation

After agreeing upon the different criteria for the respective components (primarily luminaires, sensors and lighting system) of the project, and through extensive examination of potential products available on the market, it was possible to select the adequate components for the project.

It must be noted that the official list of component extents my field of knowledge, as it also entails details such as wiring, insulation, electrical component for ensuring adequate distribution of current, boxes for storing the lighting system etc. All these details will be available in the appendix (11.7-11.13). What will be emphasized in this section is:

- The selection of lamppost: placement, height
- The selection of fixtures: placement, height, direction
- The selection of sensors: special fitting, integration in mildwide, height, direction
- The selection of lighting system

## 5.3.1 Lamp post

*Product*

The lamp post that was chosen for the project was Milewide's lamp post Ø170 (6.3m) (see appendix 11.9). The advantage of this lamp post was Frederik Borello's prior experience with it, along with its flexibility in terms of placing multiple fixtures and special integration of sensors.

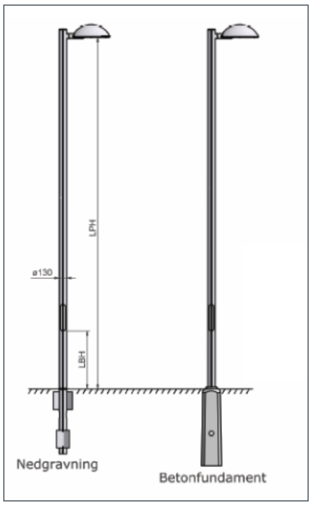


Figure 43: Milewide lamp post 6.3m

With respect to the general appearance of the installation in daylight, the amount of "obstacles" for the rider, and the simplicity of the installation, it was decided that the amount of lamp posts should be kept at a minimum. To accommodate this need, it was agreed upon, that the lamp posts should contain both fixtures and sensors.

*Placement*

The placement of the lamp post was carefully thought over, as it should both be far enough away from the pump track to prevent becoming an obstacle, should be close enough for the fixtures to provide the appropriate luminance and distribution, and should enable integrated sensors to detect people properly. Based on these considerations (which will be further elaborated in the *sensor* section) it was chosen that the lamp post should be placed 5 meter away from the pump track. This way, it was considered to be far enough away from the pump track, and close enough for allowing proper illuminance and detection. With 10m between each lamp post, the total amount of lamp posts for the pump track was chosen to be 7. Originally it was chosen that there should be 8 lamp posts, but since the fixtures on the last lamp post would likely interfere with the regular path lighting on the Musicon Path, making them superfluous, it was chosen that 7 lamp posts would be enough.

To make the lamp posts less receptive towards stickers, the mast will be painted with anti-stickers.

## 5.3.2 Fixture

In his 10 years of experience in the industry, Frederik Borello (ÅF) stressed early in the project that he has been collaborating with the Italian fixture company *DTS* in many occasions, and that they have a high quality in their products.  Thus, a fixture from this company was selected.

*Product*

DTS EOS 6 FULL COLOR MEDIUM BEAM was chosen for the project, based on its capacity to use RGB values, its beam angle, its rather low power consumption of max 18W, its lifespan, its price and its physical appearance. All information on the fixture is attached in appendix (11.12).

6 x Full Color RGBW LED;
2,300 Lumens @ 500mA
LED Channels: 4 (Red/Green/Blue/White)
LED lifespan: 50,000 hours (70% lumen output)
DMX 512, RDM and ArtNet

Figure 44: DTS EOS 6 FULL COLOR MEDIUM BEAM (full detail in appendix 11.12)

*Integration of fixtures on Milewide lamp post*
It was decided that three fixtures per lamp post would be the appropriate number to provide illuminance along 10 m's of the pump track (due to the distance between each lamp post being 10 m). One fixture in the height of 5.7m, one in 5.4m height and one in 5.1 height.

The illustration below shows three lamp posts on a linear path, with three fixtures on each.

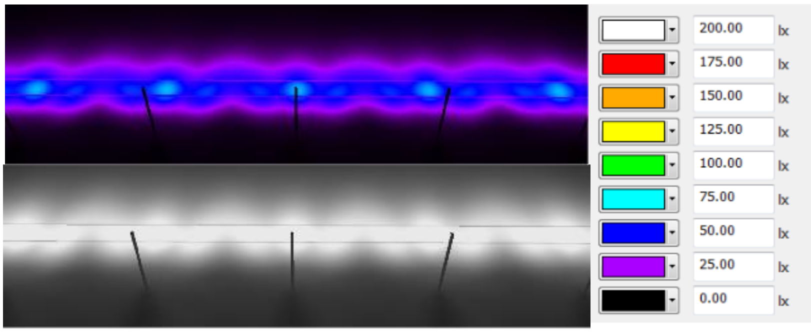


Figure 45: Luminance on the pavement from EOS 6. (Frederik Borello, ÅF)

The calculations show that the criteria for minimum horizontal illuminance of 10-30 lux defined in section 4.1 were met.

*Honey-comb filter*
To prevent users of the track to experience the sensation of glare (since the height of the fixtures are relatively low), a *Honey-comb filter* were chosen as a filter for the fixture.

Figure 46: Honey comb filter: used for preventing glare

### 5.3.3 Sensor

To select the right 2D laser sensor, a meeting was held with sales engineer Ken Skov and product manager Carsten Bruhn from the widely respected an applied German sensor company *SICK (*sensor intelligence). During the meeting, which was held at ÅF Lighting, Herlev, different 2D laser sensors were introduced and demonstrated. From the requirements that we set for the sensor, Ken Skov and Carsten Bruhn suggested a set of appropriate 2D laser scanners. Based on the discussed advantages and disadvantages of those sensors, the final 2D laser scanner was selected.

*Product*

With the goal of detecting exact positioning of multiple users on the track, simultaneously, extensive examination of different sensor technologies were conducted in the sensor analysis. Based on pros and cons of the different sensors (section 3.8.6.6) and the criteria set, SICK's 2D laser sensor TIM361-2134101 was selected. See appendix for more information (appendix 11.10).

Figure 47: TIM 361, 2D Laser Scanner

With a response time of maximum 67ms, a detection range of 270 degrees, an operating range of up to 10 meters, its ability to function under ambient light of up to 80.000 lux and temperatures between -25 and 50 degrees, this sensor was deemed to have the capabilities necessary for this project. An additional advantage of the SICK sensor has integrated software, SOPAS, which makes it easily manageable and programmable. Through the SOPAS software, it is possible to customize three detection fields (one for each fixture), and can be set to only detect objects of particular sizes. This way, the sensor can be programmed to ignore interfering objects such as birds, spiders, leafs etc.

*Placement and angle*

Deciding on the proper height and angle of the sensors was crucial for the laser sensor to be able to detect users of different heights on the pump track. With the intention of integrating the sensor in the Milewide lamp post, A 2D representation of the pump track and the Milewide lamp post (as visualized below), were used to estimate the proper placement and direction.

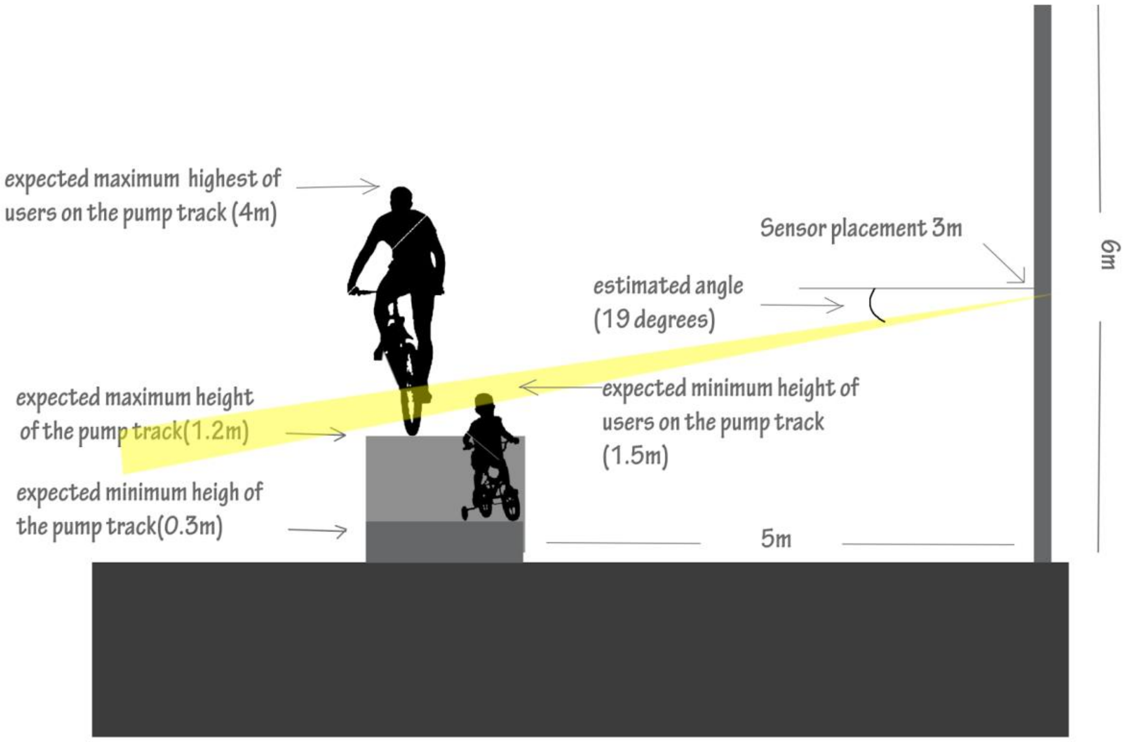



Figure 48: Calculating the angle of the TIM 361 2D laser scanner.

Placing the 2D laser scanner in the height of 3.3 meters and with a degree of approximately 19 is estimated to be appropriate for detecting users of varying heights. Since the pump track has not yet been built, and we do not have any official drawings, the values are estimated based on feedback from Dirtbuilders (the company that will build it[5]). Once the pump track has been built, the angles might need to be modified to accommodate its task.

Since integrating a 2D laser scanner in a lamp posts is a fairly new approach to interactive lighting in public (no similar projects have been found), a special solution was necessary. It must be noted, that I was not responsible for this work. The solution was solely developed by Frederik Borello in collaboration with Milewide. All the drawing are available in appendix. (11.11)

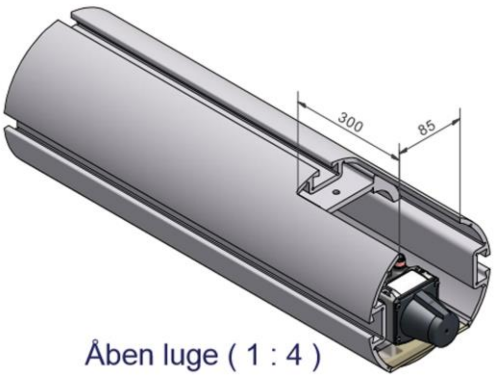



Figure 49: The image above illustrates how the SICK-TIM 361 2D laser scanner will be integrated in the Milewide lamp post.

[5] http://www.dirtbuilders.com/

The sensors have to be established on a special fitting in the mast. The fittings will be constructed in a way that allows the sensor angle to be modified, from 19 degree + - 5 degrees. As the sensors have been mounted, they must detect movements within a 10-12m wide detection field along the pump track.

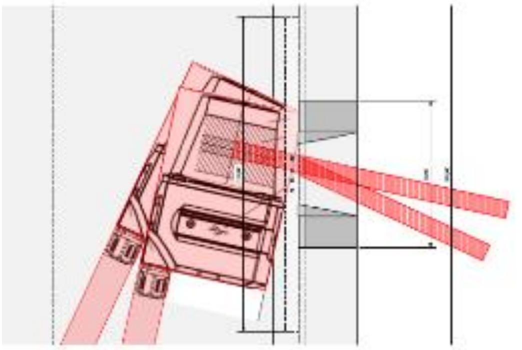


**Figure 50: Special adjustable fitting for the 2D laser to be attached inside the Milewide lamp post.**

## 5.3.4 Lighting Control System

The lighting control system that was chosen for this project is called Mosaic Designer, consisting of a compact controller, *Mosaic Show Controller* and a software for programming the light and interaction, called *Mosaic Designer 2 Software*. See appendix for more information (11.13)

*Mosaic Show Controller*

For the convenience of Frederik Borello's experience with this control system, the Mosaic Designer system was chosen. He estimated early in the project that this system would be able to handle the interaction and visual expression as explained in *Design Concept.* The controller supports DMX512 and DMX-over-Ethernet protocols to LED fixtures, making it able to output directly (DMX512) or send the data across a network (DMX-over-Ethernet). A built-in real-time clock enables the controller to recognize astronomical cues such as "sunset" and "sunrise", depending on location.

**Figure 51: Lighting system: Mosaic Show Controller**

Offering up to 2048 channels, this controller has the capacity to control a large amount of fixtures and their respective RGB (W) values.

*Mosaic Designer 2 Software*

The software provides a framework for creating a large variety lighting scenarios. The interface is rather intuitive, making the programming of individual pixels a matter of drag-and-drop. A great advantage of the software is that it also allows for different types of *triggers*. This essentially enables the integration of sensor data in the system, which is a prerequisite for making the installation directly interactive.

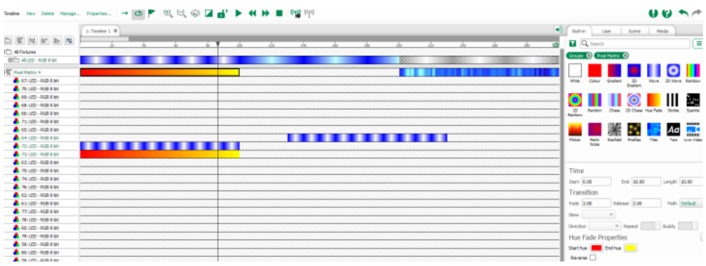


**Figure 52: Mosaic Designer Software**

# 6. Evaluation:

The *Design and Implementation* section explained how the final problem statement, "*how can we use lighting to simulate the movement of, and interaction with, water on a public pump track, while ensuring sufficient visibility?"* was approached, both from a conceptual and practical standpoint. At this point in the project, all components have been selected (available in appendix 11.7), and the overall concept for the lighting *behavior* (section 5.1.3) and *visual expression* (section 5.1.3) have been presented in *concept design.*
This section will go further in depth with assessment of different "water codes" - to get an estimate of how its visual expression is actually perceived and to pinpoint essential programming criteria for simulating the motion of water. Additionally, a physical test of the sensor will be presented, to see how well it detects.

Based on the finale problem statement, two research questions have been formulated and will be evaluated in this section:

- *"Does the light  look similar to the movement of water?"*
- *"Does the sensor detect exact position of the users?"*

The *Evaluation* section will be divided into two main sections:

- **Simulation and assessment:**
    - This section will be responsible answering the first research question. The first section will explain the pipeline of simulating/programming "fluid" in a 1-dimensional array of pixels/lights and will examine the visual expression and interaction between the users and pixels, from both a programming aspect and from the aspect of the observer.
- **Practical experiment:**
    - This section will be responsible for answering the second research question. It will entail a physical experiment with the chosen sensor. The test procedure and results will subsequently be presented.

## 6.1 Simulation and assessment:

This section will approach the research question *"does the movement of light look similar to the movement of water?"* by presenting the challenges and possibilities of programming this effect on an array of 21 spot lights. The summary and results (see section 6.1.5.4 and 6.1.5.5) will conclude the findings.

### 6.1.1 Addressing pixels in Processing:

In the process of programming a 1-dimensional representation of fluid motion, the first approach was to address pixel in Processing 2.0[6]. The reasoning behind using this software was that the online community of processing is wide, so there is a wide range of documentation and sketches available online. This was deemed a fast way of trying out different approaches to the programming of liquid motion. Additionally, it was also assessed, that in case a code would work after the intentions, it would be somewhat straight forward to use it for addressing lights. The reason for this is that there is not a big difference between addressing pixels in an array and addressing fixtures.

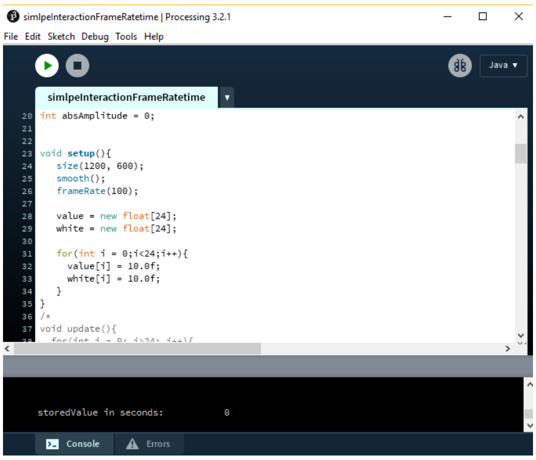



**Figure 53: Processing 2.0 was used for the early stages of addressing a 1-dimensional array of pixels.**

*Example of fluid representation*),

Below (Figure 45) is a screenshot from a sketch that applies the amplitude of a 2-dimensional wave to address intensity variations in a 1-dimensional representation of liquid motion. The colors that were chosen to represent crest and trough was extracted from the knowledge gained in section 3.6.

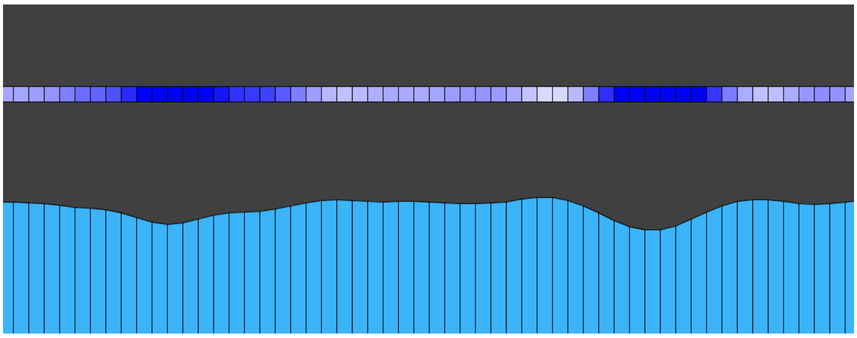


**Figure 54: Transforming a 2-dimentional wave into a 1-dimensional representation. The low points on the wave are dark blue, and the crests of the waves entail more white.**

*Example of interaction*

An attempt was made to program the *light follows (boat)* and *light responds* from the *directly interactive layer* (see section 5.1.3.3). A simple way of simulating the interaction was to make the program check the mouse position. As the program checks which pixel the mouse position is over, the intensity of the pixel will increase fast and slowly decrease afterwards. Figure 55 shows how the 1-dimensional array of lights looks as the mouse is moving rightward.

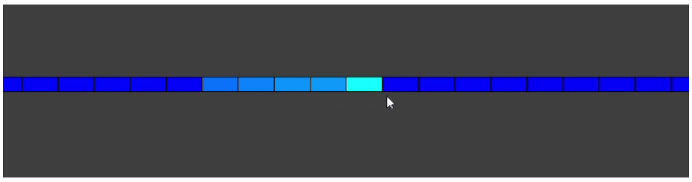


**Figure 55: Experimentation of "Boat effect"(see section 5.1.3)**

[6] https://en.wikipedia.org/wiki/Processing_(programming_language)

With the purpose of programming the *responsive wave*, the program will initiate a wave, if;
1: the mouse position has been checked over each pixel (sensor detects presence at all spotlights)
2: if the detection of the user follows the right order of pixels (user rides through the entire track)
3: if the sequence of detections follow a certain interval ( if the speed of the user is somewhat constant).
If all of the above statements are true, the average speed of the user is calculated and a *responsive wave* initiated.
The reason why this was important to test was that if this effect should be useable in the real installation, it should not be able to be triggered unless someone actually is riding through the entire track. It should be an incitement to actually ride the entire track. By checking the order of the detections and timing between each detection, the program ensures that the effect could not be triggered by other factors. With the data of the timing between each detection, the program was also able to calculate the average "speed", which was then used for the *responsive wave.*

### 6.1.2 Addressing LED strip through Arduino

As the initial idea for illuminating the pump track was to use LED strips along its path, experiments with an addressable LED strip through Arduino[7] was also conducted in the early stages of the project (as explained in the section 3.8.1). The experimentation of different codes in Processing seemed to transfer well into the programming language of Arduino - displaying a strip of fluid-like light as shown in the figure 27, section 3.8.1.

### 6.1.3 Addressing spotlights in Unity

As it became clear that spotlights were going to be used on the pump track, programming the visualization of liquid motion through LED strips and pixels on the computer was not sufficient anymore. Although the different codes that were used in Processing and Arduino were still usable, their visual representation (pixels/led chips instead of spotlight) was deemed too far from how it would actually look in real life. Thus, it was decided, that in order to provide a much more realistic setup to assess the lighting from, the codes used to represent liquid motion in Processing and Arduino would instead be used to address spotlights in a virtual environment. This way, it would be possible to get a much better estimate of how the lighting will look on the pump track, both from the perspective of riders on the track, and spectators around the track. The widely acknowledged 3D-programming software, Unity [8] has the capability to do so, and was thus chosen for simulating the lighting scenario. By utilizing a plan drawing of Raadhusparken and the pump track, a virtual representation of the area was modelled in Maya [9] and subsequently imported into Unity, where textures and lights were added. A screenshot from the simulation is presented in figure 56, showing the pump track around the Musicon Path.

[7] http://www.arduino.org/
[8] https://unity3d.com/
[9] https://www.autodesk.dk/products/maya/overview

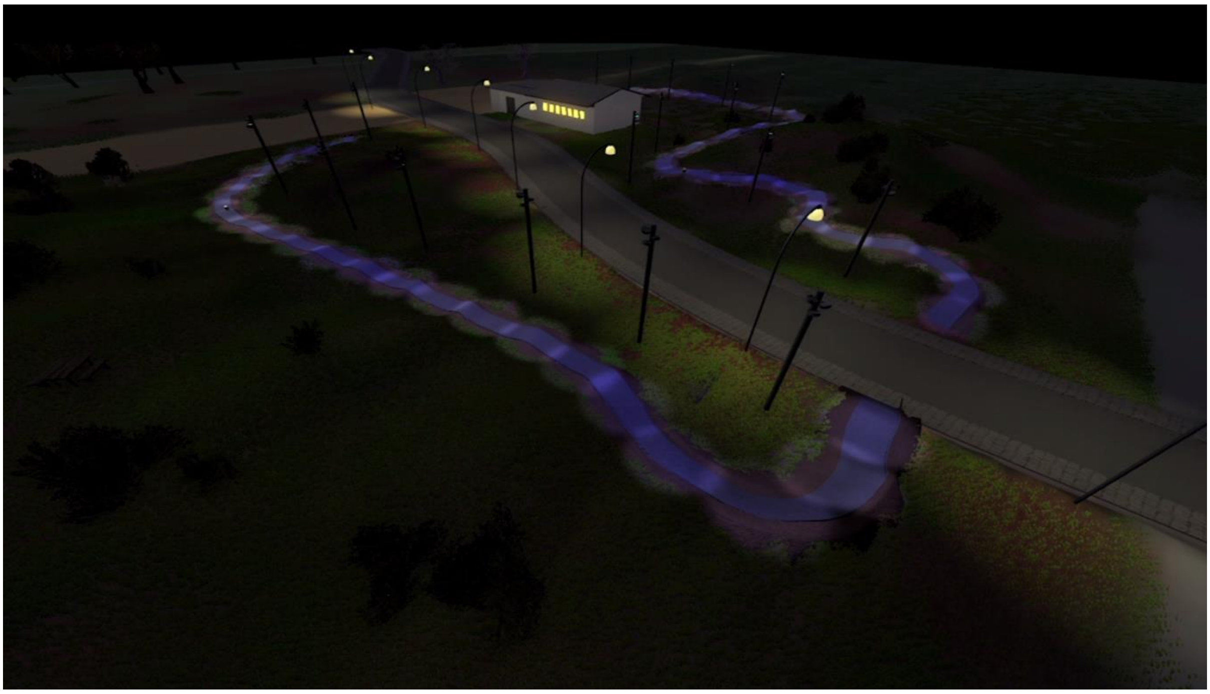


Figure 56: 3D representation of the interactive lighting on the pump track in Raadhusparken

### 6.1.4 Simulating interaction in Unity

As this project does not only concern the visual representation of light (water) in motion, but also the interaction with light (water), a prerequisite for illustrating the *behavior*(see section 5.1.3) of the light, is that it is influenced by users on the pump track. To accommodate this command, a variety of users (represented as spheres) were animated along the track. This way, it was possible to illustrate and experiment with how the lighting behaves under different stimuli.

Figure 57: Animated balls (for representing people) were animated along the track. This enabled experimentation with different interactive lighting effects, and the ability to assess the effects from the perspective of an observer in Raadhusparken.

Figure 58: An example of the Boat effect (see section 5.1.3.2) from the perspective of an observer on the Musicon Path. The ball (person) is moving leftwards and drags lights with it.

Figure 59: An example of the Boat effect (see section 5.1.3.2) from the perspective of a rider on the pump track.

### 6.1.5 Unity observations

The purpose behind simulating the motion of lighting in the virtual environment was to create a platform for evaluating the influence of different "water codes" on the general appearance of the area. Does the lighting have the intended effect when observed from the ground? How is the visual effect from the perspective of the rider? Is the interaction visually apparent? Is it too much? Too fast?

Without going too much in depth with the specific water codes, which were used and developed for purpose of this project this section will evaluate what can be learned from observing the different light scenarios (explained in section 5.1.1.1.) in Unity. With a reference to the motion of water, this evaluation will attempt to identify essential criteria that must be met when the lighting will be installed on the pump track. In addition, some considerations will also be inferred from a programming perspective.

#### 6.1.5.1 Current

One of the prerequisites for simulating water was to find a way to simulate current - like the appearance of water when being influenced by wind over long distances or when running down a river. Multiple solutions were attempted to create this effect. One algorithm that seemed to do the job particularly well - creating both flow and natural changes in intensities (amplitudes) was the *Perlin Noise*, developed by Ken Perlin in 1983 (Perlin, 1985). When applied properly, the algorithm was able to alter the intensities in a smooth, realistic, but also unpredictable fashion.
The speed of the current turned out to be a really important factor. The higher speeds seemed digital and unrealistic, and did not have that flow appearance that water would have in a similar setting. Also, due to its algorithmic proposition, the Perlin Noise wave did not create very apparent intensity variations, which as a result made the depth of the "water" less apparent. Changing the mapping between values and intensities turned out to make a more realistic scenario.

#### 6.1.5.2 Rain

In the attempt to program the appearance of rain dropping on the water surface, it was learned that the level of randomization and timing is important. Randomization was used two places in the code: it was used to randomly pick out spotlights within a certain time interval, and randomly pick a level of intensity that the light should reach before decreasing back to its low energy/idle state. This worked quite well when the timing was held relatively high (resulting in fewer rain drops), but the moment the timing was held below a certain interval (resulting in many rain drops) the lighting would become unpleasant to observe from the ground. It seems that the magnitude of "activities" (raindrops) should be held down to maintain a smoother appearance. Another attempt to work around this issue was to make the raindrops spread out and affect the adjacent spotlights. This actually resulting in a smoother appearance, but did not get closer to the appearance of rain.

#### 6.1.5.3 Boat effect

With reference to the *boat scenario* in the design chapter - having lights follow the rider and slowly degrading in intensity behind him/her, different codes were assessed through observations in Unity. In the initial attempt to program this scenario, the light around the rider would instantly jump to a certain intensity and subsequently fade out behind him. When this scenario was observed in Processing it looked good, but the moment it was possible to observe the effect from ground perspective in Unity, it was clear that the big jumps in intensities did not express the smoothness of water. Thus a prerequisite for this effect to work properly was to make smooth transitions in intensities.

#### 6.1.5.4 Summary

In the pursuit of simulating water, and the interaction of different forces on water, multiple steps were taken. As an initial standpoint, the motion of the light was programmed in Processing by addressing an array of pixels. The wide open-source community of Processing provided valuable data and available sketches to approach the programming of liquid with.
As the project progressed and it was commonly agreed upon that spotlights were going to be used, it became clear, that in order to properly assess the lighting effects, it was necessary to simulate the lighting in a different way. Thus, Unity was used to address the light in a virtual environment based on drawings of Raadhusparken and the soon-to-come pump track. Where the assessment of the lighting effects were previously based on pixels, the assessments could now be based on a much more realistic setup in Unity involving physical activity on the pump track- enabling realistic perspectives such as from an observer or from the rider him/herself.

Different lighting scenarios, based on the ones presented in *Design*, were observed and assessed in Unity - to see how they influenced the general appearance of the area, and to see how the flow of the light was perceived. Considerations were made both from an aesthetic perspective (how it is perceived) and a programming perspective (how it is coded).
From a general perspective, it was learned that in order to shape a lighting scenario that best imitates the flow of water, it is important that the speed of the current is not too high. Large intensity differences are preferable - as it gives a much more apparent perception of depth. However, for low *Vibrancy states* (see section 5.1.3)*,* small intensity differences could work as well. Transitions between intensities should be smooth, as it was learned that rapid changes in intensities appeared unnatural.
Through observations of the interaction between riders on the track and the lighting (*boat effect – see section 5.1.3.3)* it was learned that the different speeds of the riders (they were programmed to contain different speeds), had an influence on the lighting effect. The higher the speed they had, the longer the wave behind them would last. This gave good indications as to how the *boat effect* will look when the installation is done. If it turns out that detecting the speeds of the users will become too big a programming task, we now know that their different speeds will in fact have an influence on the lighting, even without actually calculating them.
It became clear that the appearance of the lighting was very dependent on the perspective from which you observe the lighting. While the effects were very visible for the observers (especially the people on the Musicon path), the effects were not as apparent from the perspective of the riders - as their perspective was fixated on the pavements ahead of them. This corresponds well to the field observations that were carried out in Musicon (see section 3.7.2), which revealed a noticeable gab between the level of focus and attention of people riding the track and people who did not ride the track.

#### 6.1.5.5 Results

To give an answer to the research question *"Did the light simulated water?"* the answer must be both yes and no. Some of lighting effects that was obtained provided the smoothness and variation that is associated with water, while other codes looked digital and unnatural. Key criteria for the visual expression of the lighting, was identified. The speed of motion of the water has to be kept down. A common tendency of the different codes in Unity was that they moved way to fast, eliciting a digital appearance which was not desired. Through trial and error, methods for slowing down the codes were learned. Another criterion that was identified was that the intensity transitions had to be smooth. While this does not necessarily mean that the transitions should be slow, it rather suggests that a transition from one intensity to another should contain as many values in between as possible. It was also learned that large variations of intensities throughout the array of spotlight was necessary for conveying a sense of depth. From a programming perspective, this issue was approaches by changing the mapping of values from the algorithms to the values of the spot lights. It seems that the codes that accommodated the above mentioned criteria, actually did the best job in simulating water. The Perlin Noise wave turned out to do the job particularly well, as it did have the smooth transitions, slow speeds and high intensity difference, but what made it really stand out, was its ability to be unpredictable. In the same way as the motion of water is extremely hard to fully predict and understand, the light on the pump track should move in unpredictable ways.

### 6.1.6 Validity of Unity

Since this project used an alternative approach to testing interactive lighting - through the use of Unity, the validity of using it as a test platform was consulted with the other project member during a meeting, and through an interview with Tine Byskov Søndergaard. After presenting a simulation of the interactive lighting installation, some general commentaries were gathered from the project members. A general opinion was that it should not be used to discuss the design, unless I had deliberately selected a set of designs that I would benefit from getting feedback on. In concern to the benefits/disadvantages of simulating such environment, Tine expressed - "*I believe it makes sense when being used for big and innovative projects. For small and regular lighting projects, I believe it doesn't make sense. This is because customers already have prior experience with similar projects, and thus have clear expectation as to what they want and what they will get. For innovative projects like this one, I believe it is different. Since customers don't have any prior experience of the kind of project of interest, a simulation can efficiently communicate the ideas to the customers - providing a frame of reference*". Head consultant of Roskilde Municipality and project member Jeremy Andrew Dennis expressed that the simulation could actually turn out to be a determining factor for providing more money for the project, because it can communicate the potentials of the installation. As it stands right now, the municipality will only cover for half of the pump track, in order to save money. So receiving additional funds would mean that we could illuminate the entire pump track. Electrical and lighting engineer at ÅF lighting and project member Frederik Borello, expressed that there could also be a risk to simulations/animations like this. Since simulations rarely provide a completely realistic representation of how it will actually look, false expectations might arise - which ultimately will lead to disappointments when the installation is constructed. His concern particularly regarded the simulation of the interactivity on the pump track. Programming in Unity is different from programming in Mosaic Designer, so there is a risk that not all the interactivity exposed in Unity will be able to be replicated in real life.

## 6.2 Practical Experiments:

As a prerequisite for answering the research question "*Does the sensors enable exact position of users on the pump track?"* this section will present a practical test on the 2D laser scanner, to see how well it detects.

### 6.2.1 Testing 2D laser scanner

Prior to permanently mounting the 2D laser scanner to the Milewide lamp post, it was necessary to see how well the sensor performed in a similar setup as the one explained in section 5.3.3. To do so, a physical test was conducted outside the office of ÅF lighting, Herlev with Frederik Borello.

#### 6.2.1.1 Setup

To be able to conduct a useful test on the integrated sensor solution, a variety of equipment were necessary. Frederik had constructed a prototype for the special fitting of the sensor, as seen in figure 60. With the help of a latter and a wall, it was possible to position the mast at the right height (where the sensor height is 3.3m) and slope (vertical), as seen in figure 62. With a laptop and the SOPAS-software which receives and illustrates real-time data from the sensor through an Ethernet cable, it was possible to set up the detection-field. The visual output of the SOPAS software can be seen in figure 61 - the yellow area signifies that an object is detected, whereas the green areas are not detecting any objects.

**Figure 60: Special fitting for the 2D laser scanner**

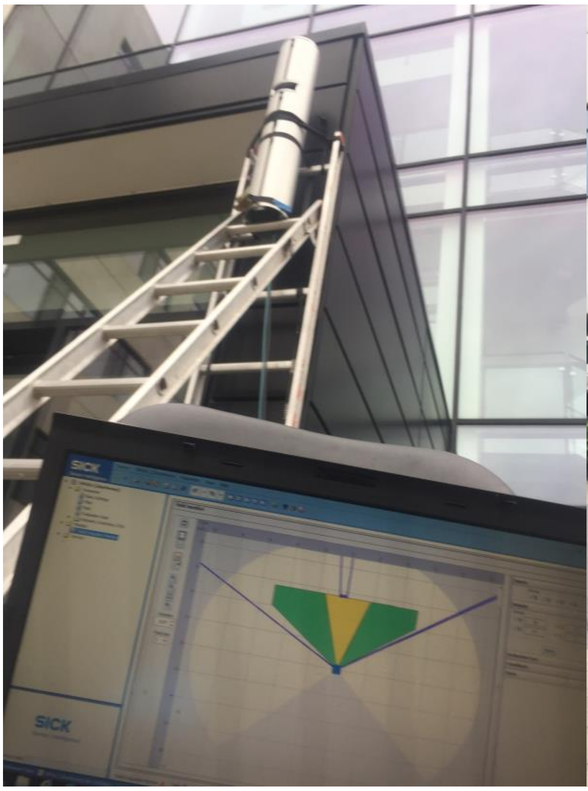



Figure 61: Image of the SOPAS software in action. It is currently detecting an object right ahead, visible through the yellow field on the computer.


Figure 62: Sensor setup with the help of a latter, strips and a wall.

The last part of the setup was to measure the right field in which the sensor should detect presence. For this, a measuring wheel was used. The measures are illustrated in figure 63.

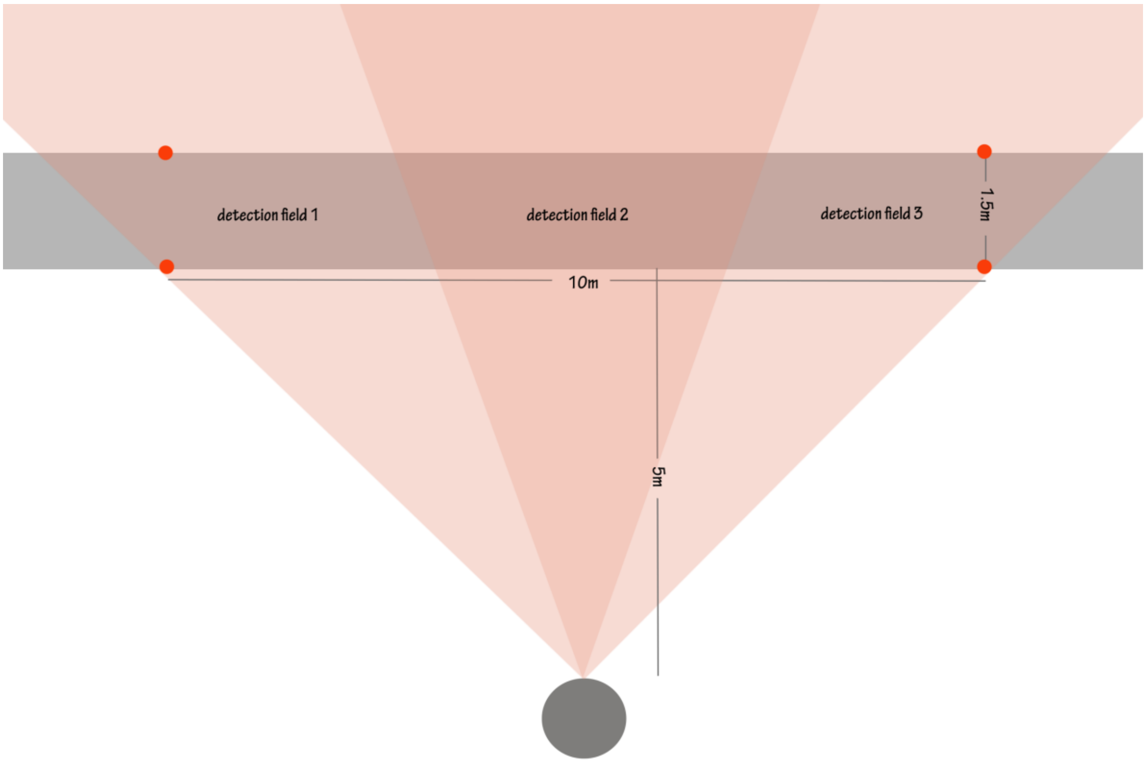



Figure 63: The setup from plan view. The red dots illustrate the boundaries of the detection fields.


Figure 64: Test setup. Red dots indicate boundaries. Sensor to the right on the latter

### 6.2.1.2 Procedure

The way to test was executed fairly straightforward. Two people were however necessary; one person for moving around in the area, and one person for observing the SOPAS software. By observing the sensor's registration of the moving person, it was possible to see if it did in fact turn yellow (yellow = on, green = off) when the person was moving around in the respective detection field. It was just as important to observe if the detection field turned off (back to green) the moment the person would move away from that detection field.
The sensor's ability to detect all types of users were also tested by walking through the field in different heights and positioning small objects in the field areas, and moving in the area in different speeds.

Figure 65: The image above shows a cyclist cycling through the 10 meter field of detection. As visible on the computer in the front, detection field 2 captures his presence and it thus switched to yellow.

Furthermore, the sensor's ability to withstand rain was also tested by throwing water directly at it.

#### 6.2.1.3 Results

In general, the practical test of the sensor went really well. The response time was so fast that it was not possible to register a delay, and it succeeded in turning its respective fields on or off at the right moments. The range of detection, which was initially estimated to be 10 meter along the path, turned out to allow detection of up to 12 meters. This could turn out to be an advantage if it will be decided that the detection field should overlap. To understand the potential challenges of ensuring that spectators will not interfere with the laser, it was additionally learned that for people to do so, they would have to position themselves closer than 1.5 meter from the track, on the side of the pump track facing the sensor. However, if people decide to jump up in the air or wave their arms - intentionally trying to interfere with the signal, they would succeed in doing so. The sensor turned out to handle water without complications. After setting a fixed size for objects that can be detected - corresponding to human size from a distance of 7.5-8m- the sensor did not register the water drops on its surface. This was an important finding as it shows that the sensor will be able to function even in humid and rainy days.

# 7. Discussion

While the design chapter discussed how the movement of water could be approached from an aesthetic and interaction perspective, and the implementation chapter demonstrated how the movement of water on a pump track could be approached from a practical perspective, the evaluation chapter examined to which extent the design and implementation was able to answer the research questions:

- *Does the sensors enable exact position of users on the pump track?*
- *Does the lighting simulate the movement of water?*

To the first research question, the evaluation of the 2D laser scanner revealed that the sensor did in fact fulfil its task in detecting people's positions. However, the laser scanner did have some limitations. While it measures the position of objects in high precision and timing, it is only able to create three detection fields for the interaction with lighting. This can turn out to be a disadvantage, as it will not be possible to measure the exact position of objects, but will just register that some object is within its detection fields. This might make it harder to estimate and predict how close the user is to the next detection field - making it harder to create smooth transitions from spotlight to spotlight.

Another point that must be discussed is the location of the test setup. Even though calculations were made prior to the test to identify the appropriate angle and direction for the sensor to register users on a pump track *(see section 5.3.3)*, the test was not conducted on a pump track. If the test had been conducted on an actual pump track, perhaps we would have discovered weaknesses that we were unable to deduce from calculation and the test. Additionally, since the pump track has not yet been built, and we do not have any official drawings on it, unexpected curves in the path of the pump track might occur - challenging the sensor's ability to detect optimally.

An attempt to answer the second research question; "*does the movement of light look simulate the movement of water?* " was done by observing the interactive lighting effects in Unity.
To give a qualified answer to this question, some considerations must be discussed first. In the process of simulating water through lighting, it is essential to understand that the complexity of information in water particles is immense. Transforming the complexity of information into, as initially proposed, 970 pixels (see section 3.8.1), all the way down to 21 spot lights, it is essential to ask the question: should the simulation of water prioritize correct physical motion in water, or correct associations to water? If correct physical motion of water was to be imitated by a lighting system of 21 spotlights, the lighting would likely be extremely vibrant and unpleasant to look at, and would likely not be associated with how we normally perceive water - fluent and smooth. If correct associations to water was to be simulated by a lighting system, the correct physics of water might not apply, but the fluency and smoothness of water would be conveyed and recognized. As the priority in this project, primarily due to the limited set of pixels available, is to apply the proper associations to water motion, it can be discussed whether the light actually simulates the movement of water, or if it simulates a simplified version of water motion.

Through observation of the lighting effects in Unity, the second research question was attempted to be answered. Did the lighting achieve the goal of simulating water motion? As mentioned above, the answer might be rephrased to *did the light simulate a simplified version of water motion?* The evaluation of the lighting effects in Unity showed that some codes did in fact achieve a great association to water movement – revealing fluency, smoothness, variation, interaction with the users, and unpredictability.
Even though the results of the observations indicate that especially the Perlin noise wave succeeded in simulating, at least a simplified version of water motion, a question must be asked: how well can simulations in Unity be trusted in terms of evaluating interactive lighting scenarios? This question might be more and more relevant to ask, since the popularity of incorporating virtual reality and 3D interactive simulation seem to increase drastically in the realm of interactive lighting. Though the advantages of testing interactive lighting projects in 3D interactive simulations/animations like this are immense (cheap, fast, does not require a real field test with all equipment, does not require people to trigger the interactivity, can be distributed easily and vastly, can be easily modified without having to physically move luminaires etc.), its reliability must be discussed. As Frederik Borello pointed out in a meeting with the Musicon Path project members - 3D simulations can also have a downside: they can form certain expectation to a project which will be hard to meet in the physical world, which as a consequence will lead to disappointments when the installation is installed.
In a project like this- which requires something as specific as interactive lighting on a pump track, alternatives to using Unity for testing would be to actually install light on a pump track and test it on the users. The amount of effort that would have to be put into realizing such a test setup would by far exceed the amount of effort in simulating it. Thus it must be concluded that, as Tine Byskov Søndergaard pointed out in an interview (see appendix 11.14), the usefulness of applying a software like Unity to simulate and test lighting scenarios, largely depends on the scale and level and innovativeness of the project.

# 8. Conclusion

The final problem statement, which was extracted from the overall goals and visions for the Musicon Path, was:

*"How can we use lighting to simulate the movement of, and physical interaction with, water on a public pump track, while ensuring sufficient visibility?"*

In an attempt to achieve a qualified answer to this, the report approached the questions from two perspectives; a practical perspective and a design perspective. The practical part of the project concerned identifying the appropriate components, while the design part concerned how to simulate light as water in the context of a public pump track, but also to come up with general criteria for the behavior of the light.

The design element of the project approached the problem statement by researching the human relation to water in terms of health and wellbeing, the natural characteristics of water movement, the emotional, psychological, physical and spatial response to the color blue, the skating community in Musicon, BMX cycling, the characteristics of pump tracks, public interactive lighting and lighting for cyclists and pedestrians. With the knowledge of the overall goals and visions for the project along with a profound understanding of the above mentioned factors, it was possible to develop a design concept.

The design concept was based on four elements: *Visual expression, Layers*, *Behavior and Timing*
The *Visual Expression* was responsible for the overall design basis for simulating water and constituted of two elements: *Scenarios*, which uses water scenarios as a reference to the behavior of the light. This entailed; how wind affects water, how rain affects water and how a boat affects water. The second element in the *Visual Expression* was *Wave Design.* The *Wave Design* describes the design parameter for simulating a wave though colors in one dimension.
The layers consisted of a *functional layer* – responsible for sufficient visibility of the users, an *aesthetics layer* – responsible for sparking an interest and conveying a general lively and fluent expression, and a *behavioral layer* – responsible for the playful element of interacting direct or indirectly with the pump track.
The behavioral layer was divided into two elements: *Indirect interaction* and *direction interaction*.
The indirect interaction constituted of a scheme that calculates the level of energy that is applied to the pump track. The more energy it has, the livelier the lighting will be. This layer was associated with the *rain and wind* effect explained in *visual expression*. More energy will be associated with higher wind speeds (*wind scenario)* and more rain (*rain scenario*), which will be conveyed through the light. The level of energy is dependent on amount of activity in Musicon, and the calculated average activity on the pump track. So in essence, the more activity in the area, the more energy is generated and the livelier the light will be.
For the direct interaction, the light will respond directly to the presence of the users. As reference to the *boat scenario*, the light will follow the user and slowly degrade behind him/her. If enough energy is applied to the area, a wave will be pushed back as the users reach the end of the pump track. The length of the wave will be based on the speed of the users.

The timing element will be responsible for keeping the light installation synched with the changing day/night cycle throughout the year, minimizing the energy consumption and light pollution.

The design concept provided a ruleset for the water behavior of the installation. In the pursuit of evaluating the extent to which it was possible simulate the described water scenarios, the interactive lighting scenarios were simulated in Unity where the effects of different codes were assessed, from the perspective of the rider on the track and from the perspective of an observer on ground. Though it was not possible to claim that the lighting scenarios simulated water, as this is largely subjective, the observations provided essential criteria for the visual expression of the lighting. The speed of motion of the light needed to be kept low, intensity transitions had to be smooth, variations of intensities throughout the array of lights was necessary for conveying a sense of depth, and the behavior of the light had to be somewhat unpredictable. From a programming perspective, it was learned that, amongst many different code, a code that did the simulation particularly well, was the Perlin Noise algorithm, developed by Ken Perlin in 1989.

The practical element of the project, which was done in collaboration with Roskilde Municipality, Dong and ÅF lighting, regarded how to identify the appropriate components for the project. With the intentions of creating an interactive lighting installation on a public pump track that responds to the movement of its users, the challenge was to identify the appropriate fixtures to simulate water and provide sufficient visibility and to identify the appropriate sensors for detecting positions of people on the track. An extensive research and analysis of different sensors technologies and luminaire solutions were carried out. Due to widespread issues with vandalism in the area of Musicon, road engineer of Roskilde Stig Nielsen strongly suggested keeping fixtures and sensors above 3 meters. With additional intentions of keeping a distance to the pump track to prevent becoming an obstacle, it was decided that spot lights were the appropriate solution. While the fixture solution was identified relatively early in the project phase, the sensor solution was a bit more challenging. Through systematic research of sensor technologies in the analysis, 2D laser scanners seemed to be the appropriate technology. By integrating them in the lamp posts for the spot light, along the pump track and directing them toward the track, the sensors should be able to detect multiple users on the track simultaneously. This was tested in an experiment at ÅF lighting, Herlev. After developing a prototype for a special fitting for the sensor in the lamp post, and calculating the appropriate height and distance of the sensors to the pump track, the test was set up. Results of the test showed that, despite a few limitations, the solution worked, and that the 2D laser scanner was capable of detecting with high precision.

All in all, the practical element of the project succeeded in identifying the appropriate components for the task, taken all aspects (such as context, users, vandalism, visibility, interactivity, aesthetics, robustness, maintenance, sustainability etc.) into account, and the design element of the project succeeded in digging deep into the behavioral character of water and provided a ruleset for the water behavior of the installation along with essential programming criteria for simulating water.

# 9. Future work

**Testing visuals and interactivity**

To get more widespread feedback on the interactivity and visual effects, I am planning on testing visuals at the next meeting with the Musicon Path group. At this meeting, Dirtbuilders - the company that will build the pump track- will also be there. The people from Dirtbuilders are experienced BMX riders (pump track users) and might thus have a perspective on the installation that we have not thought about. The test will be conducted with the use of virtual reality (VR). Using Oculus rift, Samsung gear or HTC vive, the project members and Dirtbuilders will be able to observe and assess a small number of selected visuals in a virtual environment. As they put on the head gear, they will be able to "enter" the virtual environment, look around and navigate to some fixed designations around the area. The test should give, as mentioned above, some feedback on a selected number of visuals(codes), but should also provide feedback on the use of VR as a testing platform.

**Preparing for installation**

As the construction of the pump track will be finished in august 2017 (has not yet been clarified), the lighting installation will be installed subsequently. Roskilde Municipality has hired me to do the installation and programming of the DTS EOS 6 fixtures and the TIM 361 laser scanner sensors. I believe, that in order for me to meet my project members', and my own expectations of this project, I need to attain some more knowledge prior to the installation phase. This knowledge entail;

- Getting more familiar with the lighting system Mosaic Designer and its ability to incorporate sensor data to change the outcome of the lighting.
- Studying the scripting language of LUA, which is the language that Mosaic Designer supports. With knowledge of this programming language, I will have a much better possibility of making the interaction more complex and unpredictable. In an ideal scenario, I will be able to measure people's speed and use that information for the *response wave* and the level of general *Vibrancy* (section 5.1.3), but also calculating average activities on the pump track.
- Getting more familiar with the potentials of incorporating mathematical formulas generally acknowledged for describing, measuring and visualizing liquid flow. This entail particularly;
    - Euler's equations
    - Navier Stokes (extension from Euler's equations)
    - Buoyancy equations
- Examining how to simulate complex compositions of fluid motion without being too computationally expensive. Might entail "faking" a complex composition.

**Living lab**

When the whole pump track and light installation has been built, the purpose is then to use the installation as a *Living Lab.* This will be an interesting phase, as it will involve an alternative approach to lighting designs in public. Instead of merely installing it, the approach is to expose the installation to the public <u>and</u> to assess their reaction. Do people understand it? Are they attracted to it? Do they actually use the pump track on their way to and from Musicon? Do they use it as a leisure activity?

Who are using it? Why them? Do they find pleasure in the interactivity? Do people find pleasure from observing the interaction and the general dynamism of the lighting? How would lighting, which reacts to the users' speed, have an impact on their experience? Are the people using the track distracted by the dynamism of the lighting? Will it succeed in attracting real conscious experimentation, or merely serve as an atmospheric visual play of light?

The type of interaction that the installation allows is a new approach to interactive lighting in the public (none of the project members know any installation similar to this), and thus not much knowledge has been gathered about its potentials. While we can try to hypothesize good answers to these questions, the reality is, we do not know until the installation has been installed.

Another element that will be assessed after the project has been realized, is vandalism. As earlier mentioned, the area has a bad reputation of vandalism, so equipping a lighting installation with relative expensive sensor might turn out to be a mistake. However, our believe is that, by building an installation that really adds value to the space, and becomes an attraction even for the young generation of users who commit vandalism in the area, their incitement to ruin the installation will be minimized.

# 10. References


- ArcMap n.d: "*Advantages of using lidar in GIS",* esri, ArcGis for Desktop, http://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/advantages-of-using-lidar-in-gis.htm. Viewed May 2017.

- Boyce. P, (2014):*"Human factors in lighting",* Third Edition, CRC Press.
- Cerrato, H ( 2012): "*The meaning of colors"*.

- Christophe R. C. Guibal & Birgitta Dresp (2004): "*Interaction of color and geometric cues in depth perception: When does ''red'' mean ''near''?"* Psychological Research 69: 30–40.
- Cracknell, Deborah. Wyles, Kayleigh J. Pahl, Sabine White, Mathew. Morris, Sarah · (2013): *"Towards a Marine Mindset: Visiting an Aquarium Can Improve Attitudes and Intentions Regarding Marine Sustainability",* Journal Visitor studies, Vol. 16, 2013 - Issue 1.
- Depledge Michael H., Benedict W. Wheeler (2012): "*Does living by the coast improve health and wellbeing?",* Health & Place, ISSN.
- Dewey, John (1934): *"Art as experience". Penguin*,
- Faubert, Jocelyn (1994). "Seeing depth in colour: More than just what meets the eyes". *Vision Research*.

- Faubert, Jocelyn (1995): *"Colour induced stereopsis in images with achromatic information and only one other colour"*, *Vision Research*. 35 (22):

- Hardy, A. (1960): *"Was man more aquatic in the past",* New Scientist, Vol. 7, Isssue 642.
- Jackson, D. (2015): "*Superlux: "Smart Light Art, Design & Architecture for Cities"*, Thames & Hudson.
- Kelley, R.; Kilpatrick, J.; Smith, C. (2007): "*The lightspeed automatic interactive lighting preview",* systemACM SIGGRAPH.

- Krippendorff, Klaus (2004): *Content Analysis: An Introduction to Its Methodology*, Thousand Oaks, 2nd ed., CA: Sage. p. 413.

- Massa, D. P. (2010): *"Choosing an Ultrasonic Sensor for Proximity or Distance Measurement Part 1: Acoustic Considerations"*, Sensors online. http://www.sensorsmag.com/components/choosing-ultrasonic-sensor-for-proximity-or-distance-measurement-part-1-acoustic. Viewed May 2017.

- Nakamura, J.; Csikszentmihályi, M. ( 2001): *"Flow Theory and Research"*, In C. R. Snyder Erik Wright, and Shane J. Lopez. "*Handbook of Positive Psychology"*, Oxford University Press. pp. 195–206.

- Ockenga, Wymke (2011): *"Phase Contrast - Making Unstained Phase Objects Visible"*, Leika Science Lab.
- Peeters, J. (2013): *"The Aesthetic Experience In Interactive Lighting Design",* Interactive Institute Umeå Department of Informatics.

- Perlin, Ken (1985)*: "An Image Synthesizer",* SIGGRAPH Comput. Graph.

- Perlman, Howard (2016): "*Surface Tension and Water",* The USGS Water Science School.
- Ruisin, Benoit Cushman (2005): *"Internal waves in lakes",* Thayer School of Engineering at Dartmouth.
- Poulsen, E.; Andersen, H.; Jensen, O. F. (2011): *"Full Scale Experiment with Interactive Urban Lighting",* DIS: Designing Interactive Systems.

- Sack, Robert L.; Auckley, Dennis; Auger, R. Robert; Carskadon, Mary A.; Wright, Kenneth P.; Vitiello, Michael V., et. al. (2007): "*Circadian Rhythm Sleep Disorders",* in *"Sleep"*, Part I, Basic Principles, Shift Work and Jet Lag Disorders, Vol. 30, Iss. 11, p. 1460–1483.
- Seitinger, S. (2013): "*Timing Is Everything: From Dynamic Lighting to Meaningful Experience"* Philips Color Kinetics.

- Toc toc communications, (15/05/2017): "*Blue light exposed",* http://www.bluelightexposed.com/#where-is-blue-light-found.
- Ulrich, Roger S. Simons, Robert F. Michael (1991-9): *"Stress recovery during exposure to natural and urban environments"*, Journal of environmental psychology, p. 201–230.
- Wallace J. Nichols (2014) "*Blue Mind: The Surprising Science That Shows How Being Near, In, On, or Under Water Can Make You Happier, Healthier, More Connected, and Better at What You Do",* Little, Brown and Company, First edition.


**Illustrations:**


- *Amplitude* n.d, Wikipedia, photographs, https://en.wikipedia.org/wiki/Amplitude. Viewed June 2017.
- *Gangajal*, n.d. Photograph. https://www.indiamart.com/gangotriminerals/gangajal-holy-water.html. Viewed June 2016.
- Group EDF, n.d.: *Greater Shepparton City Council, Citelum,* http://citelum.com.au/wpgallery/greater-shepparton-city-council/. Viewed May 2017.

- Luxuo (2016): SINGAPORE RENDEZVOUS Interview, photographs. Viewed June 2017.

- *Pump* (2015), Magazine's February https://jamesprovost.com/blog/page/2 Viewed May 2017.

- *Pump motion*, n.d. Photographs. http://www.svcyclesport.com/. Viewed June 2017.
- Rory (2009): *"MTB_NEW Crank Cycle News",* photograph. http://www.crank.co.za/the-anatomy-of-dirt-jumps/343. Viewed June 2017.
- *Temblor* (2012): Temblor, photographs, *http://temblor.net/earthquake-insights/can-rain-cause-earthquakes-2668/*. Viewed June 2017.
- *Interference* n.d. Interferenz(Physik) Wikipedia, photographs. Viewed June 2017.

*Sti til Musicon* n.d, Roskilde Kommune, http://roskilde.dk/sites/default/files/fics/DAG/2743/Bilag/orientering_om_proces_for_musicon-stien_og_raadhusparken.pdf.

# 11. Appendix

## 11.1 Collaboration Agreement

Lighting Metropolis

**Samarbejdstilkendegivelse om udviklingsprojektet 'Musicon-stien' mellem Roskilde Station of Musicon**

Roskilde Kommune
By, Kultur og Miljø
EAN-nummer: 5798007934934
Rådhusbuen 1, 4000 Roskilde
Gunilla Rasmussen
gunillasr@roskilde.dk

Aalborg University Copenhagen
Lighting Design
[Indsæt CVR/EAN nummer]
[Indsæt Adresse postnummer]:
Georgios Triantafyllidis
gt@create.aau.dk

DONG Energy
City Light
CVR-nummer: 20214414
Teknikerbyen 25, 2830 Virum
Tine Byskov Søndergaard
tinso@dongenergy.dk

1. Projektets formål og fælles udviklingsmål er at udvikle og realisere Musicon-stien som et demonstrationsprojekt for belysning, deer innovativt ved at anvende eksisterende teknologier på nye måder
   - er bæredygtigt i forhold til energiforbrug og vedligeholdelse
   - fungerer som Living Lab ved at undersøge interaktioner mellem intelligent belysning og brugernes adfærd

2. Partnernes selvstændige udviklingsmål for Projektet og iværksættelse af kompetencer.

   - Roskilde Kommune forventer via Projektet at få realiseret belysning på Musicon-stien - fokuseret på 7 krydsningspunkter -, der:
     - tilfører ruten en særlig identitet, som bygger op til ankomsten til Musicon
     - fungerer som pejlemærker og derved tydelig vejvisning, der på en dragende måde leder besøgende ad stien
     - inviterer til ophold og leg undervejs på ruten
     - varsler - med en ændring af belysningen -, når der foregår begivenheder på Musicon/ Dyrskuepladsen og
     - er nemt og relativt billigt at vedligeholde og anvende (energiforbrug) og overholder retningslinjer for belysning på offentlige arealer i forhold til tæthed og hærværk

   Roskilde Kommune forventer desuden at få re-designet/ videreudviklet eksisterende belysning på 3 pladsdannelser på Rabalderstræde, samt at det samlede projekt vil fungere som et interessant Living Lab for professionelle og dermed som potentielt besøgsmål.

   Roskilde Kommune vil bidrage til at opnå dette i kraft af organisationens:

Interreg Öresund-Kattegat-Skagerrak European Regional Development Fund — REGION H The Capital Region of Denmark — SKÅNE

- erfaring, kompetencer og viden indenfor udvikling og anlæg af byrum og sti- og vejanlæg samt trafikplanlægning
- lokalkendskab, kontakter til områdets brugere samt viden fra forudgående brugerdialog og udviklingsarbejde herunder specifikationer i forhold til behov, ønsker, økonomi og tidsramme
- erfaring og kompetencer indenfor overordnet projektledelse, der vil blive anvendt til at facilitere samarbejdet, lede til konklusioner undervejs i processen og overholde tidsplanen
- erfaring og kompetencer indenfor formidling, der vil blive anvendt til at kommunikere projektet overfor det samlede Lighting Metropolis-samarbejde
- erfaring og kompetencer til at vurdere løsningsforslag i forhold til behov og kontekst, der i projektet vil blive anvendt til at give feedback på studerendes arbejde i hver fase

- AAU forventer via Projektet at opnå at:
  - undersøge og analysere angående innovation, bæredygtighed, living lab, interaktion, brugernes deltagelse, Roskildes identitet, brugerprofiler, tilgængelig teknologi, økonomi etc.
  - formulere et tema og overordnet design for de 7 nedslagspunkter på Musicon-stien
  - udarbejde specifikke design (f.eks. en prototype, et specifikt design for et af de 7 punkter, specifikke belysnings-scenarier for pladsdannelser på Rabalderstræde eller fokus på et af aspekterne i design-temaet)
  - få mere teknisk viden om DMX-programmering
  - producere analyser, som kan blive anvendt i design og evaluering
  - evaluere og vurdere forskellige design og formulere problemstillinger
  - designe måder at engagere mennesker til at deltage og interagere socialt
  - udgive og formidle resultaterne af forskningen

  AAU vil bidrage til at opnå dette i kraft af organisationens erfaring, kompetencer og viden indenfor:
  - en forskningsbaseret tilgang og skabelse af ny viden og opdagelser, hvilket i projektet vil blive anvendt til at definere de problemstillinger, Living Lab'et skal undersøge og teste
  - medieteknologi
  - evalueringsmetoder

- DONG Energy forventer via Projektet at opnå:
  - bredere kendskab og erfaringer med nye muligheder, produkter og løsninger inden for intelligent belysning i 1:1 lysprojekter
  - kendskab og erfaring med etablering af fremtidens intelligente belysning
  - at bidrage til innovation og udvikling af intelligent lys
  - at deltage i og bidrage til konkrete cases på Musicon-stien til egen udvikling og udvikling af produkt/ løsning til fremtidens kundeopgaver.
  - at udgive og formidle resultater af projektet

  DONG Energy vil bidrage til at opnå dette i kraft af organisationens:
  - erfaring, kompetencer og viden indenfor rådgivning i forhold til valg af produkter, projektering, etablering og drift af belysningsanlæg, styring, Smart City m.v.
  - erfaring, kompetencer og viden indenfor projekt- og arbejdsledelse
  - erfaring, kompetencer og viden indenfor installation (Montører, Operatør ) og asset management (?)
  - brede og solide netværk af underentreprenører og leverandører.

Side 2 af 4

- viden om typiske produkter ifht. egenskaber, priser og vedligeholdelse og evne til at vurdere nye produkter på baggrund af tilgængelig data

3. Identificering af parter med nødvendige supplerende kompetencer for at nå projektets fælles udviklingsmål og leverancer:
   1. 2-3 lysdesign-virksomheder (smv'er) til at designe belysning på nogle af/ alle de 7 punkter på stien
   2. Seas NVE, som driftsansvarlig, til at kvalitetssikre design i forhold til tilslutning til overordnet vejbelysning og efterfølgende drift
   3. eventuelt lysdesign-rådgiver til at kvalitetssikre og give AAU-studerende feedback på projektforslag til lysdesign af et eller flere af punkterne på stien ( enten smv eller ÅF)
   4. eventuelt virksomheder, der kan udvikle prototyper i lille skala, til testning af idé til applikation/ intelligent belysning før installering

Samarbejdstilkendegivelsen er ikke juridisk bindende, og en part kan derfor træde ud ved begrundet ønske herom.

De nævnte parter tilkendegiver hermed at ville indgå et udbudsfrit OPI-samarbejde i Lighting Metropolis-regi om at skabe udviklingsprojektet "Musicon-stien", der så vidt muligt

- tager udgangspunkt i borgernes behov og ønsker
- er et triple helix-samarbejde (dvs. et samarbejde mellem kommune/region, virksomhed, universitet)
- er landegrænseoverskridende mellem dansk/svenske aktører
- involverer små og mellemstore virksomheder (SMV'er) og/eller startups
- skaber nye metoder, løsninger og produkter
- er innovativt
- skaber arbejdspladser.

Samarbejdstilkendegivelsens parter:

Roskilde Kommune
Gunilla Rasmussen

____________
[Skriv Dato, Underskrift]

Aalborg University Copenhagen
Georgios Triantafyllidis

____________
[Skriv Dato, Underskrift]

DONG Energy
Tine Byskov Søndergaard

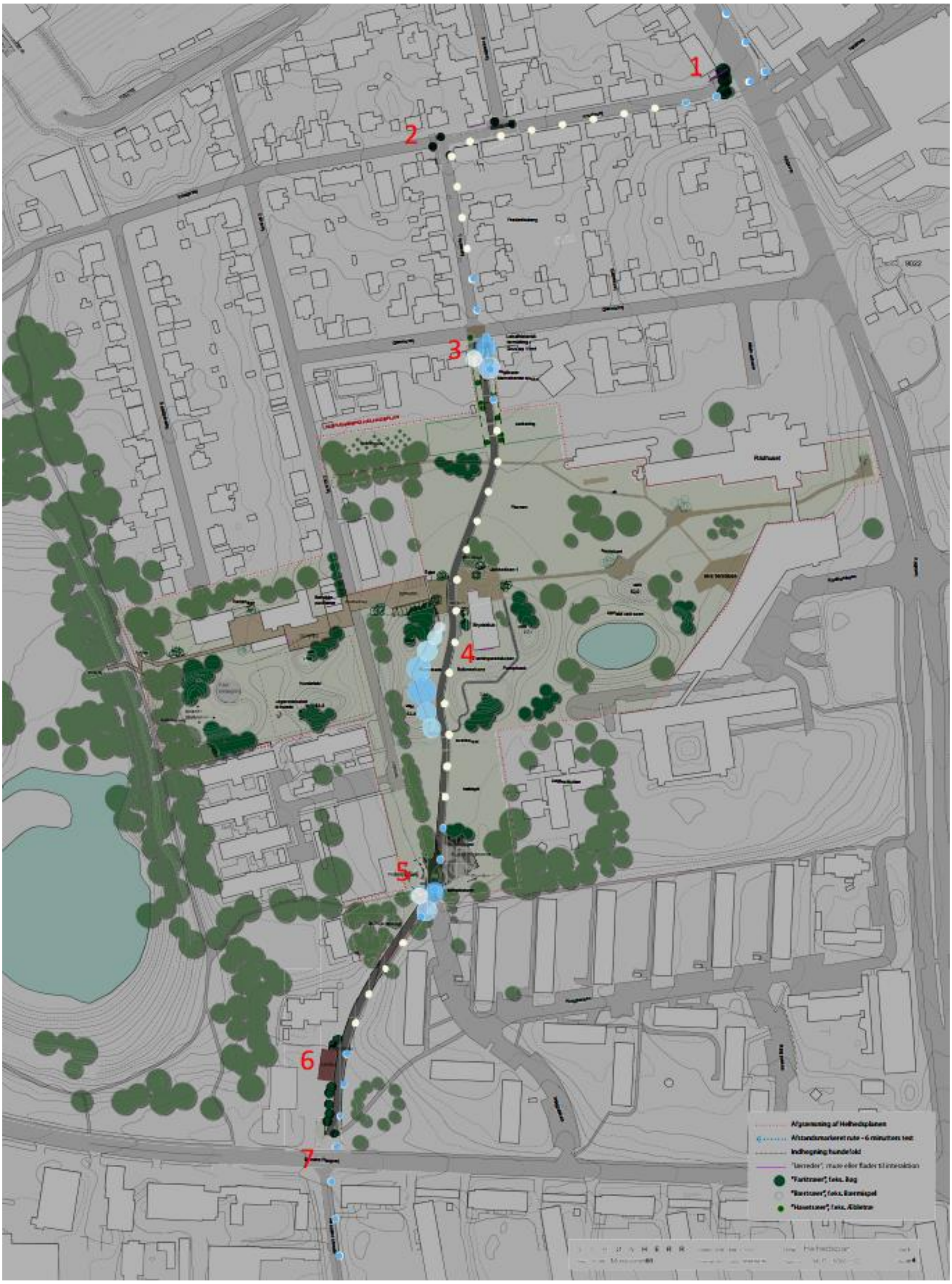
____________
[Skriv Dato, Underskrift]

Følgende punkter indgår i udarbejdelsen af en udbudsfri OPI-aftale og ikke i nærværende samarbejdstilkendegivelse

Side 3 af 4

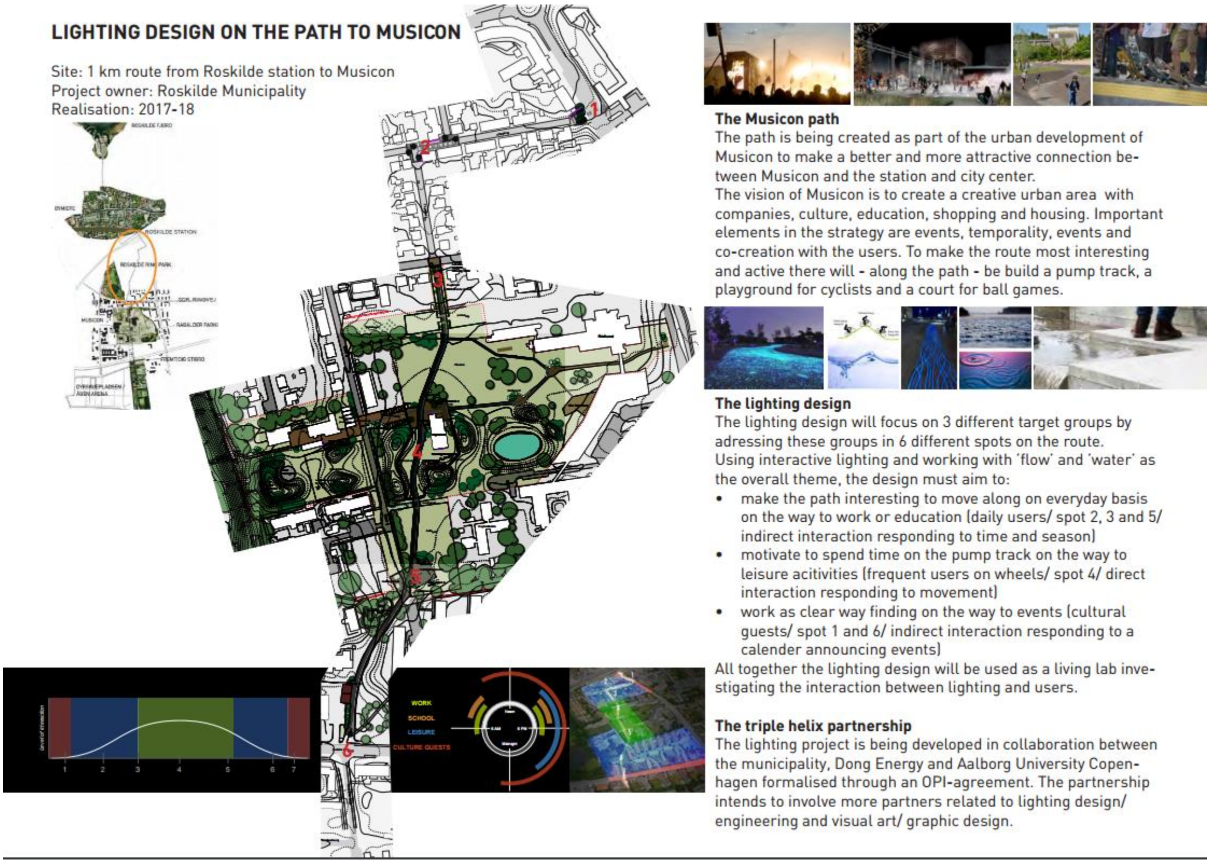
## 11.2 Drawings

## 11.3 Conclusion from fall semester




**The conclusion from the Musicon Path project was that there should be an emphasis on the middle of the path- Raadhusparken. I would be responsible for the lighting design on the pump track (spot 4), while Esben Oxholm would be responsible for spot 3 and 5. The common theme of *water* was agreed upon to be the overall theme for the lighting.**

## 11.4 Official Project Description

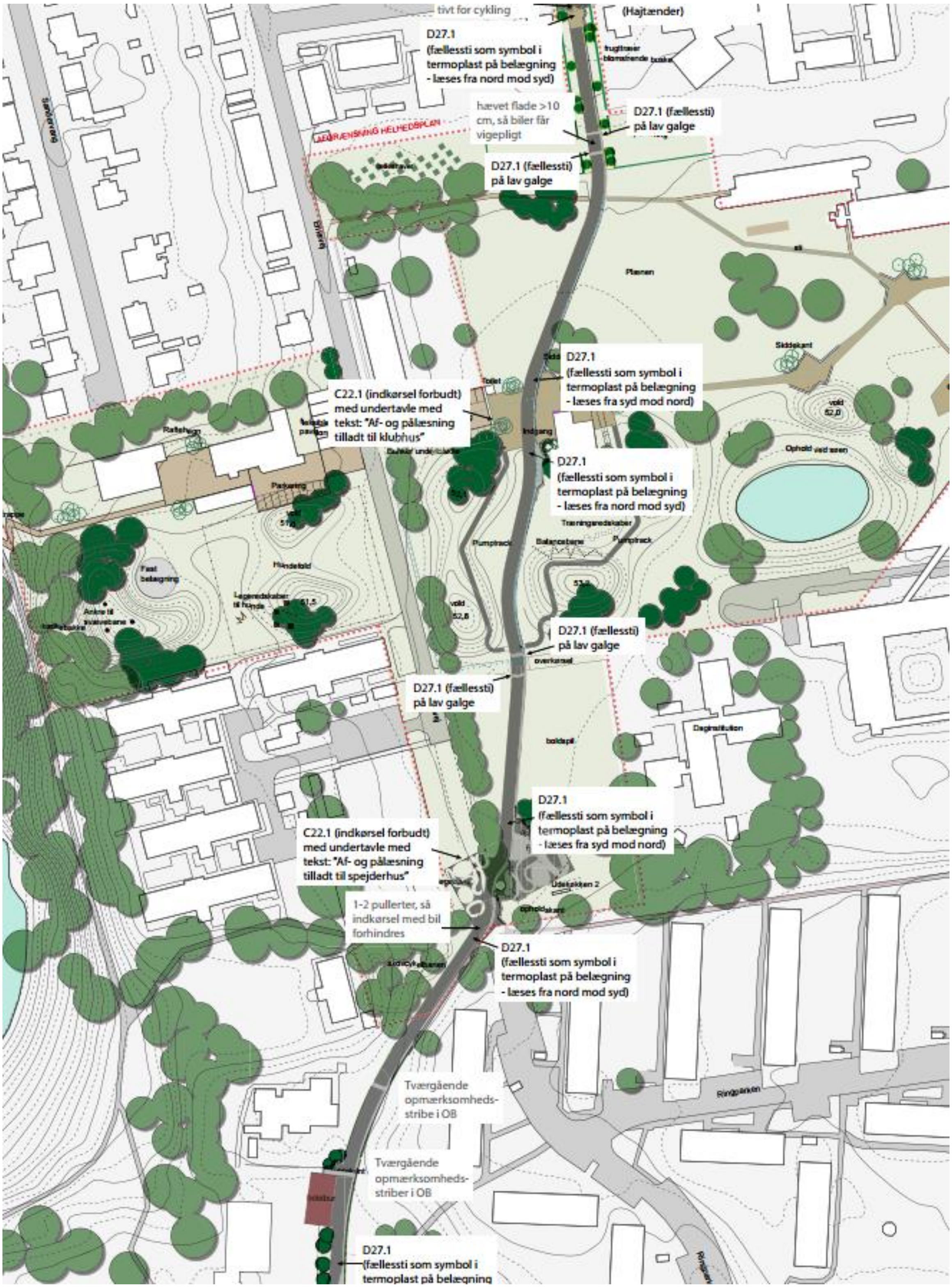



The official project description extracted from the conclusion made from the fall semester.

## 11.5 Time Table

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MUSICON-STIEN | | | | | | | | | | | | | | |
| TIDS- OG PROCESPLAN | | | | | | | | | | | | | | |
| *Seneste opdatering: 04.04.2017 v/Tine* | | | | | | | | | | | | | | |
| **Faser/uge** | **9** | **10** | **11** | **12** | **13** | **14** | **15 (påske)** | **16** | **17** | **18** | **19** | **20** | **21** | **Deltagere** |
| **OPSTART** | | | | | | | | | | | | | | |
| Opstartsmøde | 28-Feb | | | | | | | | | | | | | |
| Kontrakt | | 07-Mar | | | | | | | | | | | | |
| **KONCEPT** | | | | | | | | | | | | | | |
| Møde, afklaring af installationskrav | | | 15-Mar | | | | | | | | | | | Simon, Esben, Frederik, Tine, Jeremy, Stig og seas-nve |
| Møde, valg af koncept | | | | 20-Mar | | | | | | | | | | Simon, Esben, Frederik, Tine, Jeremy, Georgios |
| **KONKRETISERING** | | | | | | | | | | | | | | |
| Møde, valg af hardware-koncept | | | | | | 03-Apr | | | | | | | | Simon, Esben, Frederik, Tine, Jeremy, Georgios |
| Møde, afklaring af komponentvalg | | | | | | | | | 27-May | | | | | Simon, Esben, Frederik, Tine, Jeremy, Georgios, Stig og seas-nve |
| **TEST (detektering og armaturer)** | | | | | | | | | | | | | | |
| Møde, konklusion på test | | | | | | | | | | 01-May | | | | Simon, Esben, Frederik, Tine, Jeremy, Georgios |
| **STYRING** | | | | | | | | | | | | | | |
| Møde, konklusion på styring | | | | | | | | | | | 10-May | | | Simon, Esben, Frederik, Tine, Jeremy, Georgios |
| **BESKRIVELSE** | | | | | | | | | | | | | | |
| Møde, aflevering | | | | | | | | | | | | | 23-May | Simon, Esben, Frederik, Tine, Jeremy, Georgios |

## 11.6 Additional drawings of the area



## 11.7 Component List

**Punkt 4 - Interaktiv effektbelysning på pumptrack vha. projektører på master med integrerede detektorer (styret af aktivitet på pumptracken)**

| Funktion | Nr. | Komponent | Type | Fabrikant | Leverandør | Varenr. | Antal |
|---|---|---|---|---|---|---|---|
| Projektører | 1 | LED projektør **Medium Beam** | EOS 6 Full Color Medium Beam standard farve | www.dts-lighting.it | www.Futuresales.eu | Speciel nr. | 21 |
| | 2 | LED projektør (special farve) | RAL-farve | www.dts-lighting.it | www.Futuresales.eu | | 0 |
| | 3 | LED projektør (2 års ekstra garanti) | Fabriksgaranti + 2 års garanti | www.dts-lighting.it | www.Futuresales.eu | | 0 |
| | 4 | Afblænding for projektør | Honey comb specialtilbehør | www.dts-lighting.it | www.Futuresales.eu | | 21 |
| Armaturkabel | 5 | Armaturkabel | 50 meter med M12 stik / ledning for terminal | www.dts-lighting.it | www.Futuresales.eu | Speciel nr. | 21 |
| Strømforsyning | 6 | Strømforsyning for projektører | Drivenet 832 32 kanaler med terminaler | www.dts-lighting.it | www.Futuresales.eu | Drivenet 832 | 3 |
| Master | 7 | Mast inkl. fodflange og top | Cylindrisk Ø170 mm, 6 meter, 1 luge | www.Milewide.dk | www.Milewide.dk | Speciel nr. | 7 |
| | 8 | Maling af mast | Anti-sticker maling i RAL-farve | www.Milewide.dk | www.Milewide.dk | Speciel nr. | 7 |
| | 9 | Luge for detektor | Udfræsning og rude i UV bestandig polycabonat | www.Milewide.dk | www.Milewide.dk | Speciel nr. | 7 |
| | 10 | Fundament | Præfab. beton AAB Type 4 (50x50x110cm) | www.Milewide.dk | www.Milewide.dk | 170-514 | 7 |
| | 11 | Mastebeslag | Beslag for armatur med M8 bolt | www.Milewide.dk | www.Milewide.dk | Speciel nr. | 21 |
| Sikkerhedsskruer | 12 | Sikkerhedsskrue for master mv. | ? | www.Praestmark.dk | www.Praestmark.dk | ? | 100 |
| Detektering | 13 | Laser-detektor | TIM361-2134101 | www.SICK.dk | www.SICK.dk | 1071399 | 7 |
| | 14 | Beslag for laser-detektor | Specielkonstrueret | Specielkonstrueret | Specielkonstrueret | Speciel nr. | 7 |
| | 15 | Styrekabler for detektor | 5 meter - M12 / RJ45 | www.SICK.dk | www.SICK.dk | 6034415 | 7 |
| | 16 | Styrekabler for detektor | 5 meter - M12 / Ledning for terminal | www.SICK.dk | www.SICK.dk | 6042735 | 7 |
| | 17 | Forgrening | Forgreningsdåse med forskruninger monteret i mast | - | - | - | 7 |
| Overdragsrelæ | 18 | Overdragsrelæ for detektorer | DIN-skinne relæ 24V DC 1-polet | www.eltako.com | www.yousave.dk | R12-100-24V DC | 21 |
| Strømforsyning | 19 | Strømforsyning for detektorer | MEAN WELL DR-100 24V DC | www.meanwell.com | www.powertechnic.dk | DR-100 24V DC | 1 |
| Strømforsyning | 20 | Strømforsyning af lysstyring | 48V (Valgt af Atendi) | ? | www.Atendi.dk | 3141 | 1 |
| Lysstyring | 21 | Lysstyring controller | Unison Mosaic MSC1 Controller med 8 inputs | www.etcconnect.com | www.Atendi.dk | MSC1 | 1 |
| | 22 | Lysstyring inputmoduler | Unison SMC MRIO-80 I/O med 8 inputs | www.etcconnect.com | www.Atendi.dk | MRIO-80 | 3 |
| | 23 | Switch med POE | Unison Mosaic M-NET Sw 5 port PoE | www.etcconnect.com | www.Atendi.dk | MSC-NET | 1 |
| Fjernstyring | 24 | SMS modul | GSMCON | www.logtech.dk | www.logtech.dk | Speciel nr. | 1 |
| | 25 | Strømforsyning af SMS modul | Strømforsyning 12V | www.logtech.dk | www.logtech.dk | ? | 1 |
| | 26 | SIM-kort | LogTech | www.logtech.dk | www.logtech.dk | ? | 1 |
| Skab Koblingsmateriel mv. | 27 | Vejskab | CAB PX med sokkel og bagplade samt RUKO-lås | www.FIBOX.dk | www.FIBOX.dk | ? | 1 |
| | 28 | Jordelektrode | Jordspyd | - | - | ? | 1 |
| | 29 | Gruppetavle | Tilpasset mængden af DIN-skinne komponenter i skabet | - | - | ? | 1 |
| | 30 | Transientbeskyttelse | Klasse 1 + 2 | - | - | ? | 1 |
| | 31 | Fejlstrømsafbryder | HPFI frotssikker | - | - | ? | 1 |
| | 32 | Gruppeafbryder | 4-polet 3+N med 10A smeltesikring neozed D01 | - | - | ? | 1 |
| | 33 | Kontaktor | 4-polet kontaktor for nat sluk | - | - | ? | 1 |
| | 34 | Astronomisk ur | Astronomisk ur | - | - | ? | 1 |
| | 35 | Stikkontakt | DK-stikkontakt | - | - | ? | 4 |

**El-skab**

| Funktion | Nr. | Komponent | Type | Fabrikant | Leverandør | | Antal |
|---|---|---|---|---|---|---|---|
| Forsyning | 1 | Tilslutningsbidrag | SEAS-NVE | | SEAS-NVE | | 1 |
| Eltavle | 2 | Målertavle | Gruppetavle | - | - | ? | 1 |
| | 3 | Gruppetavle | Tilpasset mængden af DIN-skinne komponenter i skabet | - | - | ? | 1 |
| | 4 | Gruppeafbryder | 4-polet 3+N med 16A smeltesikring neozed D01 | - | - | ? | 3 |
| | 5 | Jordelektrode | Jordspyd | - | - | ? | 1 |
| Skab | 6 | Vejskab | CAB PX med sokkel og bagplade samt RUKO-lås | www.FIBOX.dk | www.FIBOX.dk | ? | 1 |
| Føringsvej | 7 | Kabelrør | Ø50 mm | - | - | ? | 600 |
| Kabel | 8 | Stikledning | NOIK 4x16 mm² CU | www.nktcables.dk | www.nktcables.dk | ? | 25 |
| | 9 | Kabel til skabe | NOIK 5G2,5 mm² CU | www.nktcables.dk | www.nktcables.dk | ? | 700 |
| | 10 | Kabel til nedgravningsarmaturer | NOIK 3X2,5 mm² CU | www.nktcables.dk | www.nktcables.dk | ? | 700 |
| | 11 | Kabel til detektorer | NOIK 5x2,5 mm² Cu | www.nktcables.dk | www.nktcables.dk | ? | 200 |
| | 12 | Lysstyringskabel | DMX Binary 234 ASE/EBU MKII 2 x 0,34 mm² | www.sommercable.com | www.lightpartner.dk | 520-0051 | 100 |

**Fjernstyring**

| Funktion | Nr. | Komponent | Type | Fabrikant | Leverandør | | Antal |
|---|---|---|---|---|---|---|---|
| | 1 | Firmware | Speciel konstrueret firmware | www.logtech.dk | www.logtech.dk | Speciel nr. | 1 |

## 11.8 Work Description – Frederik Borello ÅF Lighting

Author
Frederik Waneck Borello
Phone
+45 3816 5093
Mobile
+45 2441 8842
E-mail
frederik.waneck.borello@afconsult.com
Date
10/05/2017
Project ID
5795

Recipient
Roskilde Kommune

# Arbejdsbeskrivelse belysning Musicon-stien del 1

# 1 Generelt

Roskilde Kommune har haft ønske om at etablere lysprojekter i syv punkter på Musicon-stien, men har senere bestemt kun at realisere tre af de syv projekter som tre individuelle belysningsanlæg. Belysningsanlæggene er navngivet Punkt 3 (Lysport nord), Punkt 4 (Pumptrack) og Punkt 5 (Lysport syd).

Afsnit 2.4 indeholder en principtegning for opbygningen af de tre belysningsanlæg.

Der skal anvendes komponenter jf. styklisten (bilag).

# 2 Belysningsanlæg

## 2.1 Punkt 3 (Lysport nord)

Ved lysport nord skal der etableres træbelysning vha. nedgravede projektører i terræn samt scenografisk belysning vha. nedgravende lyspunkter i stien.

## 2.2 Punkt 4 (Pumptrack belysning)

Langs pumptracket skal der etableres interaktiv belysning vha. projektører på master med integrerede detektorer.

Belysningen programmeres således at projektørernes lysniveauer varierer, når detektorerne registrere bevægelse langs pumptracket.

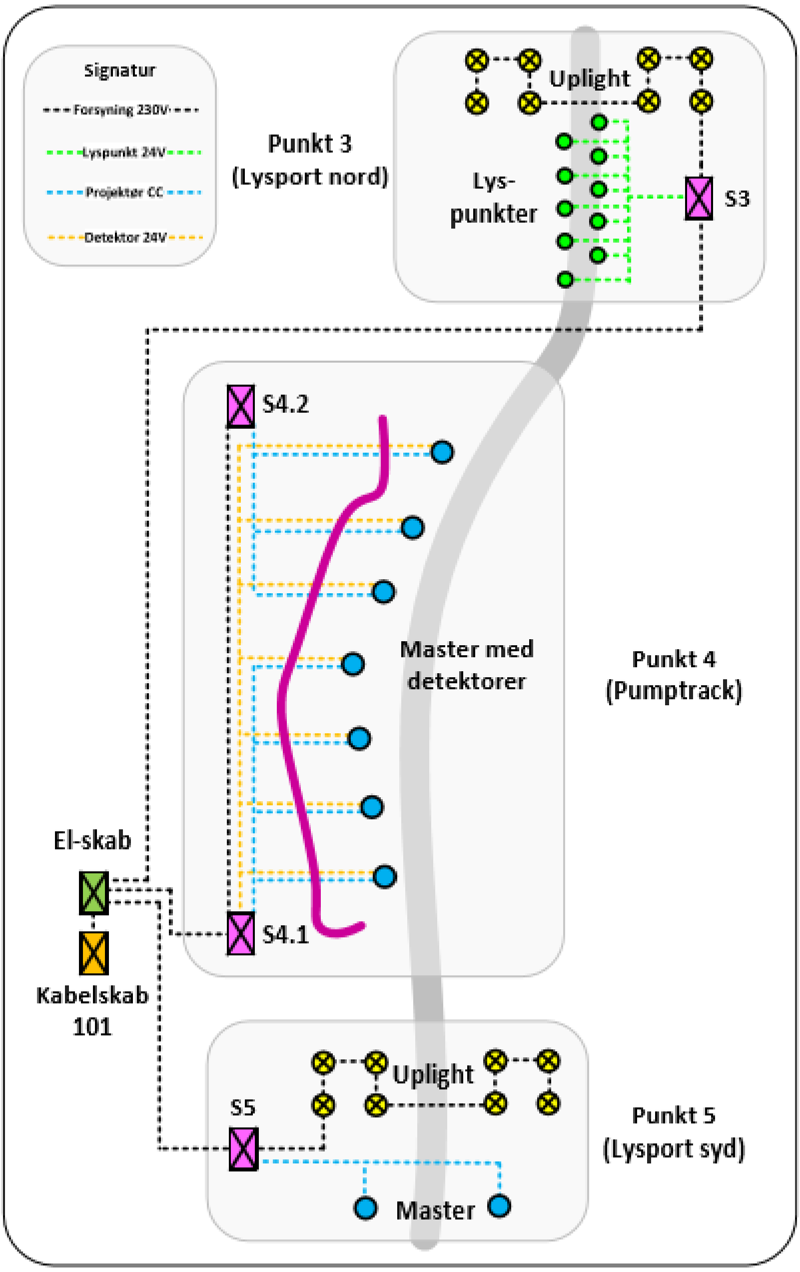
Nøjagtig placering af masterne er nødvendig for at kunne detektere effektivt og derfor skal pumptracket etableres inden masternes endelige placering kan angives.

## 2.3 Punkt 5 (Lysport syd)

Ved lysport syd skal der etableres træbelysning vha. nedgravede projektører i terræn samt scenografisk belysning på stien vha. projektører på master langs stien.

5795udb001-Rev0-Arbejdsbeskrivelse_Belysning_Musicon-stien_1 Side 2 af 12

## 2.4 Principtegning for Punkt 3, 4 og 5




5795udb001-Rev0-Arbejdsbeskrivelse_Belysning_Musicon-stien_1 Side 3 af 12

## 2.5 Projektører for træbelysning i Punkt 3 og 5

Der etableres nedgravede projektører for træbelysning. Projektørerne skal etableres i tilhørende montagehuse, og der må ikke forekomme niveauforskel mellem projektørernes overkant og overkant af det tilstødende terræn.

Ved nedgravning af kabler omkring træer er det vigtigt at der passes på træernes rodnet, og derfor må der ikke graves rundt om træernes stamme under træets krone, dvs. at hvis der skal graves under kronen, må der kun graves ind mod træet stamme og ikke på tværs af eller rundt om stammen! Gravearbejde under træernes kroner udføres som håndgravning.

Projektørerne skal placeres jf. lysdesignerens / tilsynets afsætninger på stedet.

Projektørerne skal indstilles jf. lysdesignerens / tilsynets anvisninger på stedet.

## 2.6 Lyspunkter for scenografisk belysning i Punkt 3

Der etableres lyspunkter integreret i stiens nye belægning. Lyspunkterne skal etableres i tilhørende montagehuse, og der må ikke forekomme niveauforskel mellem armaturets overkant og overkant af den tilstødende belægning. Fra PWM-modulerne i styreskabet skal der føres ét armaturkabel frem til hvert lyspunkt.

Lyspunkterne skal placeres jf. lysdesignerens / tilsynets afsætninger på stedet.

## 2.7 Master for projektører i Punkt 4 og 5

For projektører i skal der etablerers 6,3 m Milewide master. Masterne skal males med antisticker maling således at det er besværligt at sætte klistermærker på masterne. Valg af RAL-farve skal aftales inden bestilling.

Master for Punkt 4 skal yderligere leveres med luge og åbning for detektorer. Lugen og åbningen skal være som på prototypen dog uden rude. Lugen skal være 35 mm høj, 100 mm bred og udføres med center i 3,3 m højde.

For opstilling af masterne etableres der præfabrikerede betonfundamenter af Type 4 (500 x 500 x 1100 mm). Fundamenterne skal nedgraves med overkant 300 mm under

5795udb001-Rev0-Arbejdsbeskrivelse_Belysning_Musikon-ation_1 Side 4 af 12 terræn, og de skal orienteres, således at masteluger og detektorer kan orienteres i den aftalte retning.

Masterne og fundamenterne skal placeres og orienteres jf. lysdesignerens / tilsynets afsætninger på stedet.

## 2.8 Projektører for scenografisk og interaktiv belysning i Punkt 4 og 5

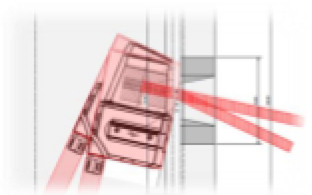
Projektørerne monteres vha. rustfrie (A4) M8 bolte og skiver på Milewide mastebeslag. Armaturkablerne skal føres ind i masten via. membranmuffer der etableres 5 cm over mastebeslagene. Projektørerne vendes således at armaturkabler mellem mast og projektør bliver så kort som muligt. Fra strømforsyningen i styreskabene skal der føres ét armaturkabel frem til hver projektør. Der anvendes sikkerhedsskruer for fastgørelse af projektører på master. Første projektør skal placeres med center 30 cm fra overkant af masten og de efterfølgende projektører skal placeres med 30 cm mellemrum.

Projektørerne skal placeres på masterne jf. lysdesignerens / tilsynets afvisninger.

Projektørerne skal indstilles jf. lysdesignerens / tilsynets anvisninger på stedet.

## 2.9 Detektorer for interaktiv belysning i Punkt 5

Detektorerne skal etableres på specialbeslag i masterne. Beslagene skal udføres således at detektorerne vippes frem over, i en vinkel af ca. 19°, hvilket skal kunne justeres +/- 5 °.



Nå detektorerne er monteret skal de 5 m foran masten, kunne detektere bevægelse indenfor et ca. 10-12 m bredt detekteringsfelt på langs pumptracket.

Fra styreskab 4.1 skal der fremføres ét installationskabel til hver detektor.

I de nederste masteluger skal der etableres IP65 forgreningsdåser med forskruninger for samling af detektorkablerne og installationskablerne fra styreskabet.

I detektorerne etableres også LAN-kabler til programmering af detektorerne. Når detektorerne er programmeret skal LAN-kablerne beskyttes med små RAYCHEM RayGel dåser.

Der anvendes sikkerhedsskruer for fastgørelse af projektører på master samt luger foran detektorer.

5795udb001-Rev0-Arbejdsbeskrivelse_Belysning_Musicon-ation_1 Side 5 af 12

## 2.10 Lysfordeling for interaktiv belysning i Punkt 4

Grafikken viser 3 master på en lige strækning, med 3 projektører på hver mast.

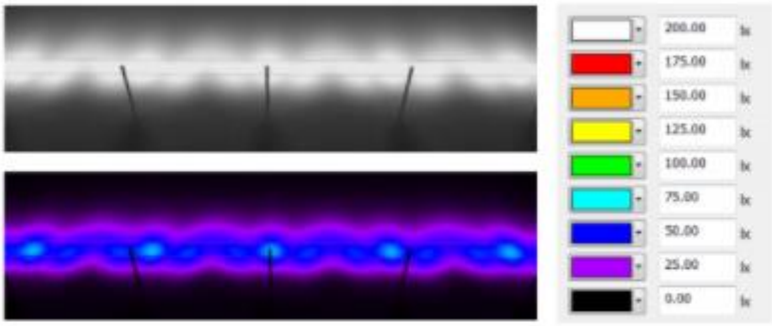
Armatur = DTS EOS 6 Medium Beam

Højde = 5,7 m (Til højre for masten) / 5,4 m (Til venstre for masten) / 5,1 m (Frem for masten)

Afstand mellem master = 10 m

Afstand fra center af master til centerlinje af pumptracket = 5 m

Belyst område = ca. 70 x 6 m som følger pumptracket




5795udb001-Rev0-Arbejdsbeskrivelse_Belysning_Musicon-stien_1 Side 6 af 12

# 3 Skabe

## 3.1 Generelt

For de tre belysningsanlæg skal der etableres et fælles el-skab med måler samt ét til to styreskabe for styringskomponenter mv. til hvert belysningsanlæg.

Skabene skal være udført i IP65 og IK10, og være udstyret med lås for MS-nøgle, og der skal leveres 3 stk. medfølgende MS-nøgler.

For montage af komponenter skal der i skabene etableres totalisolerede montage-/bagplader.

## 3.2 El-skab

Der etableres et el-skab til forsyning af de tre belysningsanlæg.

El-skabet udstyres med integreret måler eller alternativt måler i eget skab.

El-skabet skal forsynes fra SEAS-NVE's kabelskab nr. 101, som er placeret på Eriksvej ud for nr. 42A.

I skabet skal der etableres følgende:

1 stk. målertavle (placeres alternativt i eget skab)

1 stk. gruppetavle for DIN-skinne monterede lysstyringskomponenter

3 stk. 4-polede gruppeafbrydere med 16A D01 neozed smeltesikring (én for hvert belysningsanlæg)

1 stk. jordelektrode (kun ved anvendelse af metallisk skabskabinet)

## 3.3 Generelle komponenter i styreskab nr. 3, 4.1 og 5

I styreskabene skal der generelt etableres følgende:

1 stk. gruppetavle for DIN-skinne monterede lysstyringskomponenter

1 stk. jordelektrode

1 stk. overspændingsbeskyttelse **Klasse 2+3**

1 stk. fejlstrømafbryder HPFI

1 stk. 4-polede gruppeafbryder med 10A D01 neozed smeltesikring

1 stk. astronomisk ur for tænd og sluk af 4-polet kontaktor for "nat sluk"

1 stk. 4-polet kontaktor for "nat sluk" af hhv.:

- Strømforsyningerne til lyspunkterne tilsluttet i styreskab 3.
- Nedgravningsarmaturerne tilsluttet i styreskab 3 og 5.
- Stikkontakter for strømforsyning til projektører tilsluttet i styreskab nr. 4.1, 4.2 og 5.

1 stk. stikkontakt for tilslutning af eksternt udstyr f.eks. computer

5795udb001-Rev0-Arbejdsbeskrivelse_Belysning_Musicon-stien_1 Side 8 af 12

1 stk. 48V strømforsyning for lysstyringsmodul eller POE-switch

1 stk. Mosaic lysstyringsmodul

1 stk. 12V strømforsyning for SMS-modul

1 stk. SMS-modul

## 3.4 Særlige komponenter i styreskab nr. 3

I styreskab nr. 3 skal der ud over de generelle komponenter etableres følgende:

2 stk. 24V strømforsyninger for lyspunkter

3 stk. PWM-moduler for lyspunkter

1 stk. 24V strømforsyning for vejrdetektor

1 stk. vejrdetektor

## 3.5 Særlige komponenter i styreskab nr. 4.1 og 4.2

Armaturkablerne for projektørerne må maksimalt være 50 m lange, og da man ikke ønsker have styreskabe midt på pumptracket, er man nødt til at etablere 2 stk. styreskabe (nr. 4.1 og 4.2), et i hver ende af pumptracket.

I styreskab nr. 4.1 skal der ud over de generelle komponenter etableres følgende:

2 stk. stikkontakter for tilslutning strømforsyning for projektører

3 stk. Mosaic indgangsmodul

1 stk. POE-switch for strømforsyning af lysstyringsmodulerne

2 stk. Constand Current strømforsyning (nr. 1 og nr. 2) for projektører (tilsluttes i stikkontakter)

1 stk. 24V strømforsyning for detektorer og overdragsrelæer

21 stk. 24V overdragsrelæer for detektorer

I styreskab nr. 4.2 skal der etableres følgende:

1 stk. jordelektrode

1 stk. stikkontakt for tilslutning strømforsyning for projektører

1 stk. Constand Current strømforsyning (nr. 3) for projektører (tilsluttes i stikkontakt)

### 3.6 Særlige komponenter i styreskab nr. 5

I styreskab nr. 5 skal der ud over de generelle komponenter etableres følgende:

1 stk. stikkontakt for tilslutning strømforsyning for projektører

1 stk. Constand Current strømforsyning for projektører (tilsluttes i stikkontakter)

1 stk. 24V strømforsyning for vejrdetektor

1 stk. vejr-detektor

### 3.7 Generel fortrådning i styreskab nr. 3, 4.1 og 5:

L1 anvendes til forsyning af nedgravningsarmaturer.

L2 anvendes til forsyning af hhv. strømforsyninger til lyspunkter, strømforsyninger til detektorer for pumptracket samt stikkontakter for strømforsyninger til projektører.

L3 anvendes til forsyning af stikkontakt for tilslutning af PC, astronomisk ur, kontaktor samt strømforsyninger til lysstyringskomponenter, SMS modul og evt. vejr-detektor.

L1 og L2 skal tændes og slukkes af kontaktoren for "nat sluk" via det astronomiske ur.

L3 skal være permanet tændt.

SMS-modulets udgangsrelæ 1-7 skal tilsluttes lysstyringsmodulets indgange 1-7.

### 3.8 Generel fortrådning mv. i styreskab nr. 3 og 5

Vejr-detektorernes 0-10V signal tilsluttes på lysstyringsmodulets indgang 8.

Sensorer for vejrdetektoren skal placeres udvendigt på skabet og kapsles mod vandalisme f.eks. vha. en U-profil etableret over sensoren.

### 3.9 Særlig fortrådning i styreskabene

*Arbejdsbeskrivelse del 2 beskriver fortrådning og adressering af hhv. lyspunkter i stien, projektører på master og detektorer i master og udarbedjdes af ÅF Lighting ifm. etableringen.*

## 3.10 SMS-styring

Inden indkøb af de 3 stk. SMS moduler skal der udarbejdes ny firmware, hvilket udføres af leverandøren. Med den nye firmware skal SMS modulerne understøtte følgende funktioner:

- Kun ét udgangsrelæ må kunne aktiveres ad gangen
- Modulet skal aktivere relæ 1, når man sender "1"
- Modulet skal aktivere relæ 2, når man sender "2"
- Modulet skal aktivere relæ 3, når man sender "3"
- Modulet skal aktivere relæ 4, når man sender "4"
- Modulet skal aktivere relæ 5, når man sender "5"
- Modulet skal aktivere relæ 6, når man sender "6"
- Modulet skal aktivere relæ 7, når man sender "7"
- Modulet skal aktivere relæ 8, når man sender "8"
- Efter strømafbrydelse skal modulet skal starte op i samme stilling som det havde før afbrydelsen.

# 4 Kabler

Fra kabelskab nr. 101 til el-skabet, skal der etableres stikledning som NOIK 4 X 16 mm² CU.

Fra el-skabet og frem til styreskab nr. 3, 4.1 og 5, skal der etableres NOIK 5 G 2,5 mm² CU.

Fra styreskabe nr. 3 og 5, og frem til og imellem nedgravnings projektører, skal der etableres NOIK 3 X 2,5 mm² CU

Mellem styreskabene nr. 4.1 og 4.2, skal der etableres NOIK 5 G 2,5 mm² CU samt DMX vejrbestandigt kabel.

Mellem styreskab nr. 4.1 og hver detektor i masterne ved Punkt 4, skal der etabelres NOIK 5 X 2,5 mm² CU

Fra styreskabene etableres der specielkonfigurerede armaturkabler på 50 m fra armaturproducenterne til hhv. lyspunkter i stien og projektører på master.

# 5 Kabelrør mv.

Generelt skal kabler i terræn fremføres i Ø50 mm kabelrør nedgravet i 70 cm dybde.

Kabelrør skal udføres ude skarpe buk og skal føres helt op i skabene.

Ved master skal kabelrør føres helt ind i masterne via præfabrikerede huller i fundamenterne. Kabelrørene afsluttes 10 cm under de nederste luger i masterne.

Kabler for lyspunkter i stien i Punkt 3 skal fremføres hver for sig i individuelle 20 mm PEX-rør. Der kan evt. etableres en brønd for opsamling af kabler mellem styreskabet og lyspunkterne.

5795udb001-Rev0-Arbejdsbeskrivelse_Belysning_Musicon-stien_1 Side 11 af 12

## 6 El- og montagearbejde samt dokumentation

El-arbejdet skal udføres iht. gælde love og regler, herunder Fællesregulativet, Stærkstrømsbekendtgørelsen, Tavlebekendtgørelsen DS/EN 61439 og Vejdirektoratets AAB Vejbelysningsmateriel.

Der skal udføres tavledokumentation samt EF Overensstemmelseserklæring for hver tavle.

Tavledokumentation skal indeholde en dispositionstegning med placering og navngivning af komponenter, en komponentliste og et kredsskema over komponenternes som forbindelse i belysningsanlægget.

Der udarbejdes i øvrigt dokumentation jf. Roskilde Kommunes og SEAS-NVE's krav hertil.

For verificering af elinstallationernes udførsel skal der udføres el-beregninger for samtlige elinstallationer, herunder varmetabs beregninger for tavlerne inden udførsel.

Ved anvendelse af metalskabe skal der etableres udligningsforbindelse samt eksterne vandalsikre antenner for SMS modulerne.

For Punkt 4 skal det inden udførsel verificeres, at detektoren placeret længst fra styreskabe nr. 4.1, kan trække overdragsrelæerne i skabet.

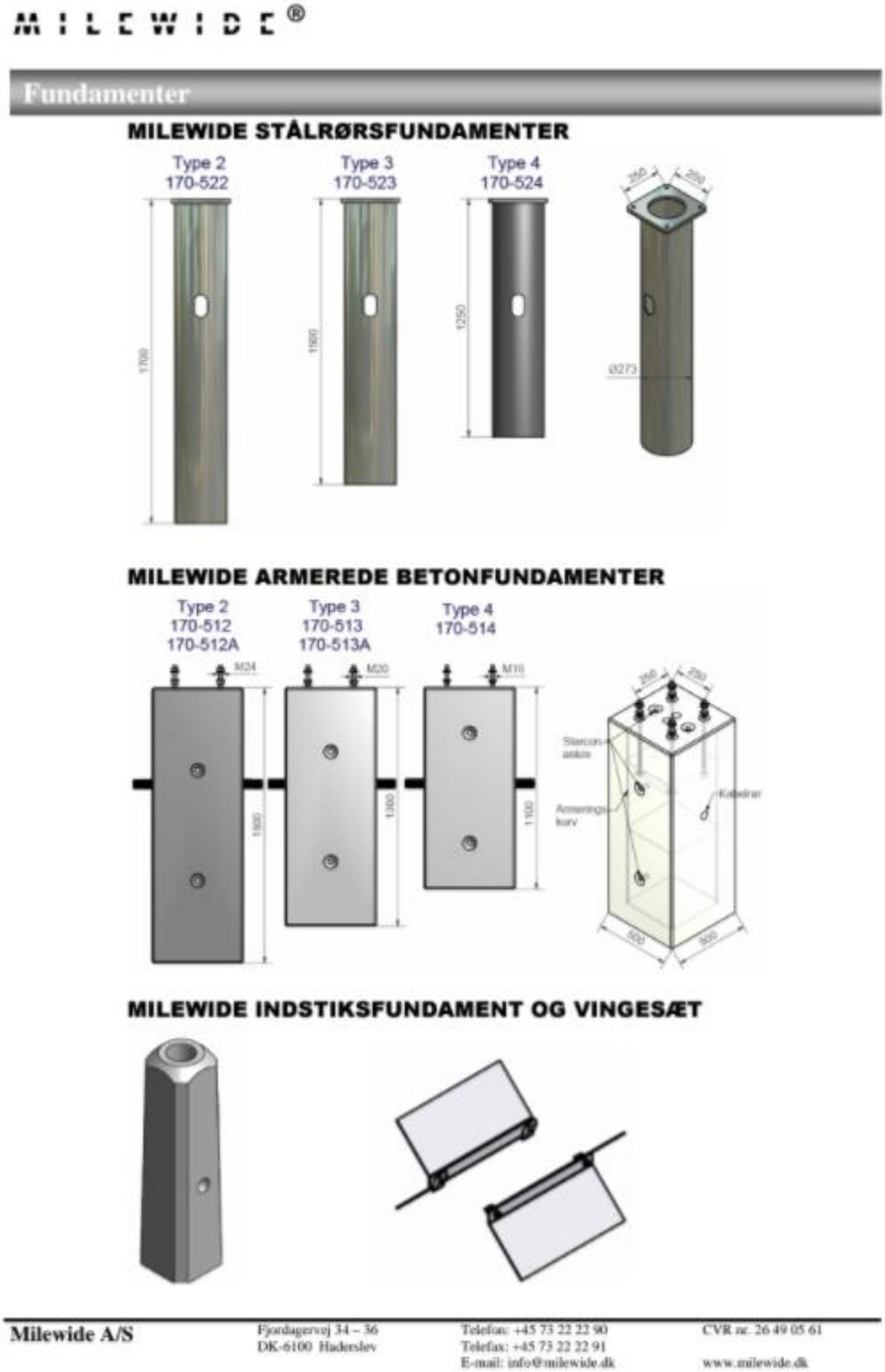
Alle komponenter skal etableres jf. fabrikantens anvisninger.

Arbejdet skal generelt udføres efter god håndværksmæssig skik.

Der skal anvendes materialer af egnet og høj kvalitet.

Belysningsanlæggene skal indstilles i samarbejde med lysdesignerne og tilsynet, og entreprenøren skal medbringe lift til brug for indstilling af projektørerne.

## 11.9 Milewide Lamp post



## 11.10 Data on SICK's TIM 361 2D Laser Scanner

Show all | Hide all

**FEATURES**

| | |
|---|---|
| Field of application | Outdoor |
| Light source | Infrared (850 nm) |
| Laser class | 1, eye-safe (IEC 60825-1:2014) |
| Aperture angle | 270° |
| Scanning frequency | 15 Hz |
| Angular resolution | 0.33° |
| Operating range | 0.05 m ... 10 m |
| Max. range with 10 % reflectivity | 8 m |

**PERFORMANCE**

| | |
|---|---|
| Response time | Typ. 67 ms |
| Detectable object shape | Almost any |
| Systematic error | ± 60 mm [1)] |
| Statistical error | 20 mm [1)] |
| Integrated application | Field evaluation with flexible fields |
| Number of field sets | 16 field triples (48 fields, Contour as reference, 1 triple (3 fields) can be configured directly at the scanner) |
| Simultaneous evaluation cases | 1 (3 fields)<br>2 (2 fields for detection and 1 field for contour as reference) |

1) Typical value, actual value depends on environmental conditions.

**INTERFACES**

| | |
|---|---|
| Ethernet | ✓ , TCP/IP |
| USB<br>Remark<br>Function | ✓<br>Micro USB<br>AUX, parameterization |
| Switching inputs | 4 |
| Switching outputs | 3 (PNP, additional 1 x "Device Ready") |
| Delay time | 67 ms ... 30,000 ms (configurable) |
| Dwell time | 67 ms ... 10,000 ms (configurable) |

**MECHANICS/ELECTRONICS**

| | |
|---|---|
| Electrical connection | 1 x "Ethernet" connection, 4-pin M12 female connector<br>1 x connection "Power", 12-pin, M12 male connector<br>1 x Micro USB female connector, type B |
| Operating voltage | 9 V DC ... 28 V DC |
| Power consumption | Typ. 4 W |
| Housing color | Gray (RAL 7032) |
| Enclosure rating | IP67 (IEC 60529:1989+AMD1:1999+AMD2:2013) |
| Protection class | III (IEC 61140:2016-1) |
| Weight | 250 g, without connecting cables |
| Dimensions (L x W x H) | 60 mm x 60 mm x 86 mm |

https://www.sick.com/de/en/detection-and-ranging-solutions/2d-lidar-sensors/tim3xx/tim361-2134101/p/p369447

**AMBIENT DATA**

| | |
|---|---|
| Object remission | 4 % ... > 1,000 % (reflectors) |
| Electromagnetic compatibility (EMC) | IEC 61000-6-3:2006+AMD1:2010 / IEC 61000-6-2:2005 |
| Vibration resistance | IEC 60068-2-6:2007 |
| Shock resistance | IEC 60068-2-27:2008 |
| Ambient operating temperature | –25 °C ... +50 °C |
| Storage temperature | –40 °C ... +75 °C |
| Ambient light immunity | 80,000 lx |

**GENERAL NOTES**

| | |
|---|---|
| Note on use | The sensor does not constitute a safety component as defined by relevant legislation on machine safety. |

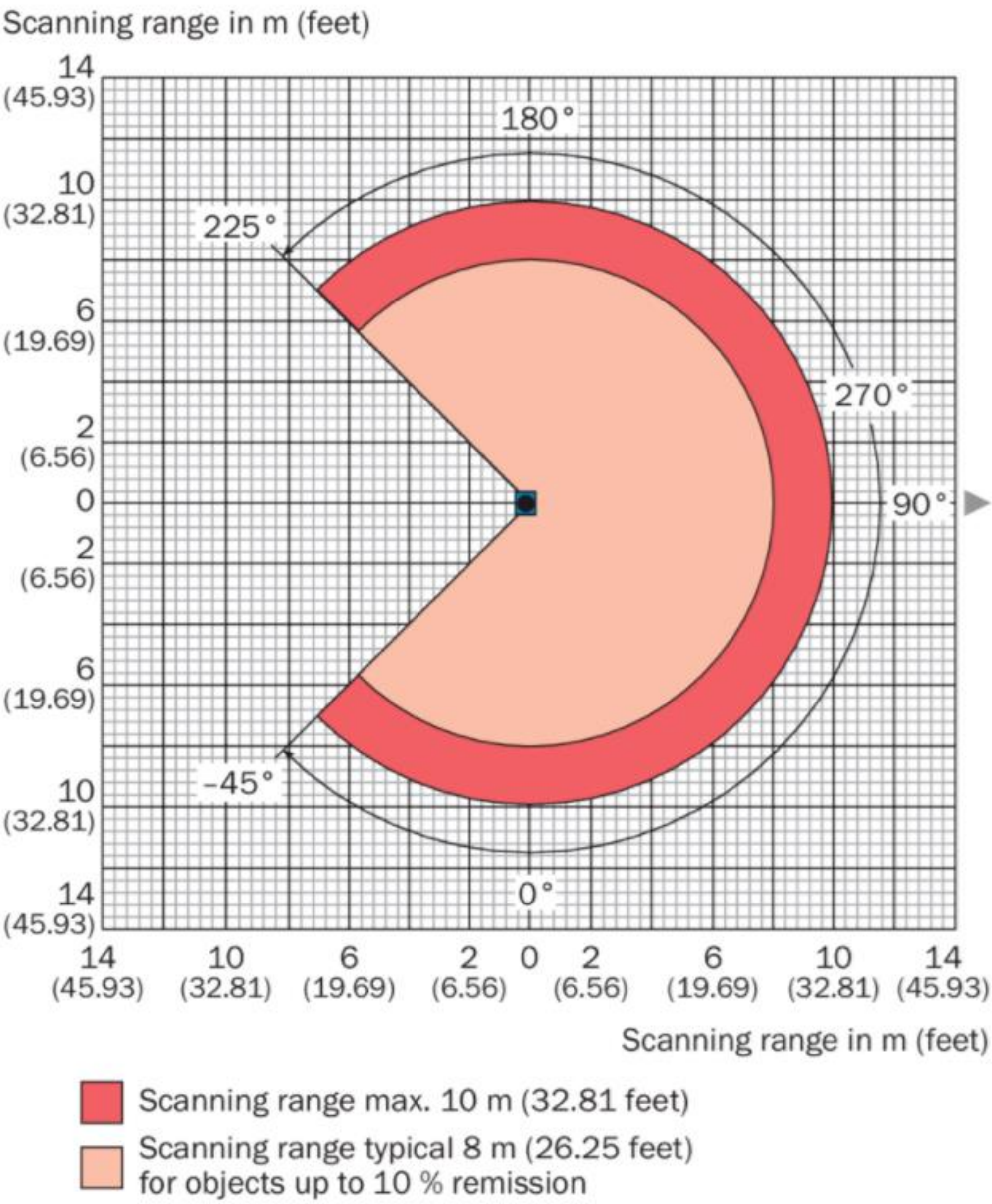
**CLASSIFICATIONS**

| | |
|---|---|
| ECl@ss 5.0 | 27270990 |
| ECl@ss 5.1.4 | 27270990 |
| ECl@ss 6.0 | 27270913 |
| ECl@ss 6.2 | 27270913 |
| ECl@ss 7.0 | 27270913 |
| ECl@ss 8.0 | 27270913 |
| ECl@ss 8.1 | 27270913 |
| ECl@ss 9.0 | 27270913 |
| ETIM 5.0 | EC002550 |
| ETIM 6.0 | EC002550 |
| UNSPSC 16.0901 | 46171620 |

Show all | Hide all

Technical drawings

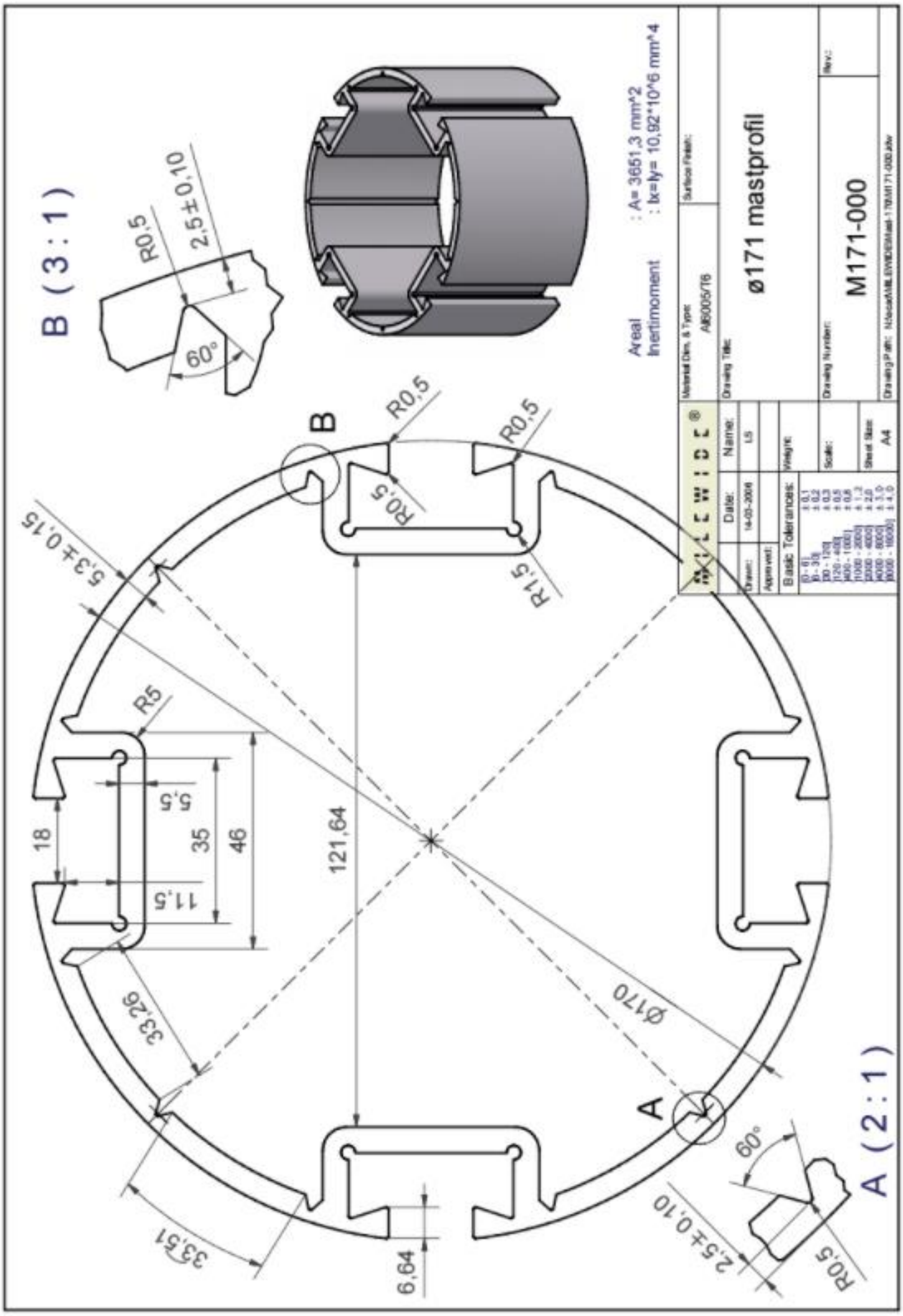
https://www.sick.com/de/en/detection-and-ranging-solutions/2d-lidar-sensors/tim3xx/tim361-2134101/p/p369447

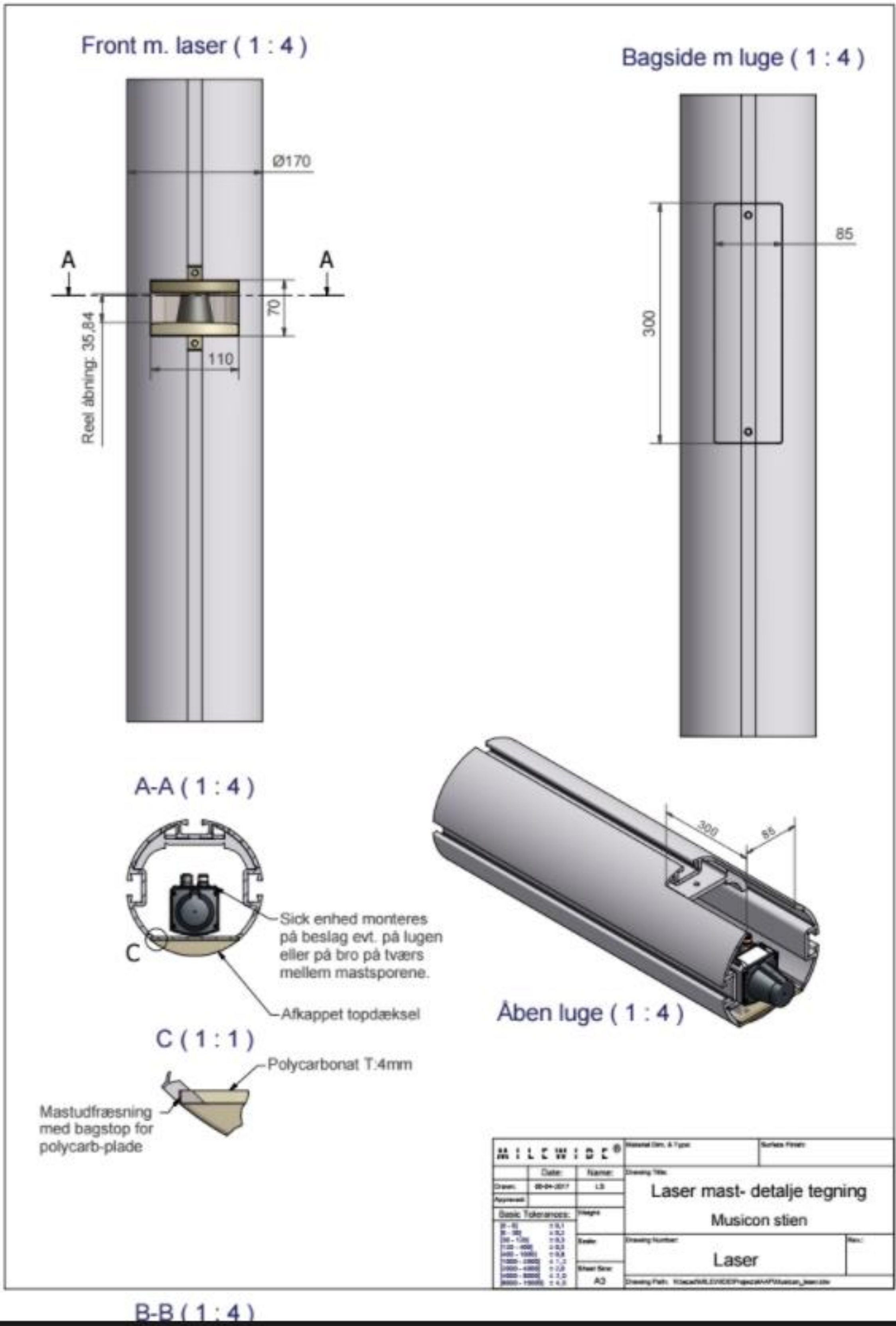


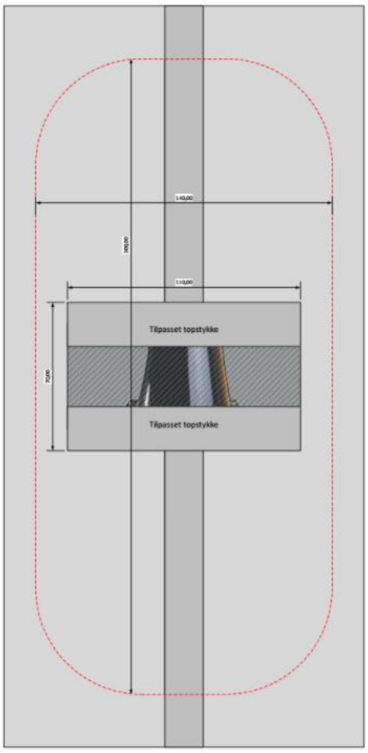

**Operating range diagram**

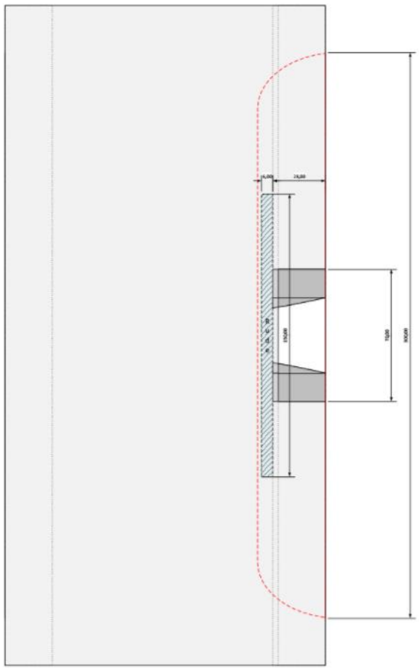
https://www.sick.com/de/en/detection-and-ranging-solutions/2d-lidar-sensors/tim3xx/tim361-2134101/p/p369447

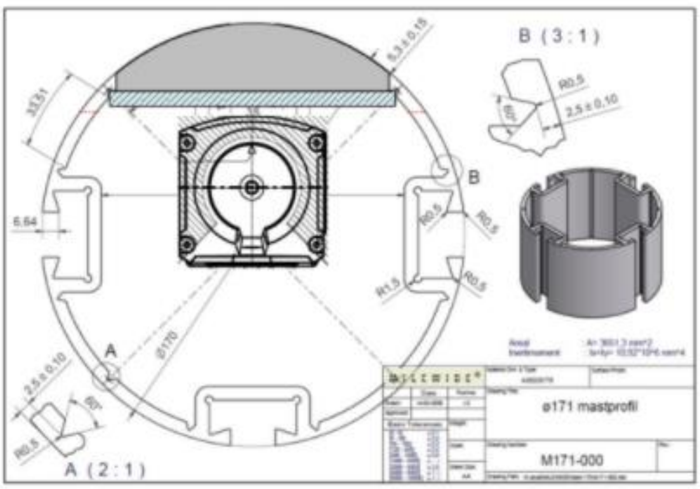
## 11.11 Special Fitting for sensor in Milewide lamp post

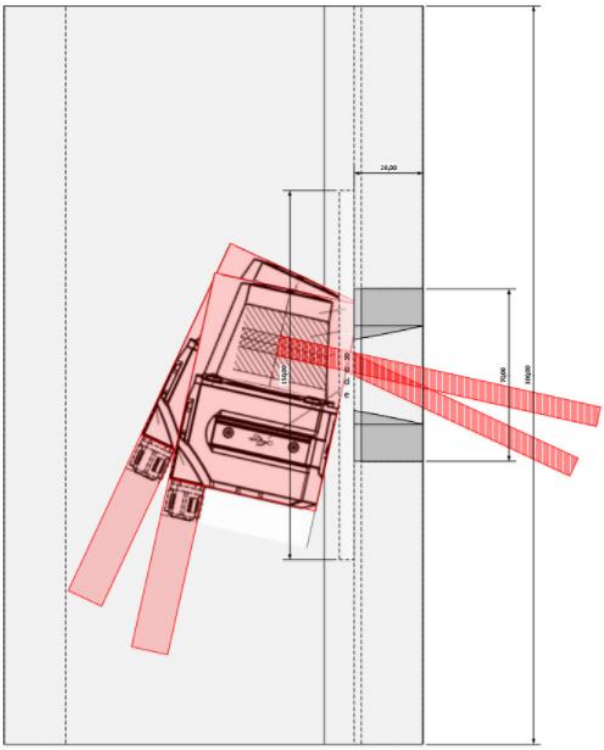


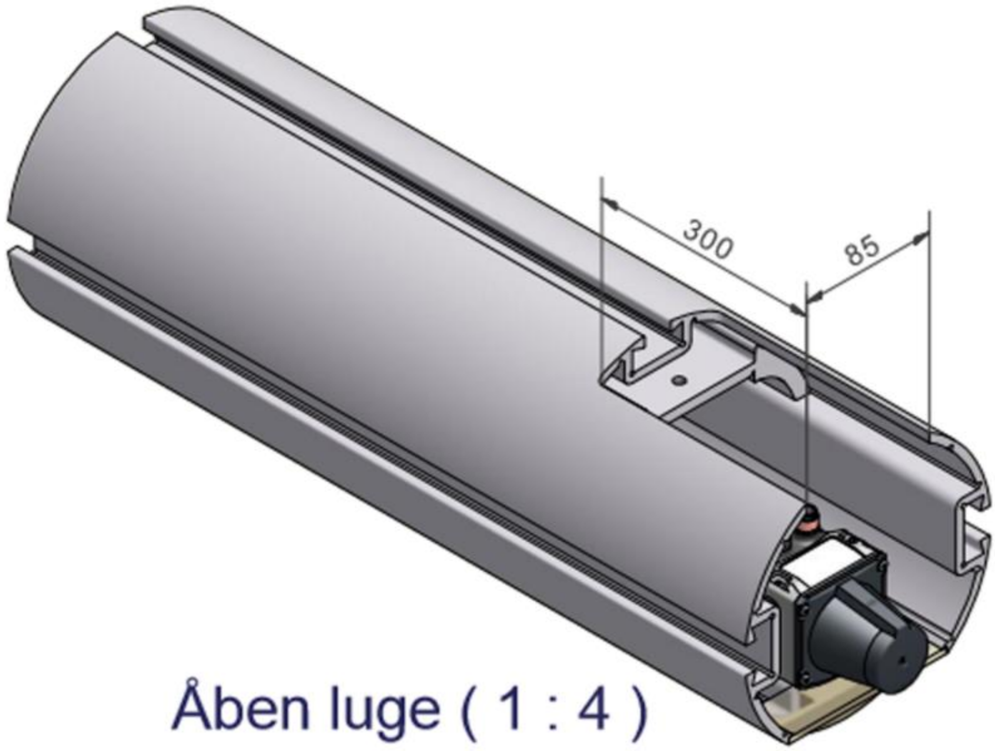

Front m. laser ( 1 : 4 )
Ø170
A
A
70
110
Reel åbning: 35,84
Bagside m luge ( 1 : 4 )
85
300
A-A ( 1 : 4 )
Sick enhed monteres på beslag evt. på lugen eller på bro på tværs mellem mastsporene.
C
Afkappet topdæksel
C ( 1 : 1 )
Polycarbonat T:4mm
Mastudfræsning med bagstop for polycarb-plade
300
85
Åben luge ( 1 : 4 )
MILEWIDE
Date:
Name:
Drawn:
LS
Approved:
Basic Tolerances:
Laser mast- detalje tegning
Musicon stien
Laser
A3
B-B ( 1 : 4 )


Tilpasset topstykke
Tilpasset topstykke

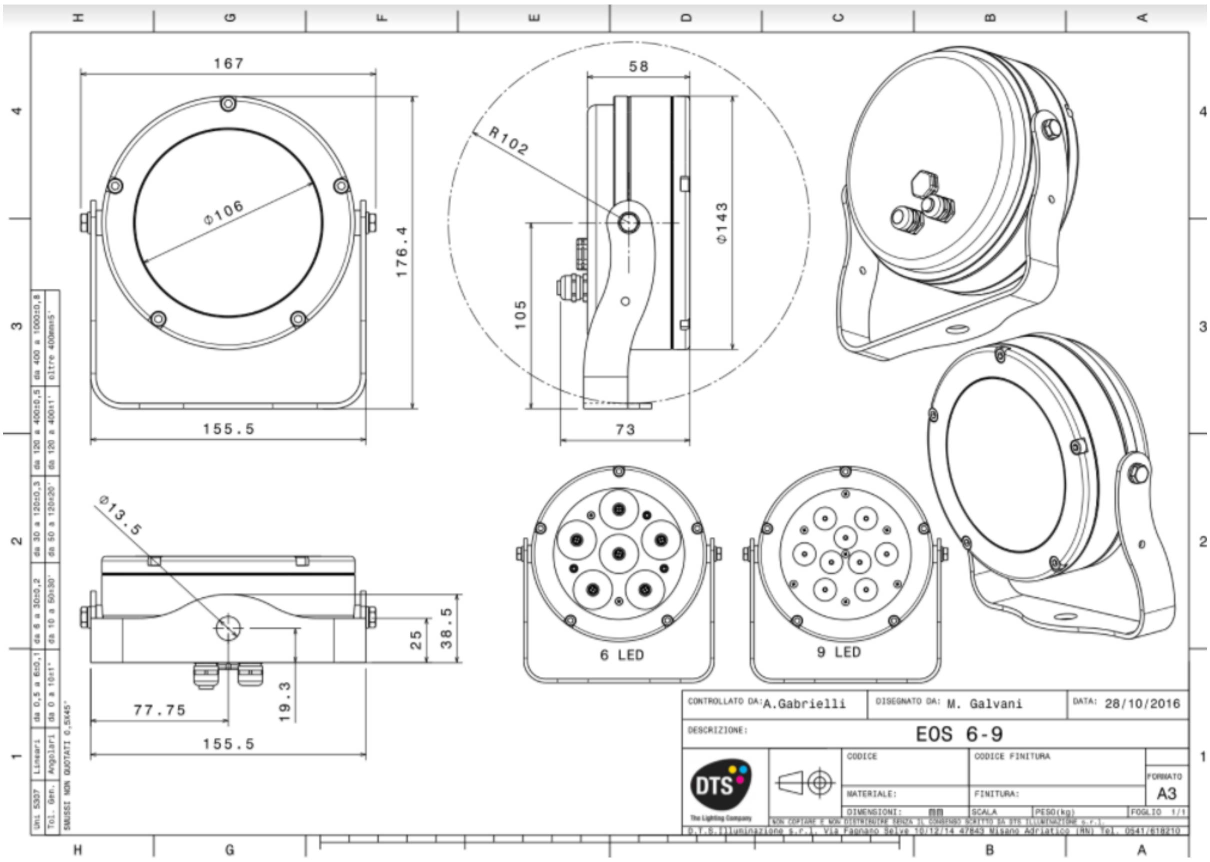



B (3:1)
R0.5
2.5 ± 0.10
B
6.64
R0.5
R0.5
R1.5
R0.5
A
ø170
2.5 ± 0.10
R0.5
A (2:1)
ø171 mastprofil
M171-000




300
85
Åben luge ( 1 : 4 )

## 11.12 DTS EOS 6 FC - Luminaire



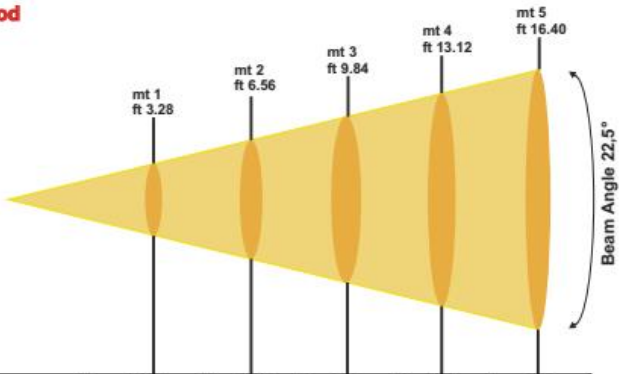

DTS
DESIGNED TO SHINE

dts-lighting.it

PROUDLY MADE IN ITALY

**EOS 6 FC**
Official Photometric Chart

Lenses set: MEDIUM Flood
LEDs current: 500mA




| | | | | | |
|---|---|---|---|---|---|
| Lux center [lx] | 5325 | 1331 | 592 | 333 | 213 |
| Foot candles [fc] | 495 | 124 | 55 | 31 | 20 |
| Diameter [cm] | 40 | 80 | 119 | 159 | 199 |
| Diameter [ft] | 1,31 | 2,61 | 3,92 | 5,22 | 6,53 |

Beam Angle 22,5°

D.T.S. Illuminazione srl via Fagnano Selve 12/14 - 47843 Misano Adriatico (RN) - ITALY - Phone +39 0541 611131 - Fax +39 0541 611111 - info@dts-lighting.it - VAT 02701930402

# EOS 6 FC

DTS
DESIGNED TO SHINE

WARRANTY 3 YEARS WARRANTY

## Ultra-compact and Luminous; perfect for temporary or fixed installations

- 6 x OSTAR RGBW LEDs
- HIGH QUALITY RGBW COLOR MIXING
- IP65 WATER PROOF LIGHT BODY
- ROBUST AND VERSATILE
- PRODUCT CUSTOMIZABLE FOR VARIOUS APPLICATIONS
- CHOICE OF DIFFERENT LEDs AVAILABLE
- DMX-CONTROLLED

EOS 6 FC is an ultra-compact and robust IP 65 Wash light fitted with high power LEDs. EOS 6 FC is ideal for rental companies, architectural applications, and outdoor temporary or fixed installations.
The unit is available with different beam angles that further enlarge its projections range. EOS 6 FC can be powered by an external PSU (DRIVENET).

D.T.S. Illuminazione srl · Via Fagnano Selve 12/14 - 47843 Misano Adriatico RN - Italy
Tel. +39 0541 611131 · Fax +39 0541 611111 · info@dts-lighting.it · dts-lighting.it

ISO 9001:2008
DTS quality system is certified to the ISO 9001:2008 standard (Certification no. 9105.DTS1)

PROUDLY MADE IN ITALY DTS products are designed and manufactured at the DTS plants in Italy

# EOS 6 FC

DTS
DESIGNED TO SHINE

**| OUTPUT |**
6 x Full Color RGBW LED;
2,300 Lumens@500mA
LED Channels: 4 (Red/Green/Blue/White)
LED lifespan: 50,000 hours (70% lumen output)

**| OPTICAL GROUP |**
3 lenses sets available:
10.2° / 22.5° / 40.7°

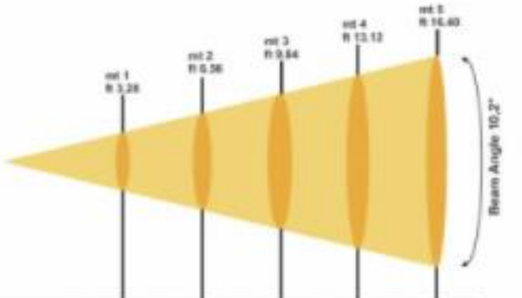
**| INTERFACE / CONTROL / PROGRAMMING |**
DMX 512, RDM and ArtNet (via Drivenet series)

**| POWER SUPPLY |**
Power consumption: 42 W max
PSU Full range 100-240Vac 50/60Hz:
- Drivenet 832 (2 items per output, total 16)
- Drivenet 1664 (2 items per output, total 32)
- Drivenet 416 (2 items per output, total 8)

**| CONNECTIONS |**
Cable with M12 male connector (1 m)

**| OPERATING AMBIENT TEMPERATURE |**
-10° / 40°

**| PHYSICAL |**
IP 65
Housing: Aluminium
Lens: 3 mm Tempered glass
Dimensions: W 167 mm / H 176,4 mm / D 73 mm
Weight: 3,9 Kg




PHOTOMETRIC DATA
NARROW LENSES

| | | | | | |
|---|---|---|---|---|---|
| Lux center [lx] | 21127 | 5282 | 2347 | 1320 | 845 |
| Foot candles [fc] | 1963 | 491 | 218 | 123 | 79 |
| Diameter [cm] | 18 | 36 | 54 | 71 | 89 |
| Diameter [ft] | 0,59 | 1,17 | 1,76 | 2,34 | 2,93 |

Beam Angle 10,2°

## 11.13 Mosaic Designer - Light System

ETC®

# Unison® Mosaic® Ethernet Switch

### Unison Control Series

GENERAL INFORMATION

The Mosaic Ethernet Switch allows for multiple Mosaic Controllers or Accessories to be network together. The MSC-NET offers five unmanaged Ethernet ports, with four ports providing Power over Ethernet (PoE). The DIN-rail mounted switch is the perfect accessory for any Mosaic Show Control System

**APPLICATIONS**

- Mosaic systems that require network connections
- Systems that use PoE to power controllers or accessories

**FEATURES**

- Five-port, unmanaged Ethernet switch with four PoE ports
- RJ45 sockets for 10/100Base-TX Ethernet (802.3af compliant)
- Supports sACN, Art-Net, KiNet and other Ethernet protocols
- Low voltage 48VDC power input
- Installer friendly for permanent installation with rising clamp terminal connections and DIN-rail installation

**GENERAL**

- ETL/cETL LISTED
- CE Compliant
- California Title 20/24 compliant
- Five-year warranty

ORDERING INFORMATION

**Mosaic Ethernet Switch**

| MODEL | DESCRIPTION |
|---|---|
| MSC-NET | Mosaic 5-port Ethernet Switch with PoE |

**Related Mosaic Show Controllers**

| MODEL | DESCRIPTION |
|---|---|
| MTPC | Tessera® Panel Controller |
| MSC_[1] | Mosaic Show Controller |
| MSCX[2] | High-capacity Show Controller |
| MALC | Mosaic Atlas™ |

[1] Available with one(1), two(2) or four(4) DMX universe output(s)

[2] Available with 10 to 100 DMX universe output

**Related Mosaic Accessories**

| MODEL | DESCRIPTION |
|---|---|
| M108 | 1-gang, 8-Button Station |
| MRIO-A | Audio/Timecode Remote Device |
| MRIO-D | DALI Remote Device |
| MRIO-I/O[2] | Input/ Output Remote Device w/ Serial |
| MSC-OPTO | 4-port DMX/RDM Opto-Splitter |

ETC.

1 of 2

# ETC® Unison® Mosaic® Ethernet Switch

## Unison Control Series

### SPECIFICATIONS

**GENERAL**
- No configuration required
- Standard Ethernet connections using RJ45 sockets

**MECHANICAL**
- 6 unit wide DIN Enclosure complies with DIN43880 and EN60715 (35/7.5 rail)
- Rugged aluminum enclosure

**ELECTRICAL**
- Five RJ45 socket supporting 10/100Base-TX Ethernet with link and data LED with Static and DHCP addressing support
- Four ports provide Power over Ethernet (IEEE 802.3af)
- PoE device detection and classification (Class 0 to Class 4)
- Provides up to 30W total power for PoE Devices
- Auto detection for full or half duplex operation
- Auto speed detection per port (10/100Base-TX)
- Supports auto detection of cable type for uplink
- Individual indicators for port activity
- Independent isolation per port
- 48VDC power input
- ETL and cETL LISTED, CE compliant

**THERMAL**
- Ambient temperature: 0-50°C / 32-122°F
- 10-50% relative humidity, non-condensing

### PHYSICAL

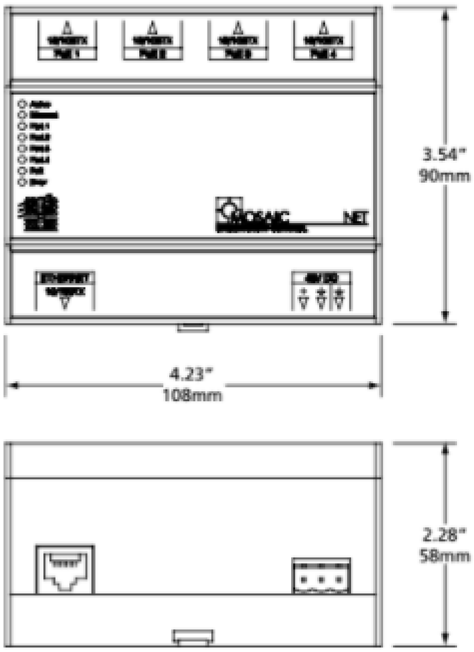
**Mosaic Network Switch Dimensions***

| MODEL | HEIGHT | | WIDTH | | DEPTH | |
|---|---|---|---|---|---|---|
| | inches | mm | inches | mm | inches | mm |
| MSC-NET | 3.54 | 90 | 4.23 | 108 | 2.28 | 58 |

**Mosaic Network Switch Weights***

| MODEL | WEIGHT | | SHIPPING WEIGHT | |
|---|---|---|---|---|
| | lbs | kgs | lbs | kgs |
| MSC-NET | 0.79 | 0.36 | 1.60 | 0.70 |

*Weights and dimensions typical




**Corporate Headquarters** • 3031 Pleasant View Rd, PO Box 620979, Middleton WI 53562 0979 USA • +1 608 831 4116
**London, UK** • Unit 26-28, Victoria Industrial Estate, Victoria Road, London W3 6UU, UK • +44 (0) 20 8896 1000
**Rome, IT** • Via Pieve Torina, 48, 00156 Rome, Italy • +39 (06) 32 111 683
**Holzkirchen, DE** • Ohmstrasse 3, 83607 Holzkirchen, Germany • +49 (80 24) 47 00-0
**Hong Kong** • Room 1801, 18/F, Tower 1 Phase 1, Enterprise Square, 9 Sheung Yuet Road, Kowloon Bay, Kowloon, Hong Kong • +852 2799 1220
**Web** • etcconnect.com • 

### 11.14 Interview with Tine Byskov (DONG ENERGY)

To get some general thoughts about the project, its potentials and pitfalls, as well as some general thoughts on the potentials of using simulations in projects like this, an interview with Lighting Consultant at DONG, and project member, Tine Byskov Søndergaard, was conducted.

How would you express the visual effect on the pump track?

- *" I am used to working with static lighting, so I think that the dynamism of the lighting is very engaging and triggers an interest in me. It is clear that there is some form of interaction between the lighting and the users - which to me is enough to spark an interest. I believe that this is the same for the general public - it is not that important whether it looks like water or not - my experience is that the general public often don't understand or recognizes the conceptual thoughts that lies behind a project anyway. However, I believe that the dynamism that the lighting provides the area with, is going to have an attracting effect on the general public"*

What impact do you think the interaction on the pump track will have on the general public?

- *"This is new, and I'm very excited to be a part of it. I think that when people realize that they can have an influence on the lighting by their mere presence, it is going to trigger a big interest in them. Though we don't know yet but will find out when the installation is constructed, I believe that the interaction will invite them to take a few more rounds, or even attract them to stick around.*

What do you see as the biggest potentials for this installation?

- *"As mentioned before, I believe the biggest potential for the installation is to attract user to, not only take a detour on their way or from Musicon, but to stick around and enjoy the space. Since the space itself will certainly attract the skating community of Musicon, the lighting can be the determining factor - as it can allow people to actually use the pump track, and the surrounding area. Adding this playful element of interactive lighting could even make the space attractive to people who don't normally find pleasure in riding pump tracks - ideally providing a space that is open to all kinds of users".*

What do you see as the potential pitfall of this installation?

- *"That the lighting will not attract people. Perhaps people will find it interesting the first time they try it/see it, but after a while they loose interest. I believe this is one of the biggest challenges of interactive lighting in public - people tend to lose interest over time. This is why it will be extremely important to use the installation as a Living Lab - to keep receiving feedback from the public in order to accommodate their needs. Another potential pitfall could be that the resident living nearby the installation will find it annoying and disturbing"*

How would you explain the benefits/disadvantages of simulating this installation in Unity?

- *"I believe it makes sense when being used for big and innovative projects. For small and regular lighting projects, I believe it doesn't make sense. This is because customers already* *have prior experience with similar projects, and thus have clear expectation as to what they want and what they will get. For innovative projects like this one, I believe it is different. Since customers don't have any prior experience of the kind of project of interest, a simulation can efficiently communicate the ideas to the customers - providing a frame of reference".*