

# PROVIDING SUPPORT FOR THE LADEGÅRDSÅEN DAYLIGHTING PROJECT

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NØRREBRO

## Abstract

This project provided Miljøpunkt Nørrebro, an environmental agency in Copenhagen, Denmark, with communication tools to gain long-lasting support for the Ladegårdsåen Daylighting Project, which seeks to reduce traffic and pollution and add green space to Nørrebro by daylighting the canal and constructing a traffic and stormwater management tunnel underneath. The team simultaneously compiled extensive research on similar projects and analyzed real-time pollution sensor data in order to form a benefits report and dynamic visual display. After gaining community feedback using a public survey and charrette, the team presented the sponsor with a benefits report and accompanying presentation along with a recommendation for the installation of a speedometer-style dynamic display in Nørrebro.

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## Executive Summary

Copenhagen is Denmark's capital and economic center, and is known throughout the world for its environmental initiatives. This project focused on Nørrebro, the most densely populated of Copenhagen's ten districts. In recent years, the city has experienced short, but heavy rainfalls called "cloudbursts", which have dropped over 160mm of precipitation in about 3 hours. The most recent one was on July 2, 2011, and it caused the city over 6 billion DKK in damage (Jensen, 2012). Over the last century, urban development has taken away natural land that would be able to absorb the rainwater and has replaced it with asphalt and concrete, which are detrimental to floodwater management. This urban expansion in Nørrebro has also caused an increase in traffic, which has led to higher air and noise pollution levels in the area. In order to solve the problems currently plaguing Nørrebro, Miljøpunkt Nørrebro, an environmental organization in Copenhagen, has proposed the Ladegårdsåen Daylighting Project, which will manage stormwater, reduce traffic and pollution, and increase green space in the neighborhood.

The daylighting project targets the Ladegårdsåen, which is an underground river located in Nørrebro. The process of daylighting involves taking a river which was previously underground and bringing it to the surface. Until the 1900s, the Ladegårdsåen was the center of the neighborhood and the residents used it for bathing, cooking, and recreational purposes. In 1897, the city of Copenhagen directed the river into a pipe and paved over it to make room for the city's rapidly expanding population, creating Ågade and Åboulevard (Ruddy, Hassan, Anglin, & Higgins, 2012). The route serves as the primary mode of through-traffic in Nørrebro, as 60,000 cars drive through these roads every day. Miljøpunkt Nørrebro is proposing the Ladegårdsåen Daylighting Project as the solution to the problems currently facing the district. The plan is to remove Ågade and Åboulevard, bring the Ladegårdsåen up to the surface and make it a canal, construct a traffic and stormwater management tunnel below the canal, and develop the surrounding land into a park (Ruddy et al., 2012). The proposed tunnel is modeled after the Stormwater Management and Road Tunnel (SMART) in Kuala Lumpur, Malaysia.

## Project Goals and Objectives

Miljøpunkt Nørrebro has had difficulty obtaining approval for the project due to concerns voiced by politicians about the costs and whether there is public support for the project. The team's goal, therefore, was to help Miljøpunkt secure long-term support for the project by making two items apparent: that the air pollution in the area is detrimental to a point where people need to take, and that the Ladegårdsåen Daylighting Project can solve the problems currently facing Nørrebro. This project accomplished this with

two deliverables: The Benefits of Daylighting the Ladegårdsåen report and presentation, and a Visual Display Recommendation.

## Background

Projects similar to the Ladegårdsåen Daylighting project include the Central Artery/Tunnel in Boston, Massachusetts and the Cheonggyecheon Daylighting project in Seoul, South Korea. The Central Artery was a system of four highways that joined and ended at Boston's Logan International Airport. To beautify the city and clean up traffic congestion, Boston began to deconstruct the Central Artery in 1994 and create a tunnel that would be easier to navigate than the complex network of highways from before. The project went several years longer and cost billions of dollars more than originally anticipated, plagued with setbacks throughout construction. However, after the project was finished in 2007, there was 15% less carbon monoxide, and traffic congestion during peak hours was reduced by up to 75% (Massachusetts, 2014). In 2007, Seoul, South Korea finished daylighting its historic river, the Cheonggyecheon. The river was originally the reason for placing the capital at Seoul, but the city converted it into a sewer during South Korea's post-war development in the 20<sup>th</sup> century. When the city removed the road and highway built on top of the sewer and exposed a cleaner, restored river, the municipality developed the area as a major attraction for tourists and residents alike (Lee & Anderson, 2013).

Traffic causes air and noise pollution, both of which cause health problems in high quantities over long periods of time, and causes approximately 4,000 deaths annually in Denmark alone (Glaser, Madruga, Gridwold, & Krag, 2013). Air pollution consists of carbon dioxide, nitrogen oxides, carbon monoxide, heavy metal pollution, and particulate matter among other airborne substances expelled from engines. This pollution can enter people's airways and lead to inflammation and exacerbation of pre-existing conditions such as asthma or COPD, among other respiratory and cardiovascular diseases (Brunekreef & Holgate, 2002). Noise pollution comes from the sounds of cars driving by and sometimes honking their horns. Noise pollution increases stress, leads to lack of sleep, and can even be detrimental to childhood development. Psychologically, noise pollution can aggravate pre-existing mental and emotional health problems. The psychological stress can have physiological manifestations, primarily increased blood pressure, increased cholesterol, blood glucose levels, and hearing loss, compounding with the consequences of air pollution (Bronzaft, 2002).

In order to determine the most appropriate method of making Nørrebro's pollution problem visible to the community, the team conducted research on visible displays. Visual displays are communication platforms that utilize symbols and colors to display information in a manner that a viewer can easily understand.

Dynamic visual displays are displays that update and present new material in real time. These displays offer additional benefits to those of a standard sign or picture. The ability to get a person's attention and to increase comprehension of the presented information is often the fundamental reason one would use real-time display. These dynamic displays are typically utilized in digital mediums such as electronic signs or phone applications due to the ability for constant connection to both the internet and the consequential incoming display information.

## Methodology

The ultimate goal of this project was provide to Miljøpunkt Nørrebro with methods for gaining public support for the Ladegårdsåen Daylighting Project. The project accomplished this with two objectives, which the team completed in parallel throughout the duration of the project. The first was to build a comprehensive research case supporting the Ladegård Daylighting project by providing concrete evidence of the benefits associated with the project. The group's second objective was to make the current state of pollution in Nørrebro visible by designing a dynamic display that will be accessible to the public through recommended communication platforms.

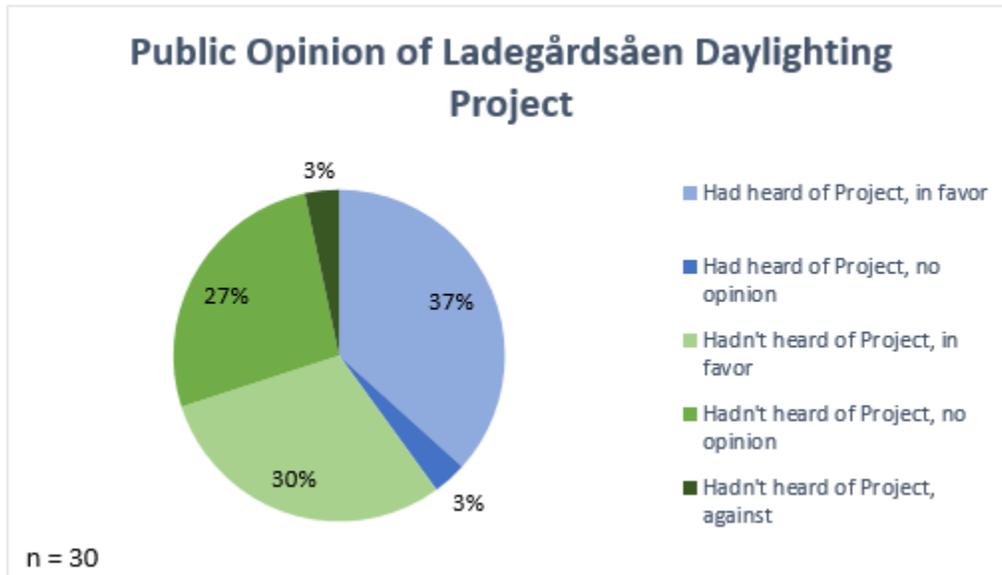
To build a case for the Ladegårdsåen Daylighting Project, the team conducted extensive research on projects similar to the proposed solution. There is no example of a project that contains all of the components of the Ladegårdsåen Daylighting Project, but there are projects related to parts of the proposed project. The team compiled several sources including books, reports, and peer-reviewed papers that connected to the various aspects of the daylighting project. In addition to researching, the team conducted the Nørrebro Pollution Awareness Survey to collect information on the public's knowledge of traffic pollution and their opinion on the daylighting project. The survey also asked participants about where they might want to see a visual display of pollution in Nørrebro. This question fed into the recommendation to Miljøpunkt Nørrebro for the design and location of the dynamic visual display.

To design a dynamic visual display that educates the public on the current state of pollution in Nørrebro, the team researched examples of apps, widgets, websites, and signs that display real-time information, and looked into the guidelines and standards on the design of pollution displays. The team decided to create a visual display that can be used with any communication platform, depending on the amount of funding that Miljøpunkt Nørrebro is able to obtain. In designing the visual display, the group had to evaluate the real-time data it would display, which is from pre-established pollution sensors around Nørrebro. The group was able to access the sensor data and gain an understanding of how to format it so that the public can easily understand it. In order to display the pollution levels, the team chose the

Common Air Quality Index (CAQI), which is the air quality measure used throughout Europe (CiteAir, 2012). After creating three visual pollution display options by researching pollution design standards and previous examples of real-time displays, the group then took the design options and held a Community Feedback Charrette to aid in selecting the final design. A charrette is used to quickly create design options while simultaneously providing input from the community. It creates a dialogue between the community and the designers, which allows for smaller design feedback loops, and a better reception of the proposed solution from the community (NCI, 2014). During the charrette, the team asked participants design they preferred the most and where they would like to see a dynamic sign with a visual display installed. After collecting this information from 40 people, the group chose the final design and communication tools and made a recommendation to Miljøpunkt Nørrebro.

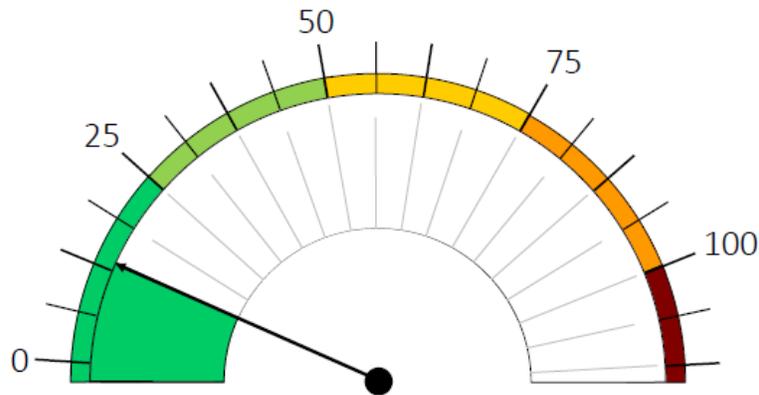
## Data and Analysis

In order to develop a research case for the Ladegårdsåen Daylighting Project, the team researched previous projects and assembled the information into a full-length report detailing the benefits of the project. The team used studies on building tunnels, daylighting rivers, removing roads, and developing parks, and the effects of all of these on the local environment. As pollution reduction is one of benefits of the daylighting project, the group conducted the Nørrebro Pollution Awareness Survey to assess the current public knowledge of the pollution levels in Nørrebro. The survey also asked people their opinion on the Ladegårdsåen Daylighting Project, so that the team could determine the existing level of support for the project. Figure 1 shows that 67% of the respondents were in favor of the project, and only 3% were against it. The team synthesized the research and the survey data in order to develop The Benefits of Daylighting the Ladegårdsåen Project report, and then condensed the report into a presentation for Miljøpunkt Nørrebro's use.



**FIGURE 1: SURVEY RESPONSES TO PUBLIC OPINION OF THE LADEGÅRDSÅEN DAYLIGHTING PROJECT**

The team developed three visual display options, taking into consideration the CAQI color regulations. Before selecting a final visual display or communication tool, the team conducted the Community Feedback Charrette. From the results of the charrette, the most popular design was the Speedometer Display, shown in Figure 2. The Speedometer Display is the most appropriate because the display is meant to address the issue of traffic pollution, and speedometers directly relate to vehicles. As pollution increases on the CAQI scale, the needle moves up, and the information section that corresponds to that range is highlighted. The user/viewer can read what that level of pollution signifies and why it is unhealthy. Charrette participants also informed the team that the ideal communication tool to utilize with the display is a dynamic sign, followed by an app.



Very Low	Low	Medium	High	Very High
0 to 25	25 to 50	50 to 75	75 to 100	> 100
Air quality is considered satisfactory, and air pollution poses little or no risk.	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive.	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.	Health warnings of emergency conditions. The entire population is more likely to be affected.

FIGURE 2: FINALIZED SPEEDOMETER DISPLAY

## Recommendations

The team provided Miljøpunkt Nørrebro with The Benefits of Daylighting the Ladegårdsåen report, The Benefits of Daylighting the Ladegårdsåen presentation, and the Visual Display Recommendations report. The group recommended that Miljøpunkt Nørrebro use the benefits report when seeking funding and support for the Ladegårdsåen Daylighting Project. Miljøpunkt Nørrebro should use the benefits presentation when educating community members and potential project sponsors. The team recommended using the Visual Display Recommendation to try to obtain funding to make a dynamic sign using the Speedometer Display. If they cannot get funding for a sign, they should try to create an app instead. With these recommendations, the team hopes that Miljøpunkt Nørrebro will be able to gain long-lasting support for the Ladegårdsåen Daylighting Project.

## 1.0 Introduction

Every year, more people in Europe die from traffic related pollution than they do from traffic accidents. There are approximately 200,000 traffic pollution deaths, compared to only 34,500 from traffic accidents (Eurostat, 2011; WHO, 2014). Traffic pollution consists of air and noise pollution, both of which can lead to severe health problems for those who experience them in their everyday lives. In urban areas, especially cities with a high level of commuters, there are increased levels of traffic pollution due to the large number of cars traveling through the area regularly. Congestion often plagues cities, leading to traffic jams, idling cars, and air pollution, which in turn leads to pollution related health effects. Green space can alleviate some of these problems by providing a healthy environment and noise barriers. Typically, cities have minimal amounts of green space due to the large amount of urban development. By reducing the levels of traffic pollution and adding more parks and recreational areas in cities, the overall physical and mental well-being of the inhabitants can be greatly improved ("Echo: Green Spaces Benefit Health in Urban Areas," 2003).

Nørrebro, one of 10 districts in Copenhagen, Denmark, faces the same traffic problems as any city, but to a larger degree than the rest of Copenhagen due to the high through-traffic in the district to get to the rest of the city. Originally located in the countryside, Nørrebro experienced a building boom in the 1800s when the city abandoned the demarcation lines, a set of lines blocking off green space and restricting urban development. The increased growth has continued to the present day, leading to a high population density in Nørrebro- almost 20,000 inhabitants per square kilometer, compared to only 6,400 people per square kilometer in the rest of Copenhagen (City, 2013). An average of 1,000 people move to Copenhagen every month, and Nørrebro is currently struggling to handle this severe population influx (Larsen, 2014a). At seven square meters of public green space per resident of Nørrebro, the district has significantly less green space than the rest of Copenhagen, which has about forty-two square meters per person. When paired with the large amount of traffic that travels through Nørrebro from the rest of Copenhagen, the hazardous pollution effects on the residents of the area are notably larger than elsewhere in the city ("Welcome to Copenhagen," 2014).

Miljøpunkt Nørrebro, the project sponsor, is looking to remedy the traffic situation by moving a road underground and bringing a river aboveground in a process called daylighting. Currently, the Ladegårdsåen canal runs underneath Ågade and Åboulevard, two roads that form the southern border of Nørrebro. The city paved over the river in 1897 to make room for the increasing urban development. The idea proposed by Miljøpunkt Nørrebro involves bringing the Ladegårdsåen back to the surface level, as

this would help manage storm water flooding and provide a recreational area for the local residents. In addition, Miljøpunkt Nørrebro hopes to lessen the effect of the through-traffic on Ågade and Åboulevard by moving the roads underground into a tunnel (Larsen, 2014b).

The people of Nørrebro deal with the negative effects of traffic pollution daily, but most have no grasp on the severity of the situation (Larsen, 2014b). In order to gather lasting support for the daylighting and tunneling projects, there must be evidence of the current pollution levels in the area and their adverse health effects as well as a strong argument that the proposed solution is the best one for the problem. Miljøpunkt Nørrebro has access to real-time air pollution data from two sensors in Nørrebro, but they need to know the best strategy for communicating this information to the public. Additionally, they need hard evidence that projects similar to the proposed daylighting project have had a positive, tangible impact on the residents of their surrounding areas, and they need to develop a method of communicating the severity of the current pollution problem to ensure the long-term support for this project.

The ultimate goal of this project was to help Miljøpunkt Nørrebro gain public support for the Ladegårdsåen Daylighting project by creating a communication platform that spreads awareness about the negative health effects of noise and air pollution caused by the unusually high automobile traffic in the area. By gathering evidence of the benefits of this project and creating a visual display that effectively communicates the pollution levels in the area, the project group provided tools to help garner long-lasting support for the Ladegårdsåen Daylighting project. The project provided Miljøpunkt Nørrebro with recommendations on the most appropriate methods of incorporating the pollution data into the visual display. The group also wrote a benefits report about the daylighting and tunneling projects in the form of both a paper report and a presentation for Miljøpunkt Nørrebro to use when presenting the project to gain support from potential sponsors and politicians.

## 2.0 Literature Review

The high number of cars that regularly pass through Nørrebro create higher amounts of noise and air pollution than anywhere else in Copenhagen (Larsen, 2014b). This chapter starts by providing a brief history of Nørrebro and its growing traffic problems. The amount of through traffic in Nørrebro and the relatively small amount of green space, as compared to rest of the city, exacerbate the health and wellness issues that the pollution from traffic creates. The solution proposed by Miljøpunkt Nørrebro, the project sponsor, involves taking a river the city of Copenhagen previously paved over and reopening it, a process called daylighting, while moving the existing road underground. This chapter explores other projects comparable to the proposed solution and the effect that they have had on the health and well-being of the surrounding population, as well as the potential challenges and difficulties that the project could face. In order for the project to continue to construction, local politicians, potential sponsors, and the residents of Nørrebro have to remain convinced of the benefits of the project. The background discusses the previous and current education efforts conducted by Miljøpunkt Nørrebro, possible future education efforts, and the current public opinion of the project. Finally, the chapter discusses different aspects of the design of visual displays, which will promote public awareness regarding current pollution levels.

### 2.1 Nørrebro

Nørrebro (see Figure 3) is one of ten districts in Copenhagen, Denmark. Nørrebro contains two administrative districts, Inner Nørrebro and Outer Nørrebro, and its residents are mostly young, working-class citizens. As of 2012, Nørrebro occupies an area of 3.82 square kilometers and has a population of approximately 75,000. It is the densest area of Copenhagen at 20,000 inhabitants per square kilometer, representing close to 14% of Copenhagen's total population of about 550,000 (Bunch-Nielsen, Benbella, Jessen, & Cornet, 2012).



FIGURE 3: MAP OF NØRREBRO ("FILE:NORREBRO MAP.PNG - WIKIMEDIA COMMONS," 2009)

### 2.1.1 Nørrebro Traffic Situation

The traffic problem in Nørrebro began after the city abandoned the demarcation lines, which prohibited building on designated green space. This led to a building boom, which in turn brought thousands of new residents to the area. To accommodate for the influx of people, green spaces and canals were paved to make room for the new traffic (Ruddy, Hassan, Anglin, & Higgins, 2012).

A 2009 study shows that at 13 vehicles per 100 inhabitants, Nørrebro has the lowest car ownership rate in Copenhagen. For reference, there is an average of 18 cars per 100 inhabitants in Copenhagen and 37 cars per 100 inhabitants in Denmark as a whole (Bunch-Nielsen et al., 2012). Nørrebrogade, the main road through Nørrebro, is a perfect example of the current traffic problem in Nørrebro. Despite the low car ownership in the area, the commuters who use Nørrebrogade to travel to the rest of Copenhagen have caused the road to suffer from both heavy car traffic and a lack of commercial development (Glaser, Madruga, Gridwold, & Krag, 2013). The Ladegårdsåen Daylighting Project focuses on Åboulevard and Ågade, two roads that run along the southern edge of Nørrebro. These roads face similar problems as

Nørrebrogade, most notably the high traffic pollution levels, heavy traffic, and low amount of overall development around the roads.

### 2.1.2 Miljøpunkt Nørrebro

The project sponsor, Miljøpunkt Nørrebro, formerly known as Agenda 21, is the Nørrebro chapter of the Agenda 21 Plan, an action plan created at the UN Conference on Environment and Development (UNCED) in 1992. Miljøpunkt Nørrebro used to be one of 17 Danish Agenda 21 Chapters (Ruddy et al., 2012). These Agenda 21 chapters later dissolved and eight chapters within Copenhagen became Miljøpunkts, or environmental points, in the city. The Miljøpunkts work on the same items that the Agenda 21 chapters did, but they are now located solely within Copenhagen. The municipal government in Copenhagen later decided to move some of the environmental work to inside the government, and only four Miljøpunkts remain today. They are Miljøpunkt Nørrebro, Miljøpunkt Amager, Miljøpunkt Østerbro, and Miljøpunkt Christianshavn. The decrease from eight to four Miljøpunkts caused a decrease in the funding that the four remaining offices receive, but they have persevered and all of them are still functioning today (Larsen, 2014a). The United Nations designed the Agenda 21 Plan to be open ended. Thus, Miljøpunkt Nørrebro has reasonable flexibility with the projects they undertake, as they have no set mandates. They create projects to work on as they identify a need. Miljøpunkt Nørrebro is run as an NGO and funding is provided from various sources, such as the city of Copenhagen, the Danish government, and the EU (Larsen, 2014b).

The organization focuses mainly on “big picture” issues, such as combating climate change and reducing greenhouse gas emissions in Nørrebro. Their primary goals include educating the people of Nørrebro on environmentally friendly practices and trying to improve their quality of life. Miljøpunkt Nørrebro aims to create “green solutions for blue problems”, meaning they attempt to solve water-related issues by incorporating green space into the daily life of Nørrebro residents (Larsen, 2014b).

Some of their current initiatives include traffic reduction and relocation, environmentally friendly waste disposal and recycling, and the addition of more green space. One of Miljøpunkt Nørrebro’s most well-known projects is the daylighting of the Ladegårdsåen canal, which is the focus of the group’s efforts while in Copenhagen (Ruddy et al., 2012).

## 2.2 Pollution from Traffic

Traffic is a normal occurrence in any heavily populated urban area, and it is one of the main reasons for the typically high levels of pollution, compared to less populated areas. Heavy automobile traffic results in two forms of pollution: air and noise pollution. Traffic air pollution is a result of the fuel emissions given off by the exhaust pipes in vehicles. Sounds such as car horns, emergency vehicle sirens, and construction

on the roads, generate noise pollution. These heavy levels of pollution can negatively affect the lives of those who experience it, as prolonged exposure to both air and noise pollution can be detrimental to both a person's physical and mental well-being. In Denmark alone, pollution from traffic, both air and noise, kills 4000 people a year, compared to 400 a year from traffic accidents (Glaser et al., 2013). Nørrebro experiences a particularly severe level of traffic-related pollution, and as such, the following sections examine the associated health effects.

### 2.2.1 Air Pollution and Health Effects

The examination of all forms of air pollution is necessary in order to fully understand the severity of the health problems associated with traffic pollution. There are four types of air pollution: gaseous pollutants, persistent organic pollutants, heavy metals, and particulate matter. The combustion of fossil fuels, in both stationary and mobile combustion sources, creates gaseous pollutants. They consist of chemicals such as SO<sub>2</sub>, NO<sub>2</sub>, ozone, and Volatile Organic Compounds (VOCs). The majority of this pollution type comes from combustion that occurs in transportation vehicles when exhaust emission gives off VOCs. Persistent organic pollutants are a group of toxic chemicals that include pesticides, dioxins, and furans. Created in any industrialized process including combustion; dioxins make up the largest part of these pollutants. People living in more industrialized areas tend to have higher levels of dioxins in their systems (Schechter, Birnbaum, Ryan, & Constable, 2006). Persistent organic pollutants tend to enter food sources, which magnifies their negative health effects every time they move up the food chain due to a process called bio-magnification. Heavy metal pollution includes elements such as lead, mercury, chromium, nickel, and other metals, which come from the earth's crust and are indestructible. They can enter the earth's water and food supply by traveling through the air; combustion reactions and manufacturing facilities can introduce additional metals to the atmosphere. Particulate matter pollution consists of all pollution particles that are suspended in the air that people breathe. These particles come from factories, automobiles, construction sites, and many other places. Many things make up particulate matter, including metal, organic compounds, reactive gases, ozone, and ions. It can also be a variety of sizes, ranging from 1 micrometer (µm) to 10 µm, and smaller particles tend to be more hazardous than larger ones (Kampa & Castanas, 2008; Katsouyanni, 2003). A vehicle's combustion system produces gaseous pollutants, heavy metal pollutants, particulate matter, and persistent organic pollutants, and then releases them through the exhaust pipe.

#### 2.2.1.1 Effect of Air Pollution on the Respiratory System

Exposure to air pollution can have a severe impact on the respiratory system. Noise and throat irritation are symptoms of exposure to gaseous and heavy metal pollutants. Particularly harmful pollutants include

nitrous oxides, ozone, sulfur dioxide, arsenic, and nickel. They can increase the risk for chronic bronchitis, asthma, emphysema, and lung cancer, as well as worsen pre-existing conditions such as lung lesions or lung diseases (Kampa & Castanas, 2008; Künzli & Tager, 2005).

#### 2.2.1.2 Effect of Air Pollution on the Cardiovascular System

The cardiovascular system is extremely susceptible to the negative effects of air pollution. Heavy metal pollution can increase blood pressure and tachycardia, which is a faster than normal heart rate. Particulate matter can affect blood clotting and lead to angina or myocardial infarctions (Kampa & Castanas, 2008). Higher levels of air pollution yields higher risks for arrhythmia, thrombosis, and strokes (Künzli & Tager, 2005).

#### 2.2.1.3 Effect of Air Pollution on the Urinary and Nervous Systems

Heavy metal pollution negatively affects both the nervous system and the urinary system. Exposure to these metals can result in neurotoxicity, which can result in memory loss, sleep disorders, tremors, fatigue, blurred vision, and slurred speech. Mercury, in particular, causes certain types of neurological cancer. Intake of heavy metals can also lead to kidney damage, and increase the risk of both kidney stones and renal cancer (Kampa & Castanas, 2008).

#### 2.2.1.4 The Overall Health Risks of Air Pollution

A study conducted in Austria, France, and Switzerland showed that air pollution causes 6% of the combined total deaths in these countries every year. Half of these fatalities were due to traffic-related air pollution (Künzli et al., 2000). Specifically within Denmark, air pollution from traffic kills 3400 people a year due to the resulting medical conditions associated with this pollution (Glaser et al., 2013). Exposure to air pollution results in more deaths than traffic accidents. For every 10  $\mu\text{m}/\text{m}^3$  increase in daily air pollution exposure, there is 0.5% elevation in the number of associated respiratory or cardiovascular-related deaths (Künzli & Tager, 2005). Living in areas with high levels of air pollution shortens a person's life expectancy by 1-2 years, which is relatively large compared to other environmental factors (Brunekreef & Holgate, 2002).

### 2.2.2 Noise Pollution and Health Effects

Noise pollution is any loud or disruptive sound made by airplanes, automobiles, trains, etc. that is annoying and/or detrimental to the health of the people who experience it ("Noise Pollution," n.d.). Theoretically, anything that can make a sound can contribute to noise pollution, including everyday occurrences such as a neighbor playing their stereo too loud or emergency sirens passing by a building (Bronzaft, 1996). Noise pollution tends to happen more in higher populated and urban areas, such as cities

and airports, due to the larger volume of automobiles, low-flying planes, and other key contributors to noise pollution. Poor urban planning can also contribute to higher noise pollution levels. In places where residential and industrial building are situated close to each other, increased levels of noise pollution can be experienced by the people living in the residential area ("Noise Pollution," 2012). Noise pollution can have a surprisingly detrimental effect on a person's health. In Denmark alone, it kills 600 people each year because of the consequential health effects that noise has on the human body (Glaser et al., 2013).

#### 2.2.2.1 The Effect of Noise Pollution on Sleep

Noise pollution can have a serious effect on a person's ability to get a good night's sleep, which can lead to adverse psychological and physiological health effects. Sleep is an essential part of resting after a long day, and without proper recuperation during sleep, one may be unable to refresh his or herself, which can be detrimental to both physical and mental health. Sleep loss from noise disturbance can result in poorer task-performance and make a person less attentive during the day, which can make one more accident prone, as they are less aware of potential danger around them. Studies have also shown that people who were exposed to high levels of noise pollution while sleeping tend to be unhappier the next day and more irritable overall. Nighttime noise disturbances can change people's sleep patterns, as well as increase their heart rate and blood pressure (S. Stansfeld & Matheson, 2003). People who live in noise polluted areas are more likely to use sleep aids such as tranquilizers regularly, which can lead to many other negative health effects as well (Bronzaft, 2002).

#### 2.2.2.2 The Psychological Effects of Noise Pollution

A typical human reaction to noise pollution is annoyance, and this increase in annoyance can lead to psychological effects, which can ultimately decrease a person's mental health. People exposed to higher amounts of noise pollution are more likely to get into aggressive disputes with their neighbors and react violently to stressful situations. In addition, people tend to ignore others around them when walking in a noisy urban area, even if they are asking for help (Bronzaft, 1996). Exposure to noise pollution can slow a person's memory rehearsal and affect their memory's selectivity, as well as decrease their ability to pick up on normal social cues (S. Stansfeld & Matheson, 2003). K. Hiramatsu and her associates conducted a study on the people who reside near the Kadena Air Base in Ryukyu, Japan, an area with a large amount of noise pollution from the heavy air traffic near the base. These researchers conducted a survey asking people about their perception of their mental well-being. Those who lived closer to the air base, and thus experienced higher levels of noise pollution, reported that they felt more mentally unstable, depressed, and nervous than those who lived further away, showing the negative correlation between noise pollution and mental health (Hiramatsu, Yamamoto, Taira, Ito, & Nakasone, 1997). There is also evidence that a

change in a person's environment that leads to higher levels of noise pollution can aggravate pre-existing mental and emotional health problems, leading to psychologist intervention for a problem that a potential patient would have normally been able to handle on their own (Bronzaft, 2002).

#### 2.2.2.3 The Physiological Effects of Noise Pollution

Researchers have most convincingly linked exposure to high levels of noise pollution to harmful effects on the cardiovascular system. This can be attributed to the stress that a person undergoes while experiencing high levels of noise pollution, as high stress levels have been proven detrimental to a person's health, most notably to the cardiovascular system (Bronzaft, 1996). Studies have definitively shown that people who regularly experience noise levels of 85 dB have significantly higher blood pressure than those who experience less noise.

High levels of noise exposure can lead to the need for treatment for hypertension and other heart problems. Although there have also been studies done that have shown relations between noise pollution and effects on cholesterol levels, total triglycerides, blood viscosity, platelet count and glucose levels, these relationships have not been conclusively proven (S. Stansfeld & Matheson, 2003). Each year in Denmark, 200-500 people die from cardiovascular problems that can be traced back to noise pollution from traffic (Glaser et al., 2013).

Noise pollution can affect other parts of the human body such as the gastrointestinal and circulatory systems, hearing, and any other weakened area of the body. People who chronically experience noise pollution are more likely to have hearing loss than those who do not. A study comparing a typical United States population and Maaban tribesmen proved that repeated exposure to moderate to high levels of noise can lead to an increase in hearing loss ("Noise Pollution," 2012). Exposure to high noise levels in industrial settings can raise levels of noradrenaline and adrenaline secretion. People who experience regular noise pollution have reported that they feel like they are in worse health than those who have very little noise pollution in their everyday lives. People have also reported that high noise levels render them unable to do normal activities such as having conversations, watching TV, and opening windows, as the noises around them were too disrupting to partake in these activities.

#### 2.2.2.4 The Effect of Noise Pollution on Children

Noise pollution affects children the most, because they are the most vulnerable demographic. Similar to noise-exposed adults, noise-exposed children are at the same risk for elevated stress levels, detrimental cardiovascular effects, and raised adrenaline and noradrenaline levels. A notable study examined the effects of noise pollution on primary school children within four 32-floor apartment buildings on a busy

road. The researchers assumed that children living on the lower floors would experience more noise disturbances from the road than those living on higher floors. They tested seventy-three children for reading comprehension and auditory discrimination and concluded that the children living on the floors closer to the road had significantly lower scores for these tests. Children exposed to chronic noise have a harder time concentrating than children who are more often in quieter settings. There is evidence suggesting that noise exposure negatively affects a child's cognitive functions such as central processing and language comprehension. Noise pollution also affects children's performance on standardized tests and their memory for high processing problems. Regular noise exposure decreases a child's motivation. Studies have found that children are more likely to give up on difficult puzzles if they have been exposed to high noise levels (S. Stansfeld & Matheson, 2003). Linear correlations exist between road and air traffic noise and children's annoyance levels, reading comprehension, and recognition memory (S. A. Stansfeld et al., 2005).

### 2.2.3 Other Approaches to Reducing Traffic Pollution

With new advances in technology, it is becoming more possible to take action against pollution. A tactic to combat noise and air pollution is by researching and designing inventions such as fuel-efficient engines, clean energy vehicles, and improved noise dampeners. Some countries have also implemented new protocols, such as only allowing a limited number of cars to travel on a street on a given day as a method to decrease pollution, and have suggested building clean energy trains to replace pre-existing modes of transportation (D Aquino, 1992; Mowad, 2007).

In the past, dangerously high levels of air pollution have led to enforcing drastic short-term solutions to the pollution problem. In 1992 in Italy, the pollution from traffic became so bad that cities put driving restrictions on their citizens. A few cities limited the number of people who could drive each day by only allowing cars with license plates ending in an odd number to drive one day, and cars with even number-ending license plates to drive the next day, essentially cutting the number of cars on the road in half. Florence took a more severe path, and banned automobiles for seven hours each day. This solution made people walk to their destinations and helped them rediscover the pleasures of walking through car-less streets (D Aquino, 1992).

Groups have also recommended maglev, or magnetic levitation, trains as replacements for more traditional, car-based methods of transportation (Mowad, 2007). Electromagnets on both the train cars and the sides of the railways control the maglev trains. They lift and move the trains at extremely high speeds (up to 310 mph) with lower emissions than cars and traditional trains. Without the necessity for

traditional fuel, maglev trains have the benefit of drastically reducing pollution in the areas in which they are used. China currently uses maglev trains; other countries, including the United States, are considering implementing them in order to alleviate traffic congestion and its associated air pollution.

People have suggested clean fuel vehicles as a method to reduce air pollution from vehicle emissions, but they have faced many challenges. Natural gas is a cleaner fuel than traditional gasoline and produces 90% less carbon monoxide, 85% less ozone, and emits zero particulates into the air. Clean fuel vehicles have not gained popularity due to the lack of fueling station infrastructures around the world. People do not want to buy a clean fuel car if they will not be able to refill it, and until there is no longer a refueling problem, clean fuel vehicles will not be a viable solution to air pollution reduction (Meotti, 1995).

While clean fuel vehicles are not currently a viable option, other alternatives to gasoline engines are gaining popularity. Every year, automobile manufacturers produce new vehicles that boast quieter, cleaner burning engines. Manufacturers such as Mercedes and Volkswagen have started producing clean diesel passenger cars. These cars are both more fuel efficient (which gives off less emissions) and quieter than normal gasoline-powered engines (Douthit & Rob, 2007). Additionally, many of the main automobile companies are now selling hybrid cars, which use gasoline but because they run on both gasoline and electricity, they produce less emissions than an average vehicle. Hybrid engines are also significantly quieter than a normal engine. Most gas stations sell both regular and diesel gasoline, which means that both diesel and hybrid cars are a feasible option as a way to reduce traffic pollution, since there are already infrastructures in place for both of them.

Another viable option for reducing traffic air pollution is using electric cars. As their name suggests, electric cars run purely on electricity, and therefore do not give off any emissions, making them a completely clean-energy vehicle. Most electric cars have a range of 60 to 100 kilometers, which is ideal for commuters. As their technology has improved and become more affordable, the number of people buying electric cars is steadily increasing. One limiting factor for electric cars is similar to that of clean-fuel vehicles, which is the lack of existing infrastructure for charging. With such a short traveling range, it can be difficult to plan a long trip due to the absence of charging stations. While electric cars are not ideal for long-distance travel, they are perfect for commuting and driving around cities, and their widespread use would greatly decrease the air pollution in cities (Meotti, 1995).

While companies are working on creating quieter engines, researchers are also exploring different types of noise barriers, as a method to dampen the sounds made by existing engines. Certain types of plants

can act as natural dampeners to noise. One study in particular examined the effects of plant barriers in Ankara, the capital of Turkey. By placing three rows of plants such as English Ivy (*Hedera helix*), Blackberry shrubs (*Rubus Fruticosus*), and Silver Lace Vine (*Polygonum aubertii*) in a “noise curtain” that absorbs the noise, the amount a noise is decreased by 5 dB, meaning that a person can hear half as much noise as they would be able to without the plants. The closer the bush or plant is placed to the noise source, the more effective it will be as more noise will be absorbed by the plants before it has a chance to deflect past the barriers (Ropuš, Ivana, Vesna, & Biserka, 2013).

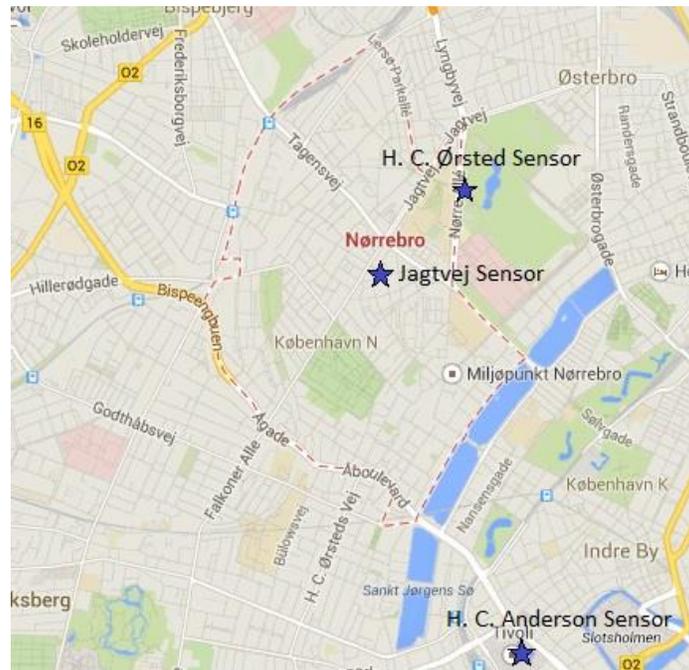
There is ongoing research happening on artificial noise reduction solutions, mainly on coatings. By damping a material with a water-based coating, there is substantial noise suppression in the material. Some of the newer research into acoustically dampening coatings involves nanotechnology. Multi-walled carbon nanotubes are excellent additions to coatings, due to their ability to drastically increase the surface area of the coatings, which can lead to a 700% improvement of noise dampening. There are a variety of noise dampening coatings that can be applied to different materials, dependent upon the material, the desired dampening effect, and the size and shape of the item to be dampened (Ropuš et al., 2013).

The city of Copenhagen has taken action to reduce traffic pollution. As previously mentioned, Nørrebrogade is a major road that runs through Nørrebro. It has undergone major redesigns in order to decrease the number of cars that travel on it each day and to increase the livability of the residents. Klaus Bondam, the former Traffic Mayor of Copenhagen, enacted a four-stage plan in order to accomplish this feat. Beginning in September of 2008, the city widened the cycle lanes on both the Queen Louise’s Bridge and a stretch of road from Fælledvej to Dosseringen and added more bus-only traffic lanes to the road. As of 2010, car traffic on Nørrebrogade has fallen by 60% (15000 to 6000) cars a day, and traffic in the entirety of Nørrebro has decreased by 10% as well. Due to the decrease in cars on the street, noise pollution has been reduced by 1.5 – 3.5 dB, as the only truly effective way of reducing noise pollution is to take the source of the noise – in this case cars – away (Glaser et al., 2013; Grimar, 2010).

#### 2.2.4 Air Pollution Sensors and Data Collection

Organizations can use local pollution data to educate the public about the risks of the pollution levels in their area. There are three sensors within Copenhagen that gather real-time data on Nørrebro’s air pollution. The University of Aarhus, in cooperation with the Danish Department of Environmental Science, maintains these sensors. Miljøpunkt Nørrebro has access to the database containing all of the data provided by these sensors. The sensing stations are located in different areas of the district (shown in

Figure 4) to give a representative view of pollution data when there is little traffic, moderate traffic, and high traffic (University, 2014).



**FIGURE 4: MAP OF NØRREBRO WITH POLLUTION SENSOR LOCATIONS (GOOGLE, 2014)**

The first low traffic control station is located on the campus of Hans Christian Ørsted Institute at the University of Copenhagen and measures  $\text{NO}_2$ ,  $\text{NO}_x$ ,  $\text{CO}$ , and  $\text{O}_3$ . The second pollution sensor is on Jagtvej, a road near the center of Nørrebro (see Figure 5). This sensing location experiences a moderate amount of traffic, and the sensor records  $\text{NO}_2$  and  $\text{NO}_x$ . The third and most important pollution sensor resides on Hans Christian Anderson Boulevard. H.C. Anderson Boulevard is the continuation of Åboulevard and Ågade, meaning the data gathered from this station deals with high traffic and is similar to the pollution data that can be measured at the potential daylighting site. This pollution station records the most thorough information, as it is able to measure  $\text{NO}_2$ ,  $\text{NO}_x$ ,  $\text{CO}$ ,  $\text{O}_3$ ,  $\text{SO}_2$ ,  $\text{PM}_{10}$ , and  $\text{PM}_{2.5}$  (University, 2014).



**FIGURE 5: POLLUTION SENSOR ON JAGTVEJ IN NØRREBRO**

The pollution sensors read out the average level of the pollutants in one-hour periods, resulting in the ability to stream the gathered data in near real time. The sensor records the density of the pollutants in the air, allowing for precise particulate measurements, but an average member of the community cannot easily understand the outputted data. Many places account for this difficulty by converting the pollutant densities into readings of pollution specific air quality measurements. People commonly use measurements of air quality because they transform pure pollution data into a unit-less number that corresponds with recognizable color and health risk groupings. By transforming a broad range of potential readings into five or six ranges with corresponding health, members of the community are able to understand the current pollution problem without needing an extensive scientific background (EPA, 2009).

#### 2.2.4.1 Common Air Quality Index

Places throughout Europe, use the Common Air Quality Index, or CAQI, as a means to display and analyze air quality in hourly, daily, and yearly indexes (see Table 1). The index uses pollution levels set by the European Union to provide a scale for different particulates, and also distinguishes between roadside and background pollution. Though the CAQI utilizes three different indexes, the hourly resolution is the most

prevalent in the display of everyday pollution due to the goal of displaying pollution in “real-time” (CiteAir, 2012). The annual and daily resolutions are a result of the analysis of long-term pollutant exposure. While there are limits for particulate densities on the short term basis, looking at the bigger picture is required when trying to assess the true health risk in a location (CiteAir, 2007). The Common Air Quality Index (CAQI) has a designated color for each of its five categories. These colors range from a pale green for very low levels to a deep red for very high levels, but there are no specific RGB or CMYK colors that are necessary to use (CiteAir, 2007). Table 1 details the standard colors for each CAQI classification. For each air quality measurements, the colors are indicative of the level of the air quality, alerting viewers to the severity of the situation.

**Common air quality index calculation grid**

Index Class	Grid	ROADSIDE INDEX						BACKGROUND INDEX							
		Mandatory pollutant				Auxiliary pollutant		Mandatory pollutant				Auxiliary pollutant			
		NO2	PM10		PM2.5		CO	NO2	PM10		O3	PM2.5		CO	SO2
			1 hour	24 hours	1 hour	24 hours			1 hour	24 hours		1 hour	24 hours		
Very High	>100	>400	>180	>100	>110	>60	>20000	>400	>180	>100	>240	>110	>60	>20000	>500
High	100	400	180	100	110	60	20000	400	180	100	240	110	60	20000	500
Medium	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
Low	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
Very Low	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

**TABLE 1: CAQI LEVELS AND CORRESPONDING COLORS (CITEAIR, 2007)**

#### 2.2.4.2 Air Quality Index

Another index used to convert particulate levels to an easily understandable scale is the Air Quality Index, or AQI. The US Environmental Protection Agency originally created the AQI (see Table 2), and the United States uses it as the main air quality measurement system. The main differences between AQI and CAQI are the scale and coloring scheme. The Air Quality Index (AQI) values have very specific corresponding color codes, as the EPA has set out specific RGB and CMYK color codes for each of six air quality categories (good, moderate, unhealthy, etc.) (EPA, 2009). Table 2 shows the associated colors for each AQI level, and Table 3 displays the appropriate RGB and CMYK codes for each color. AQI also has the added benefit of

standardized descriptions for the level of pollutants, the different colors are synonymous with at-risk-groups, meaning it is simple for people to understand (AirNow, 2013).

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
<i>When the AQI is in this range:</i>	<i>..air quality conditions are:</i>	<i>...as symbolized by this color:</i>
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

**TABLE 2: AQI LEVELS AND CORRESPONDING COLORS (AIRNOW, 2013)**

**What colors do I use in my AQI report?**

If you report the Air Quality Index in a color format, the appropriate colors are specified in Appendix G as the following:

For this category ...	... use this color
Good	Green
Moderate	Yellow
Unhealthy for Sensitive Groups	Orange
Unhealthy	Red
Very Unhealthy	Purple
Hazardous	Maroon

Specific colors are defined in the table below<sup>2</sup> for red, green, blue (RGB) and cyan, magenta, yellow, and black (CMYK) color formulas:

Color	R	G	B	C	M	Y	K
Green	0	228	0	40	0	100	0
Yellow	255	255	0	0	0	100	0
Orange	255	126	0	0	52	100	0
Red	255	0	0	0	100	100	0
Purple	153	0	76	10	100	40	30
Maroon	126	0	35	30	100	100	30

Notes: The RGB model is traditionally used for screen colors, while CMYK is traditionally used for printing processes. The color models are based on a 0 - 255 scale (e.g. 50% is 126).

**TABLE 3: AQI RGB AND CMYK COLOR FORMULAS (EPA, 2009)**

## 2.3 Major Urban Infrastructure Projects

The ongoing support for the Ladegårdsåen Daylighting project is dependent on evidence from similar cases that prove that the project will be beneficial. Section 2.3.3 fully explains the Ladegårdsåen project. While there are not many examples of construction projects that involve moving a highway underground, it is possible to build a case study using data collected from areas with traditional roads versus areas with tunnels. This includes the hazards of living near a major roadway that is above ground, the negative effects of the construction itself, and the positive effects of having an underground roadway with green space over it.

### 2.3.1 Highways and Tunnels

Eleven percent of US households live within 100 meters of a major 4-lane highway. In the United States, governments only monitor and regulate pollution at a regional level, and ignore the increased exposure to pollutants at the community level for those living nearby. After 1000m, the effects are relatively homogeneous, but within 100m of a highway, the amount of pollution exponentially increases as you get closer. The concentration of particulate pollution is five times higher in the first 30m within a highway than the next 30m. Beyond 100m, the concentration is lower but the particles are larger, so the effects are relatively the same (Brugge, Durant, & Rioux, 2007).

People consider tunnels safer for the local residents because the particulate pollution does not go directly into the air and affects those who live around them. However, there are still pitfalls to consider. Nørrebro has high levels of through traffic and its main roads are prone to traffic jams (Larsen, 2014b). Traffic jams can be very dangerous in a tunnel, where carbon monoxide can build up at a rapid rate. Simulations and measurements of a major tunnel in Melbourne, Australia showed that even with the fans working at maximum power, carbon dioxide and carbon monoxide built up at a dangerous rate (Bari & Naser, 2010). If something interrupted the power or the ventilation system unexpectedly stopped working during a traffic jam, there would need to be an evacuation. Despite this, in most situations, the level of pollution within a tunnel is manageable.

One of the benefits of building a tunnel is the control of noise pollution. The sound from traffic stays within the tunnel instead of disturbing the lives of local residents. However, if the workers do not build the tunnel properly, this effect happens only around the main body of the tunnel. A study found that the noise pollution does not simply disappear just because it is below ground. Instead, the sound reverberates within the tunnel until it leaves out either end. Essentially, the noise pollution is relocated and concentrated at the openings of the tunnel (Woehner, 1992). The only effective technique to reduce noise

pollution is by using sound-absorbing material. Workers must place the material inside the walls in the understructure of the tunnel in order for it to be effective. When placed on the walls themselves, it has almost no effect. The material is expensive, but it actually reduces noise pollution instead of simply redirecting the sounds (Herman, Seshadri, & Pinckney, 1999).

### 2.3.2 Central Artery/Tunnel Project

In the earlier part of the 20<sup>th</sup> century, urban centers in the U.S. were rapidly expanding with brand new infrastructure. Colossal projects began in New York City, Philadelphia, Los Angeles, Boston, and other major U.S. cities. One of these large projects was the elevated highway at the end of I-90 in Boston, which led to Logan International Airport. Residents instantly reviled it, because it was an eyesore and the pollution made the nearby residential area a terrible place to live due to the low property values. A proposal was made in the 70's to remove all the elevated highways going through downtown Boston, known as the Central Artery, and place them in an underground tunnel where expansion would no longer mean displacing hundreds or thousands of residents. People commonly refer to the CA/T Project as the Big Dig. The mastermind behind the project was Fred Salvucci, a graduate of the Massachusetts Institute of Technology, who was hired by the Massachusetts Department of Transportation as the transportation secretary (Gelinias, 2007).

The various statistics concerning the Big Dig, such as person-hours and material used, are far beyond that of any infrastructural renovations in recent decades. Because there were less space restrictions and no worries about expansion displacing homes and businesses, the architects planned for the tunnel to be between 8 and 10 lanes, in comparison to the original 6-lane highway. Altogether, it is 161 miles of single lane road with 14 on-off ramps, significantly sleeker than the original Central Artery. The research and fieldwork that went into planning the Big Dig is still currently the largest geotechnical study performed in North America (Massachusetts, 2014). When construction began, workers had to dig out 16 million cubic yards of dirt, some of which workers then used to cap landfills and create parks. This large cavity was to be replaced with 26,000 linear feet of steel-reinforced concrete slurry tunneling, the largest amount ever used for a single project, set 120 feet below the surface (Massachusetts, 2014).

While the long-term benefits of the project included decreased pollution in the surrounding neighborhoods, the construction itself caused a significant amount of pollution. Construction vehicles are not subject to the same environmental regulations as normal vehicles because of their heavy-duty use. Pollution from just 70 of the construction vehicles was equivalent to 1,300 diesel buses, the type of pollution that the Big Dig aimed to reduce (Allen, 1998). The constant construction also generated

excessive noise pollution, further disturbing residents in the area and lowering property values (Kim, Park, & Kweon, 2007). The city of Boston ended up placing filters on the construction vehicles to reduce the short term cost of pollution of the Big Dig and keep them in line with their long term benefits (Allen, 1998). People have already begun to notice the long-term benefits. Elevated highways created wasted space; not only did they not leave room for parks or recreational areas, but they destroyed homes, businesses, and urban development. The Big Dig opened up space for 300 new parks, filled with 2,400 new trees and 26,000 new shrubs (Massachusetts, 2014). Figure 6 displays the before and after pictures of the Big Dig. The expansive tunnels allowed traffic to move through at a smoother pace, decreasing congestion at peak hours by 42 to 74 percent. This reduction in traffic build up has led to a 12% reduction in carbon monoxide emissions (Massachusetts, 2014). Overall, the Big Dig has led to less pollution, less traffic, and more green space, very similar to the goals of Nørrebro.



**FIGURE 6: BEFORE AND AFTER VIEW OF THE CENTRAL ARTERY/TUNNEL PROJECT (VERNICK, 2009)**

### 2.3.3 Cheonggyecheon Daylighting Project

Daylighting is gaining popularity as a method to improve urban development. Seoul, South Korea is on the forefront of the movement, having daylighted the Cheonggyecheon River. Seoul is a prime example of rapid expansion and population boom leading to the shrinking of natural spaces and increase in pollution. After the Korean War, South Korea wanted to develop as quickly as possible to make an economic

recovery, and Seoul was the focus of this effort. Seoul's city proper has a population of 10 million, which is a fifth of South Korea's population, making it the most populous city in the world. Its metropolitan area contains 25.6 million citizens, half of South Korea's population, making it the second most populous area in the world behind Tokyo (Lee & Anderson, 2013).

In 2002, Seoul elected Lee Myungback as its first conservative mayor, hoping to see a change from the long line of liberal mayors. He ran on the platform of daylighting the Cheonggyecheon, a river that is central to Seoul's history. A king of the Choson dynasty moved Korea's capital to Seoul over 600 years ago because of the beauty of the Cheonggyecheon (A. C. Revkin, 2009). By the end of the Korean War, the river was a rank open sewer, leading to the city paving over it and constructing an elevated highway over it. In 2003, Seoul began to demolish the elevated highway and strip the asphalt to restore the Cheonggyecheon. When they finished in 2006, the result was a beautiful river and green space where tourists and residents come to enjoy the city (see Figure 7).



**FIGURE 7: BEFORE AND AFTER VIEW OF THE CHEONGGYECHEON DAYLIGHTING (NAPARSTEK, 2014)**

Within a few years after the daylighting's completion, the number of fish, bird, and insect species increased several times over. The small particulate air pollution in the area decreased from 74mcg per cubic meter to 48. Property values in the area went up and the river attracted 90,000 pedestrians daily (A. C. Revkin, 2009). The daylighting of the Cheonggyecheon in Seoul was a major success that decreased pollution, increased green space, and restored the beautiful, historical center of most populous city in the world.

### 2.3.4 Ladegårdsåen Daylighting Project

In 2012, a group of students from Worcester Polytechnic Institute proposed a design for daylighting the Ladegårdsåen canal by bringing it up above ground. The goal was to expose the waterways and help prevent flooding from storm water (Ruddy et al., 2012). The construction project has expanded to include a plan to remove the road paved over the canal and rebuild it in an underground tunnel.

In the earlier days of Copenhagen, the Ladegårdsåen River was an open stream running from Damhussøen through Nørrebro and emptying into the Lakes, five rectangular manmade bodies of water in Copenhagen. In 1897, the city of Copenhagen paved over the canal and encompassed it in pipes to make way for the rapidly expanding population. They also constructed buildings over the roads that were previously on either side of the canal. This area was formerly used for bathing, cooking, and recreational purposes (Ruddy et al., 2012). The push for more green space along with the need for flood prevention has led to the proposal of bringing the Ladegårdsåen above ground to bring back much needed green space in Nørrebro, falling in line with Miljøpunkt Nørrebro's slogan, "green solutions to blue problems."

Creating green space in Nørrebro would have multiple benefits, which include improving drainage, absorbing rainwater, absorbing pollutants through vegetation, attracting upscale businesses, and providing a recreational area for residents (Ruddy et al., 2012). The city of Copenhagen is pushing for green space, especially in Nørrebro, which has the lowest amount of green space per capita in the city. Miljøpunkt Nørrebro believes that daylighting the Ladegårdsåen is the perfect solution, providing the green space and managing the storm water flooding.



**FIGURE 8: MAP DISPLAYING THE LOCATION OF THE DAYLIGHTING PROJECT (GOOGLE, 2014)**

With the daylighting of the Ladegårdsåen, Miljøpunkt Nørrebro also hopes to find a solution for reducing car traffic around the area to further its effectiveness in reducing pollution while capturing rainwater. Currently, the most promising plan is to eliminate the above ground traffic completely by taking the road over the Ladegårdsåen and moving it underground. Essentially, this would mean that the Ladegårdsåen and the road paved over it (Å St. and Å Blvd) would switch places. Figure 8 shows the location of these two roads, which is the proposed location of the Daylighting Project (Ruddy et al., 2012) This plan is very similar to the Big Dig, in that it aims to tunnel a road that is above ground. The major difference is that it also involves redirecting a canal so that it is on the surface. Based on the successes of the Big Dig, this ambitious project could solve several issues and become a template for other countries to use if it avoids some of the pitfalls the Big Dig had (Larsen, 2014b).

## 2.4 Visual Displays

There are various types of communication platforms including digital displays, dynamic signs widgets, apps, and websites. Throughout the world, organizations have used these tools to communicate issues, including pollution, to the public. All of the communication tools in the following discussion have the ability to have real-time information incorporated into their designs, which makes them all viable options for visual displays that can display real-time pollution data.

## 2.4.1 Digital Displays

Visual displays that provide real time information are much more complex and expensive to design and build than a standard symbolic image. Since these displays are more costly to implement there must be a positive aspect that heavily outweighs the inevitable costs. The ability to gain a person's attention and have them understand the information is often an added benefit of real-time displays (Rose & Williams, 2004). The parties that use this type of display are seeking the ability to effectively catch people's attention and not ignore the presented information. A digital display containing pollution information could update in real time to let people know about the current pollution levels in the area.

### 2.4.1.1 Digital Display Case Study: Periyar Monitoring System

A digital display set up in Eloor, India (see Figure 9) in January of 2014 monitors the air and water quality of the local river and surrounding area. The large digital display compares the real time measured data to the limit in the area. Parameters include the SO<sub>2</sub>, NH<sub>3</sub>, and NO<sub>2</sub> levels. Several monitoring stations, along with eight surveillance cameras, measure the air quality as well as visually monitoring the changes in color of the water. The goal of the digital display is to identify the polluters in the area and make sure the city is upholding the pollution control laws. Though simple, the display's real time information provides a clear and understandable picture of the current pollution levels in the area (Jha, 2014).



FIGURE 9: PERIYAR MONITORING SYSTEM, INDIA (JHA, 2014)

### 2.4.1.2 Digital Display Case Study: Nørrebrogade Cyclist Counter

Another digital display is located close to the targeted daylighting area in Nørrebro. It is the cyclist counter on Nørrebrogade (see Figure 10). In the past the Danes have labeled Nørrebrogade as the heaviest cycled road in the world, with a supposed average of 36,000 cyclists using the road every day (AFP, 2010). Implemented in May 2009, the sign serves the purpose of showing how many people in the current day have ridden past the counter, and the total cumulative riders throughout the year. The new dynamic display created a media buzz around cycling in Copenhagen, which was utilized by the city to announce the goal of having 50% of commuters biking into work by 2015 (Copenhagen, 2010).



FIGURE 10: NØRREBROGADE CYCLIST COUNTER (GLASER, 2009)

### 2.4.2 Dynamic Signs

While a digital display contains basic real time information, a dynamic sign can contain more imagery to help further convey the message, such as comparative statistics or pictures. A dynamic sign could contain information about health effects, pollution levels in other areas, or simply a more visual and comprehensive representation of the data. A dynamic sign requires more resources than a digital display, as it contains more graphic details. Therefore, it takes more time and is more expensive to design and implement.

#### 2.4.2.1 Dynamic Sign Case Study: Roosevelt Field Mall

After the Roosevelt Field Mall implemented a dynamic sign (see Figure 11), researchers studied how viewers reacted to the sign. The researchers that studied the effect of dynamic signs in the mall questioned people about the impact the signs had on the shopping environment. The group took special

care in recording age and the frequency in which a person shopped at the mall, a “frequent shopper” was a person that had been to the mall more than ten times in the past three months. Nearly 90% of shoppers noticed the new digital displays, while approximately 80% had actually watched the displayed programming. Both of those statistics also improved while looking at the tendencies of frequent shoppers (Rose & Williams, 2004).



**FIGURE 11: DYNAMIC SIGN IN ROOSEVELT FIELD MALL (ROSE & WILLIAMS, 2004)**

### 2.4.3 Websites

Similar to dynamic signs, websites are good platforms for communicating extremely large amounts of information to the public. A website is not as visible a form of communication as a sign, but through the use of QR codes, social media, and links on other already-trafficked websites, it is possible bring in more visitors, as these methods assist in bringing attention to the page. With a website, you are able to display much more information than with other communication tools and can provide the users with links to other websites, which allows you to further educate the website’s visitors. Websites can easily display detailed information about pollution levels for a specified area, in the area in a visually pleasing manner alongside comparisons with the option to display an extensive history of pollution data. For this specific project, a website could display pollution information about Nørrebro for the people who live, work, and commute through the neighborhood.

### 2.4.3.1 Website Design Case Study: Aqicn.org

Aqicn.org is a website that shows real time pollution data for various cities around the globe (see Figure 12). Along with a map of the world with different sections color coded to correspond to their current pollution levels, the website gives extremely detailed information about different pollutants and their current levels, along with temperature, humidity, and wind data. The website makes it very clear, both through words and color coding, the pollution levels and their health effects, ranging from good to hazardous, based on the US EPA’s air quality index (aqicn.org, 2014).

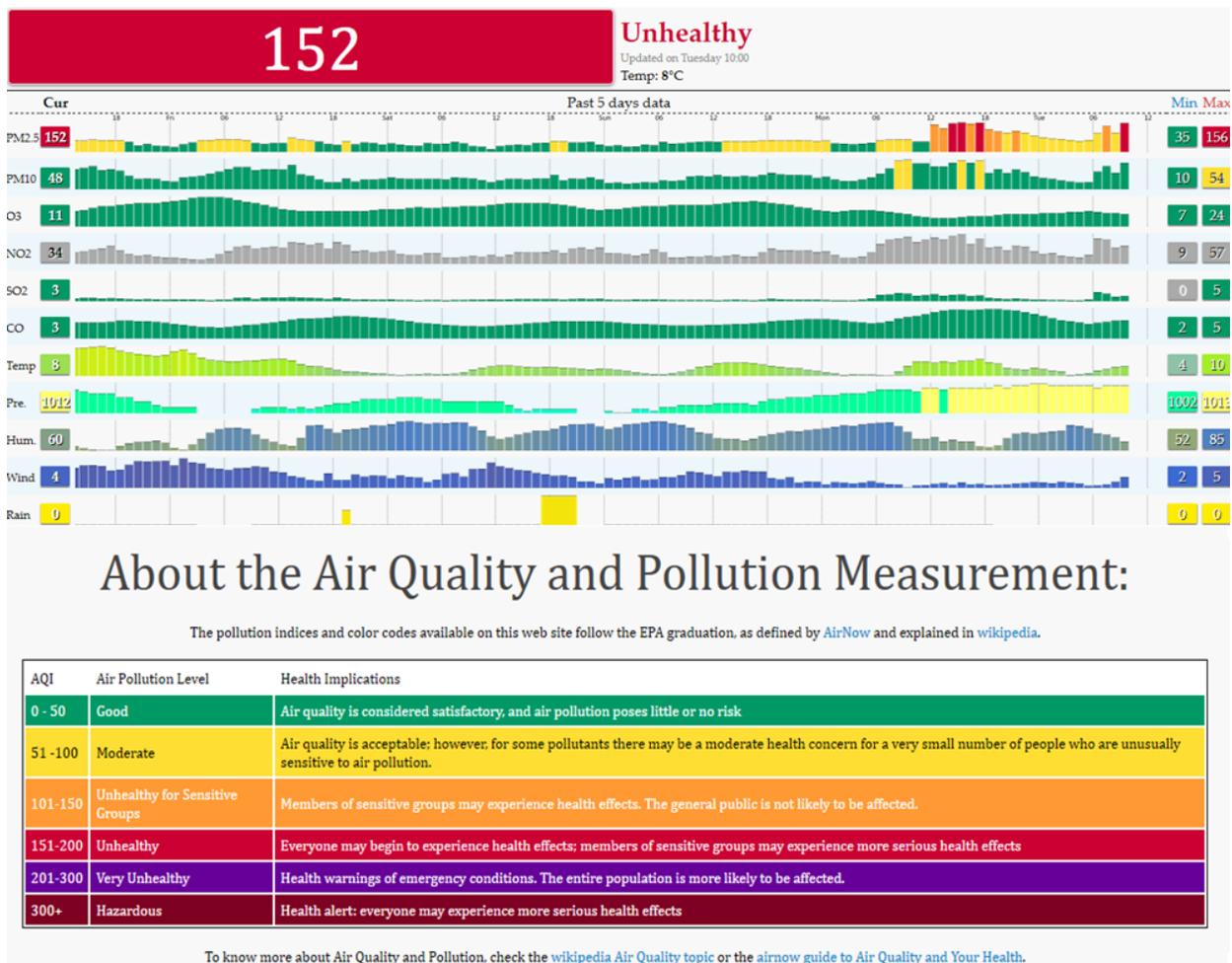


FIGURE 12: WEBSITE DISPLAYING POLLUTION DATA FOR H.C. ANDERSEN’S BOULEVARD, COPENHAGEN, DENMARK (AQICN.ORG, 2014)

### 2.4.4 Smartphone Apps and Widgets

While websites can provide the user with an extensive amount of detail, smartphone apps and widgets usually have less detailed information but are a great mechanism to reach a large number of people. Once someone installs the app or widget, the program can send real-time alerts to their phone or tablet. This

concept works with pollution, as an app can provide users with information about the pollution levels in their city. People can also install widgets on websites as a way to reach a broader audience. Typically, these widgets would be on the sidebar or at the bottom of a website. The ability to present your information to people who may not have even known that there was a problem is invaluable. By creating a visually pleasing widget or app that displays information in an easily understandable manner, one can reach the most important group of people those unaware of the full extent of the problem.

#### 2.4.4.1 Smartphone App Case Study: Hong Kong Environmental Protection Department

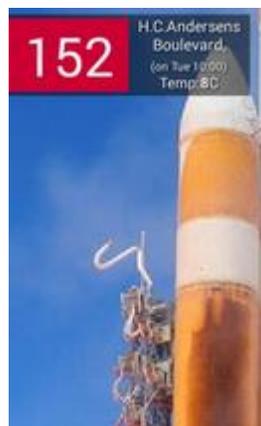
A smartphone app (see Figure 13) created as an initiative from the Hong Kong Environmental Protection Department provides those with the app with real-time information regarding the pollution levels in their area. The app contains ratings of the associated health risks so that those planning on outdoor activities can be aware of the potential risks they face. Along with the air quality health index (AQHI) level, the app displays the concentrations of various pollutants in the air. In the app pictured below the data is easily understood, but naturally the app is unable to display as much information as a website (Kang-chung, 2013).



FIGURE 13: APP DISPLAYING POLLUTION DATA FOR HONG KONG (KANG-CHUNG, 2013)

#### 2.4.4.2 Widget Case Study

In addition to a website, Aqicn.org also provides widgets for others to use on their personal devices and websites. There are five different sizes of widget and the user can choose the city for which they wish to receive the widget. The website provides easy instructions for widget installation on a personal device or website. Widgets are extremely useful in their ability to be seen as a passive feature on a phone or a website, but still able to display pertinent information. The widget from Aqicn.org (see Figure 14) does a good job at being subtle while being informative to the user, but fails to convey the bigger picture from the raw data. Although it displays the number corresponding with the pollution level and the appropriate color code for the corresponding risk level, the typical user has no understanding of the implications from the pollution levels.



**FIGURE 14: WIDGET DISPLAYING POLLUTION DATA FOR H.C. ANDERSEN'S BOULEVARD, COPENHAGEN, DENMARK (AQICN.ORG, 2014)**

## 2.5 Summary

The root of the problem that the project solves is that the pollution in Nørrebro is greater than it is elsewhere in Copenhagen. The pollution comes from the high levels of traffic that pass through Nørrebro on a daily basis. This noise and air pollution has a negative effect on the health of those who live in the general vicinity of a number of large roads that run through Nørrebro. Although things like sound barriers and various plants can diminish the effects of noise pollution, the only significant reduction in traffic air pollution would be through relocation of a road. There is currently an active effort to gain support for a project that would bring a previously covered river above ground, creating green space, and move the preexisting road underground into a tunnel, significantly reducing or eliminating air and noise pollution in the area. The project sponsor, Miljøpunkt Nørrebro, wants to secure long-term support for the project by making two items apparent: that the air pollution in the area is detrimental to a point where people need

to take action for the good of the public health, and that the Ladegårdsåen Daylighting Project is the best solution to the problem.

### 3.0 Methodology

The goal of this project was to help Miljøpunkt Nørrebro gain long-lasting public support for the Ladegårdsåen Daylighting project by both providing evidence of the benefits of similar projects and spreading awareness about the negative health effects of noise and air pollution caused by the unusually high automobile traffic in Nørrebro.

The team worked on this project from March 17, 2014 through May 6, 2014. The project resulted in two finished products: the research case study supporting the projected benefits of the Ladegårdsåen Daylighting project and multiple mock-ups of different types of visual representations of the pollution that work with various public communications platforms. The team compiled research that Miljøpunkt Nørrebro can use in the future to gain support for the project. The team presented Miljøpunkt Nørrebro with a visual display design that has the potential to incorporate real-time pollution data and be adapted for the communication platform that they ultimately build. Additionally, the group provided recommendations on the ideal communication tool for Miljøpunkt Nørrebro to utilize.

In order to execute the project, the group completed the objectives listed below. Appendix A contains the Gantt chart with the timeline that the team followed throughout the project.

- To build a comprehensive research case supporting the Ladegårdsåen Daylighting project by providing concrete evidence of the benefits associated with the project.
- To make the current state of pollution in Nørrebro visible by designing a dynamic display that will be accessible to the public through recommended communication platforms.

This chapter details the plan that the group used to complete both goals. Section 3.1 describes how the team selected the community feedback tools. The next section details the steps taken to build the research case. The chapter concludes with an explanation of the process used to create different visual representations of the information collected and the different ways to display it to the public. Figure 15 provides an overview of the chapter and the methods the team used to complete the project.

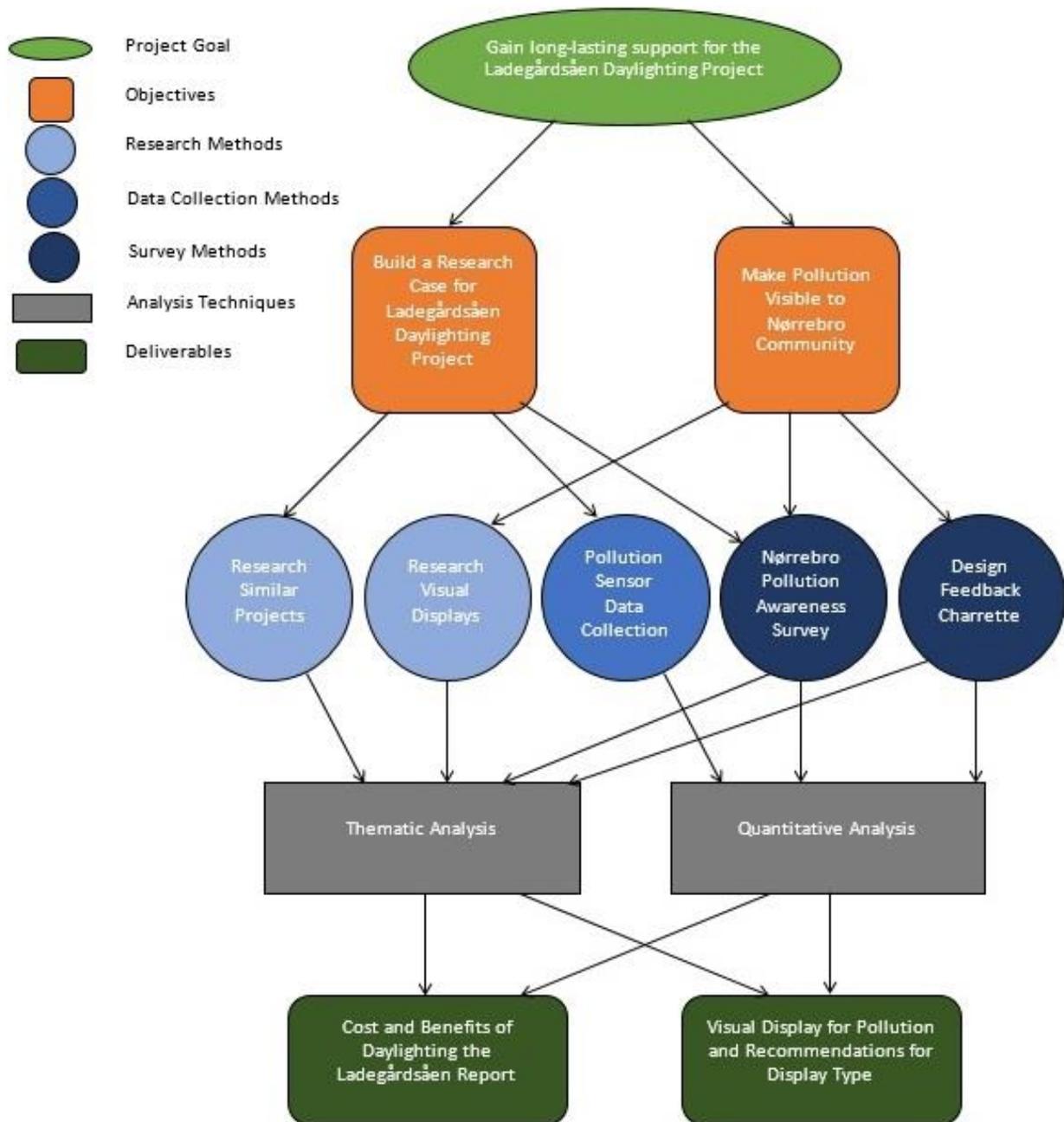


FIGURE 15: PROJECT METHODS OVERVIEW

### 3.1 Outreach and Education Efforts

In order to acquire support for the daylighting of the Ladegårdsåen, the group first needed to determine how to educate the public on the effect the project will have on the community. By dividing this education effort into two parts, the team was able to focus on two education areas, traffic pollution in Nørrebro and the benefits of daylighting. The goal was to show the people of Nørrebro the severity of the current

pollution problem to convince them of the necessity of change, since the construction of the project would reduce the pollution in the area. In addition to educating people on the pollution, the project team needed to determine how to inform them of the other positive effects that the project would have for Nørrebro. Informing the community of these issues is vital for gaining support for the Ladegårdsåen Daylighting Project, because without their support the municipality will not approve the project.

### 3.1.1 Determining the Current Public Opinion

Before the education efforts could begin, the team needed to determine the current public opinion of the Ladegårdsåen project. It was not possible to complete the research case or designing the visual display without first understanding what information the community was lacking. This knowledge influenced how the team determined the information to include in both deliverables, as it was necessary to make sure that detail level was adequate. For example, attempting to inform the public of the benefits of daylighting would have been ineffective without first explaining the basics of daylighting. Additionally, before completing the display designs, the group found it necessary to bring the rough drafts to the community to receive their feedback, since it was undesirable to create a display that the community did not like.

### 3.1.2 Selecting Methods to Obtain Community Feedback

In order to obtain the desired information, the group needed to select appropriate community feedback tools. As the information that the team wanted to obtain was personal feedback and knowledge from the community, the team compared interviews, surveys, focus groups, and charrettes because they are the most practical and relevant to the project's objectives.

Interviews are appropriate because the project needed a wide range of opinions to represent all groups in the community, such as residents of Nørrebro, those who commute through Nørrebro, and those who work in the area. They have the ability to receive more in-depth information from a smaller number of people. Although conducting interviews would have allowed the group to gather detailed information, they are too time consuming to provide a diverse representation of the community of Nørrebro. The team would have wanted to interview multiple people who live in, work in, and commute through Nørrebro, but the team determined that this was not time effective because it would not have been possible for the team to get the amount of feedback they desired in the limited time frame of the project. The team's sponsor at Miljøpunkt Nørrebro, Mr. Larsen, also cautioned that the response time from the people that the team would have approached would have been too slow to make interviews a feasible option. The team determined that interviews were not a viable feedback tool to use for this project because of both the anticipated response rate and the time that they would take to complete.

Surveys can theoretically provide a sample that statistically represents the whole population, making them an appropriate tool for the project. They are a method that enables one to gather a large quantity of data in a relatively short amount of time. The data gathered from a survey can model the community response to a proposal, which helps predict the way the community will respond to the different proposed communication tools, as well as their opinion on the proposed daylighting project. The communication aspect of surveys is very limited though, as there is minimal discussion and interaction between the investigators and the survey subjects, which can make it hard to gain any extra information outside of what the survey questions specifically ask. This is fine for collecting information about current public pollution knowledge, but it would make getting feedback of the visual display options difficult, as a survey typically does not allow for a conversation between the researcher and subjects. The team decided to use surveys to acquire pollution awareness information as it allowed them to get the responses from a larger amount of people than would have been possible otherwise.

Focus groups tend to contain similar types of people and aim to create an open discussion, which is what the project needs to receive the most productive feedback. Typically, a moderator facilitates an open-ended discussion about a topic for a focus group in order to ensure that the group does not stray too far from the topic (Krueger, 2002). Another person is usually the designated note taker to make sure that the researchers record all comments and suggestions. The team was originally going to hold focus groups to get feedback on the visual displays, but after arriving in Copenhagen and discussing this option with Mr. Larsen, the team learned that focus groups might not be practical. Asking people to participate in a focus group would likely not be received well, and it would be extremely challenging to get enough people to commit to participating for it to work well. Therefore, the project did not utilize focus groups as a community feedback tool.

A less well-known feedback tool is a charrette, which people usually use to quickly create design options while simultaneously providing input from the community. Typically, the designers hold a series of design sessions and meetings where they develop solutions to a problem and then have the public provide their recommendations immediately afterwards. A charrette opens up a dialogue between the community and the designers, which allows for smaller design feedback loops, and a better reception of the proposed solution from the community (NCI, 2014). The project team decided to hold a modified charrette in Nørrebro in order to obtain feedback on the visual display designs. The team developed a set of basic opinion questions to ask each participant, but then asked follow up questions to each person to get as

much detail out of each person as possible. This way it was still possible to obtain detailed feedback from numerous people that the team could easily incorporate into the revised designs.

## 3.2 Developing a Research Case for the Ladegårdsåen Daylighting Project

The key to approving any public works project is gaining the public's confidence. For the public to be confident in anything there needs to be comprehensive evidence of past attempts that have been successful. The only complete tunneling of existing roadways are the Big Dig in Boston, Massachusetts, USA and the M30 in Madrid, Spain. These types of projects involve multiple components, all of which the team studied in isolation and then compiled into the Benefits of Daylighting the Ladegårdsåen report.

### 3.2.1 Conducting the Nørrebro Pollution Awareness Survey

Before the team completed a research case in support of the Ladegårdsåen Daylighting project, the team first established what the public knows about the current situation in Nørrebro. To achieve this, the team conducted street surveys on Nørrebros Runddel, which locals consider the center of Nørrebro. This survey is the "Nørrebro Pollution Awareness Survey". The team chose this surveying technique for multiple reasons. By surveying people in person, it ensured that the participants fully understood each question in the survey and that the team answered any questions that the participants had about the survey. There is also a higher response rate associated with in-person surveys than with other methods, such as mailings or on-line surveys (Charnwood, n. d.).

In order to conduct a survey effectively, the team did the following (Charnwood, n. d.):

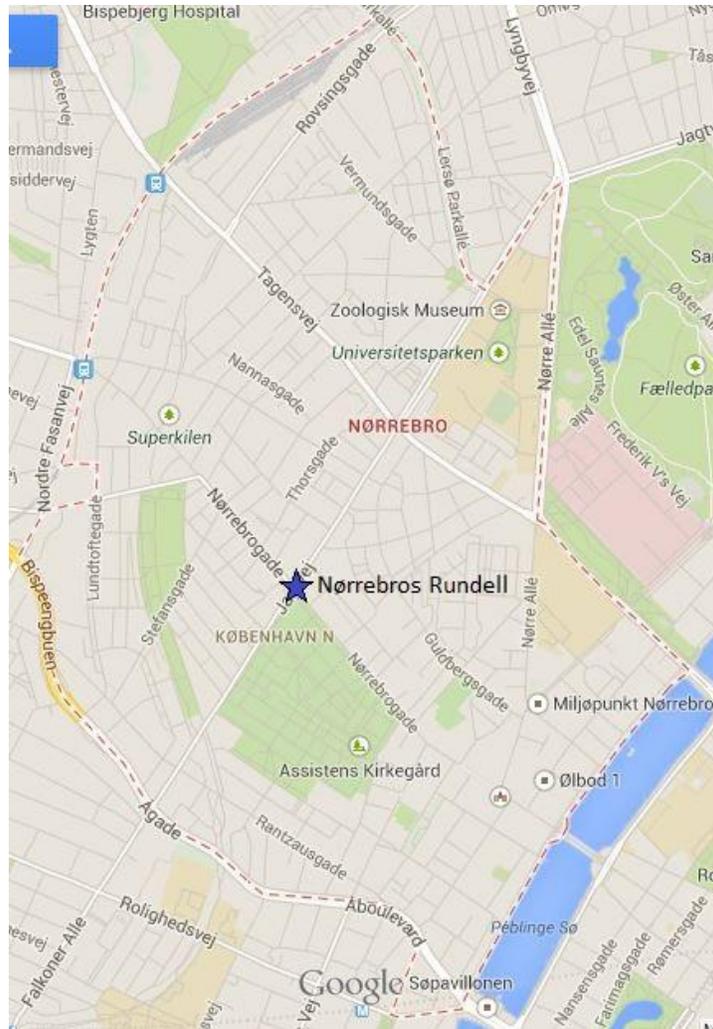
- Designed the survey
- Pre-tested the survey, and made necessary changes
- Selected what areas and times to conduct the survey
- Decided on how to approach people to take the survey
- Determined how many people needed to fill out the survey
- Analyzed the data gathered

In designing the Nørrebro Pollution Awareness Survey, the group developed questions that helped to gather information regarding the public knowledge of traffic pollution within Nørrebro and their opinion on the Ladegårdsåen Daylighting project. The goal for writing the survey was to survey people who either live in, work in, or commute through Nørrebro. Questions asked people to rate the level of both air and noise pollution in Nørrebro, and state which factors led them to believe this. The team asked about the participants' opinions on the Ladegårdsåen Project, removing cars from the streets, and potential

pollution sign locations. There were also basic demographic questions to help analyze the information obtained based on gender, age, and relation to Nørrebro.

After designing the initial survey, the team pre-tested it. Four people who work in the office below Miljøpunkt Nørrebro completed the survey and provided feedback on the questions. These people were not overly familiar with the Ladegårdsåen project; therefore, it was possible to see how someone less informed reacted to the survey. The pre-testers provided valuable feedback regarding improvements for the survey. Recommendations included both changes to the demographic questions and to the actual survey questions. Originally, in the demographic section of the survey, the only options under “Marital Status” were “Married” and “Not married”. A pre-tester suggested adding a “Cohabiting” option, as many Danes do not actually marry. Other people recommended providing more information about both the Ladegårdsåen Daylighting Project and the importance of a potential pollution sign in Nørrebro. Some of the questions in the survey had participants rate the current pollution levels in Nørrebro and then check off possible sources of this pollution. From the pre-testing, the group realized that there was no option for not being able to determine the level of pollution on the ranking scale. There was also no check box to say that there is no/low pollution in the neighborhood. After completing the pre-testing and compiling the suggestions from the participants, the group made the appropriate changes and then finalized the survey. The finalized Nørrebro Pollution Awareness Survey is in Appendix B.

After finalizing the survey, the team decided on the time and location to conduct the survey. The group picked the Nørrebros Runddel due to its central location within Nørrebro and the high foot traffic in the square. Figure 16 shows the location of the Nørrebros Runddel on a map of Nørrebro. The team surveyed people for three hours on Thursday, March 27, 2014. The surveying occurred from 10:00 – 11:00, then from 14:00 – 16:00. The team avoided going out during morning rush hour because the people at the Nørrebros Runddel would be too busy at that time. Late morning and afternoon rush hour had a better chance of finding people with free time to complete the survey. The team initially surveyed thirty people, at a rate of ten people per hour. After reviewing the demographic data, the results showed that the age and gender breakdown of the responses matched the statistics for the Nørrebro population. Since the goal of these surveys was to get a small sample of the views of the Nørrebro community, after a preliminary review of the responses, the team decided that thirty surveys were sufficient to achieve this goal.



**FIGURE 16: MAP OF NØRREBRO DISPLAYING SURVEY LOCATION, NØRREBROS RUNDDEL**

In order to be as productive as possible, the team decided that only two members would go out and survey. The team decided this because Mr. Larsen required that he be with the team during the survey in order to introduce them as members of Miljøpunkt Nørrebro and explain the survey to people in Danish, as no one on the team speaks the language. The team knew that the likelihood of having four people willing to take the survey at the same time was very low, so it was not practical to have all four members stand on the streets waiting for Mr. Larsen to convince people to take the survey. This led to keeping two people back in the office working on other parts of the project so that the team could make the best use of their time.

The team compiled and analyzed the information from the completed surveys. A team member inputted the survey data into an excel file so that the team could create tables and graphs to display the responses

to each question. The team used this information to identify common trends in the survey responses. This determined both the public knowledge of traffic pollution and their opinion on the Ladegårdsåen project. Additionally, the survey asked participants if a pollution sign were to be put in Nørrebro, where in Nørrebro would they suggest installing it. The team plotted these on a map of Nørrebro to identify the common trends in these responses and to visualize the suggested locations. The team analyzed the survey data to determine the gaps in public pollution knowledge and the levels of pre-existing support for the project, so that they could be adequately addressed in the Benefits for the Ladegårdsåen Report.

### 3.2.2 Research for the Benefits Report

The daylighting of the Ladegårdsåen involves redirecting the currently underground canal to the surface while taking the major roadway paved over it and moving it to a tunnel below ground. The surface above the tunnel will then be reserved for green space and the canal. The research must include the following individual aspects to be able to compile a comprehensive case study:

- Major above ground roadways and the associated pollution
- Underground roadways and the associated pollution
- Green space above tunnels
- Pollution from previous construction projects
- Daylighting a river

The goal was to create a report that effectively showed the benefits of tunneling the Ågade and Åboulevard. The primary source type for this research was journal articles and scholarly papers that are case studies of pollution health effects and the pollution levels around projects similar to the daylighting of the Ladegårdsåen. Several scholarly papers each show negative consequences of air and noise pollution at multiple levels. The compiled papers contain research on many of the complications caused by pollution. There is also research showing the positive effects associated with green space. The team conducted this research in order to set up a background for the case studies used in the Benefits of Daylighting the Ladegårdsåen report.

The case studies examine roadway projects around the world and their effect on the air and noise pollution in the surrounding areas. Study locations included India, Lithuania, and the United Kingdom, as all these locations have varying levels of traffic and industry. This was to show that regardless of where or under what circumstances a roadway was built, there was always a detrimental environmental impact resulting from the project. The research needs to show that elevated highways and roads on the surface

are harmful to the environment, while the removal of roads is positive and that tunnels are a better alternative to roads on the surface. Large-scale projects such as the SMART Tunnel in Kuala Lumpur, Malaysia and the Cheonggyecheon Daylighting in Seoul, South Korea are examples of projects that provide an alternative to elevated highways and surface roads. The team conducted this research in order to show that cities have completed projects similar in scope to the Ladegårdsåen Daylighting with overwhelmingly positive results, despite the financial costs.

After completing the comprehensive research analysis, the team assembled the data to detail every aspect of the Ladegårdsåen Daylighting Project. This research led to the completed and Benefits for the Ladegårdsåen Report, which contains the pollution data and the analysis of the research. The pollution data includes both the real-time air pollution data as well as static noise maps of the Nørrebro area. The completed report applies a local context to the supporting evidence in order to qualitatively estimate the impact of the Ladegårdsåen Daylighting Project on the Nørrebro community.

### 3.2.3 Compiling the Benefits Report

One of the project deliverables is the report titled “Benefits of Daylighting the Ladegårdsåen,” which provides Miljøpunkt Nørrebro with research and statistics to show project stakeholders the effectiveness of prior efforts around the world, and is in Appendix D.

The Benefits Report is a thematic synthesis of the compiled research. It begins by introducing the report itself, the reasons it is necessary, and the justification behind using the method of compiling the research from papers and case studies to strengthen the report’s arguments. The report then details the history and design details of Daylighting the Ladegårdsåen in order to provide a background and focused purpose to the report. After introducing the purpose of the report and proposed project, it delves into a comprehensive background that focuses on the negative effects of air and noise pollution, and the benefits of green space. As previously stated, the point of this research is to describe the hazards of pollution, so that the reader fully understands the destructiveness of increasing pollution levels in the presence of traffic and roadways when it is detailed in the case studies later on in the report.

After providing the reader with detailed background research, the report transitions into describing case studies that deliver supporting evidence for the Ladegårdsåen project. The case studies cover topics including the exponential increase of pollution levels that occur when moving towards a major roadway, to environmental effects associated with the addition of another highway in India in an attempt to decrease traffic congestion. These studies show the impact of roads in regards to pollution, the surrounding communities, and the physical land. The report also includes research on tunnels and their

various logistics, such as a simulation of a tunnel in Melbourne showing the management of the air inside and guidelines on tunnel pollution.

The Benefits Report then shifts into a discussion of large-scale infrastructural renovations. The report categorizes these projects into three sections: tunneling, storm water management, and daylighting. The report explains the Central Artery/Tunneling project (the Big Dig) in Boston, Massachusetts first, as it is was the first of his kind and is still the most ambitious infrastructure renovation in North America. The Madrid M30, located in Madrid, Spain, is the other tunneling project examined in the Benefits report, which was constructed after the Big Dig. In regards to the storm water management section, the team chose to focus on the SMART Tunnel in Kuala Lumpur, Malaysia, as it was a major inspiration for many of the design aspects of the proposed Ladegårdsåen tunnel. The team chose to highlight the daylighting of the Cheonggyecheon in Seoul, South Korea as the major daylighting project. This project was a success because it focused on the aesthetic purposes of removing elevated highways and daylighting, as opposed to reasons such as reducing congestion and flood prevention. The large-scale infrastructure project section concludes by addressing the concerns about construction pollution. Construction causes a non-trivial amount of pollution, though research shows that this pollution is easy to manage if the project takes the proper precautions.

The beginning of the final section of the Benefits of Daylighting the Ladegårdsåen report compiles all of the research in the report and provides a summary. There are a few paragraphs on traffic pollution, green space, the Big Dig, etc. The team chose to include this to ensure that the reader does not forget the most pertinent information from each section of the report. The research in the rest of the report alludes to some key findings, but does not make any concrete arguments. Each of these paragraphs makes these arguments, reinforces the point of view supported by research. The following subsection of the report focuses on highlighting the data and analysis compiled from the Nørrebro Pollution Awareness Survey and briefly mentions the data from the pollution sensors in Nørrebro. The report uses the survey data to provide evidence that the Nørrebro community supports the Ladegårdsåen Daylighting Project. The reports final subsection summarizes the report and uses the survey data to put it into the context of Nørrebro in order to reinforce the point that the Ladegårdsåen Daylighting Project will be beneficial to Copenhagen.

### 3.2.4 Preparing a Presentation

A report can be an effective tool to present thorough evidence, but at 39 pages, it can be a lengthy read. Politicians and potential sponsors may want a quicker and more convenient media to receive the same

information. In this situation, Miljøpunkt Nørrebro would need a way to convey the important points of the benefits report in a more concise form for a 10-20 minute speech. The group has taken key aspects of the report and compiled it into a PowerPoint accompanied by an outline.

The story of the daylighting project is the most important part. Politicians and potential sponsors need to understand why Miljøpunkt Nørrebro is advocating for this after having experienced destructive flooding. Like the benefits report, the presentation outlines the main details of the tunnel and river channel's design, but does not overwhelm the audience with logistics.

The second half of the presentation goes through the background research and case studies. The important difference between the presentation and report is that the report details the conclusions of each paper individually, while the presentation gives general overall conclusions of the research as a whole. The audience does not need to sit through the details of the bypass project in India, or how traffic and pollution data was compiled in Lithuania; just the essence of how bad pollution is and how traffic creates it are sufficient. After the general research, the presentation gives brief overviews of the Central Artery/Tunnel Project, SMART Tunnel, and the Cheonggyecheon, and most importantly, lessons learned from each of these projects. It is not crucial for the audience to know the history behind each project because the focus of the presentation is the daylighting project. The audience needs to hear how all of this is pertinent to the project, and why this project will succeed, where others have succeeded, and why it will avoid the failures of each of these projects.

This leads into the finale of the presentation, which connects everything back to the Ladegårdsåen project. It quickly reiterates all the research, puts it in local context using the sensor and survey data collected, and addresses possible concerns such as disruptions from construction and financial costs. The presentation mentions the Visual Display, to ensure the audience that informing the public about the project and the need to eliminate pollution is a primary concern. The presentation concludes with rhetoric about Nørrebro and the effect the Ladegårdsåen project will have on the neighborhood, urging the support of politicians and potential sponsors.

### 3.3 Creating a Communication Tool

In order to educate the community of Nørrebro about the current state of pollution, the team designed multiple options for a basic visual display with the ability to utilize the real-time pollution data from the existing pollution sensors in Copenhagen. The team chose to develop a visual display at the sponsors request and the recommendations of the 2012 Ladegårdsåen Daylighting IQP in which the team suggests

that a visual display be created in order to educate the people of Nørrebro about pollution levels. The display can be modified for a variety of communication platforms, and Miljøpunkt Nørrebro will develop the appropriate tool based on both the group's recommendations and the amount of funding they receive for the project. The group made two recommendations for Miljøpunkt Nørrebro; the first is for the visual display and is based on the mock ups of basic designs that the team developed, which are shown in Chapter 4, and the second is for the type of communication platform that should be used, whether it is a website, a widget, or a dynamic sign. The team made recommendations based on the benefits and challenges of each type of platform along with the community feedback surveys. The group did not consider price and feasibility, as they were outside of the scope of the project.

### 3.3.1 Communication of Pollution Information

The background chapter discussed the higher levels of pollution in Nørrebro and the associated negative health effects. The project sponsor also informed the team that the residents of Nørrebro are generally apathetic towards the pollution problems. The team decided to create a type of visual display that relays information about the health effects associated with the real time Common Air Quality Index number that will be displayed to the people who live in Nørrebro and makes them more aware of the health problems related to pollution levels in the area.

Aarhus University has established three pollution sensors in Nørrebro, and Miljøpunkt Nørrebro has access to all of this data, as previously discussed in section 2.2.4. Of the three sensors, the team chose to use the sensor on H.C. Anderson Boulevard, because the road is an extension of Ågade and Åboulevard, the data gathered here is the most similar to that for the area of concern. The team designed the display with the idea of being able to use real time information in mind, but the raw data had to be reformatted before it could be considered appropriate to display. The processes and methods that the team used to account for outliers and calculate the CAQI are discussed in the Data and Analysis chapter.

#### 3.3.1.1 Choice of Air Quality Measure

Part of the group's tasks included developing a strategy to make the information understandable and quantifiable for people who do not ordinarily deal with pollution data. The project explored several options for quantifying the data, including comparing it to pollution data from other areas in the world and comparing the pollution levels to the potential health effects at that level. The group decided to use the Common Air Quality Index value, the standard measure of air quality in Europe. Because the main focus of this deliverable is making the Nørrebro public more aware of the health concerns related to the pollution levels in the area, the group wanted to make sure that the general public could understand what

each CAQI value meant. Though the CAQI scale does not have specific pre-assigned health effects for each level, the Air Quality Index (AQI) does. The Air Quality Index is the standard of air quality used in the United States. The team compared the CAQI values to the AQI values and chose the corresponding AQI descriptor for each CAQI value. Table 4 displays the AQI values and descriptors, alongside the descriptors that the group assigned for each CAQI value, and the respective health concern description for each level that the team used then writing the descriptions for the levels on the visual displays.

AQI LEVEL	CAQI LEVEL	DESCRIPTION OF LEVEL
0 – 25: Low	0 – 25: Very Low	<ul style="list-style-type: none"> <li>• Air quality is considered satisfactory, and air pollution poses little or no risk.</li> <li>• No health impacts are expected when air quality is in this range.</li> </ul>
25 – 50: Moderate	25 – 50: Low	<ul style="list-style-type: none"> <li>• Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.</li> <li>• Unusually sensitive people should consider limiting prolonged outdoor exertion.</li> <li>• Unusually sensitive people should consider reducing prolonged or heavy exertion.</li> </ul>
50 – 75: Unhealthy for Sensitive Groups	50 – 75: Medium	<ul style="list-style-type: none"> <li>• Members of sensitive groups may experience health effects. The general public is not likely to be affected.</li> <li>• Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.</li> <li>• People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion.</li> </ul>
75 – 100: Unhealthy	75 – 100: High	<ul style="list-style-type: none"> <li>• Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.</li> <li>• Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children should limit prolonged outdoor exertion.</li> <li>• People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion.</li> </ul>
100+: Very Unhealthy	100+: Very High	<ul style="list-style-type: none"> <li>• Health warnings of emergency conditions. The entire population is more likely to be affected.</li> <li>• Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.</li> <li>• People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.</li> </ul>

**TABLE 4: AQI AND CAQI LEVELS AND DESCRIPTIONS (EPA, 2009)**

### 3.3.2 Design of Visual Sign Mock Ups

The team spent weeks two and three of the project creating several mockups of different types of visual data representations. In order to have the most effective final project, the group wanted to have multiple options from which to choose. There are many different ways to display the information that Miljøpunkt Nørrebro wishes to present to the public, and the team hoped having several options to evaluate would result in a better end product.

The chosen designs are all modifications of basic graphs. The pie chart and bar chart were chosen because they are modifications of what can be called two of the most basic graphs. The speedometer design was inspired by the constant focus the group has had on cars and their associated pollution. In order to make sure the designs are visually appealing, the group kept them as minimalistic as possible, only showing the basic information needed to get the point across.

### 3.3.3 Community Feedback Charrette

Once the group finished designing the mockups for different visual representations of the data, the team needed feedback from the community. The group wanted to determine which design was the most effective at relaying the information, which is the most understandable by the widest variety of people, and which one was preferred by the most people. The group decided to hold a street charrette in order to gain feedback from the general public regarding the different design options. Because the Community Feedback Charrette contains a question regarding potential sign placement, the team decided to conduct the charrette in two different locations to account for the location bias presented with the first survey. Along with the location used for the Nørrebro Pollution Awareness Survey, the Nørrebros Runddel, the team also surveyed at the Dronning Louises Bridge, as its proximity to the target road and large amount of foot traffic allowed for a large number of well-informed responses.

The method used, which was a charrette, is typically a type of street event in which a table is set up and passersby are asked for feedback on a set of designs. Though the project did not use a table due to size constraints, the team still gathered feedback in a more conversational manner as opposed to a traditional survey. The beginning of this chapter discussed the details of the general surveying process, therefore this section only covers the differences in surveying methods from the first round of surveying that the team did.

For this round of feedback, the group members wanted to start conversations as opposed to simply handing out papers. Though the team members had a basic ranking sheet for each design (visual appeal, ease of understanding, etc.), the majority of the targeted feedback concerned each person's opinion on the designs, which was better communicated in a conversation. Though open ended, the conversations the team kept the conversations within the same basic guidelines, shown in the charrette questions in Appendix C, so that each member of the team received feedback that could be compared to each other's data. The surveys were not handed out; instead, the team asked the questions while showing the designs to each person so that they could make comments on each design, which a team member then recorded.

### 3.3.4 Analyzing Communication Tools

The four communication tools that the group assessed included a website, smartphone app, widget, and dynamic sign. Chapter 2 discusses each of these communication tools in more detail. In order to provide Miljøpunkt Nørrebro with a recommendation of which tool to implement, the team researched each tool and evaluated their attributes. They also included a question in the Community Feedback Charrette about which communication tool the respondent preferred. The team only considered public opinion of each design in their recommendation; price and feasibility were looked at as background information, but did not hold weight in the recommendation that the group made as they were outside the scope of work of the project.

### 3.3.5 Selection and Use of Communication Tools

The team based the selection of a communication tool on the results from the Community Feedback Charrette. The charrette focused on the public's opinion of both the designs and communication platforms. Chapter 4 discusses the results of the charrette. From the design of mock ups to a final recommendation, the team created a design that they presented to Miljøpunkt Nørrebro for future development into a finished product.

## 4.0 Data and Analysis

There were two separate objectives in this project. The first was to develop a research case for the Ladegårdsåen Daylighting Project. The second was to provide Miljøpunkt Nørrebro with a recommendation on a communication tool and visual display for increasing public awareness of the traffic pollution in the area. Section 4.1 evaluates the two community outreach efforts the project utilized, the Nørrebro Pollution Awareness Survey and the Community Feedback Charrette. Section 4.2 discusses the research case and summarizes its key findings. Section 4.3 contains the projects results and conclusions in regards to the visual display recommendation.

### 4.1 Community Outreach Results

The group conducted two community outreach efforts, the Nørrebro Pollution Awareness Survey and the Community Feedback Charrette. The team analyzed the data from both of these questionnaires before applying the results to the project deliverables.

#### 4.1.1 Nørrebro Pollution Awareness Survey Analysis

Using the Nørrebro Pollution Awareness Survey, the team surveyed 30 people at the Nørrebro Runddel, the center of Nørrebro. The team conducted the surveys on Thursday, March 27, 2014 from 10:00 – 11:00 and from 12:00 – 14:00. The team then compiled the survey responses in order to identify important aspects of the project, including the public opinion on the Ladegårdsåen Daylighting Project and the community's knowledge about traffic pollution. The project used these findings to appropriately construct both the Benefits of Daylighting the Ladegårdsåen report and the visual display.

##### 4.1.1.1 Survey Data Validation

The Nørrebro Pollution Awareness Survey (see Appendix B) consisted of nineteen questions. The first eight were demographic questions, which the project used to determine if the respondents were a reasonable representation of Nørrebro's population before analyzing the actual survey questions. Evaluating the survey for representativeness was important because as it only consisted of 30 people, the team had to check that the rest of the information obtained from the survey accurately represented the community of Nørrebro. Demographics that were the most important for seeing if the results were representative were age, gender, and car ownership. Calculating the percentages of each response to each question provided the demographic breakdown for each category and by comparing these percentages to known demographic statistics for Nørrebro, the team established that the data collected from the survey provided what appeared to be an accurate representation of the Nørrebro community. As seen in Table 5, the survey results match the Nørrebro statistics (Klubbydelsplan, 2013), most notably the car ownership

rate. The car ownership rate of the respondents matched the statistics perfectly, indicating that the group received typical results for survey questions involving cars. The age distribution is not perfectly in line with the statistics, but that is partly because the statistics were for people from age 0-80, and the survey only reached people ages 19-69, so the percentages do not match exactly. Additionally, people who were younger (20-29), were more likely to stop to take the survey, which accounts for the higher percentage of responses from that age group. In regards to gender, although there is a difference between the survey data and the Nørrebro statistics, with only 30 surveys, three more women instead of men would have made it even, so the team considered the distribution to be reasonably characteristic for the purposes of the survey.

<b>QUESTION</b>	<b>NUMBER OF RESPONSES</b>	<b>SURVEY DATA STATISTICS</b>	<b>NØRREBRO STATISTICS</b>
<b>AGE (YEARS)</b>			
10-19	2	7%	7%
20-29	14	47%	33%
30-39	7	23%	21%
40-49	3	10%	11%
50-59	2	7%	7%
60-69	2	7%	5%
<b>GENDER</b>			
MALE	18	60%	49%
FEMALE	12	40%	51%
<b>CAR OWNERSHIP</b>			
OWNS CAR	4	13%	13%
DOES NOT OWN CAR	26	87%	87%

**TABLE 5: SURVEY DATA DEMOGRAPHICS COMPARED TO NØRREBRO STATISTICS**

In addition to confirming that the data appeared to represent Nørrebro, it was important that the data came from people with different lifestyles and connections to Nørrebro. The team calculated the percent of responses for the remaining demographics, which were number of children, employment status, connection to Nørrebro, and method of commuting. Table 6 displays the results. Although only 30 people completed the survey, some people utilize multiple methods of transportation to get to work, and have multiple connections to Nørrebro, which is why the total number of responses for some questions is greater than 30. To account for this, the table displays the total number of responses for each question but the percentage of responses is out of 30 people, since one person can fall into more than one category per question. The surveyed people were evenly divided between being married or cohabitating and not married. The majority of the respondents did not have kids, though there were still people who had from 1-4 children. In regards to employment status, the majority of the respondents were employed, but the

survey still reached students and unemployed people, meaning that the project received opinions from people in different financial situations. The people surveyed were mostly people who lived in Nørrebro, which is expected since the team conducted the survey in the center of the neighborhood, but there were still people who worked, commuted, and had friends in Nørrebro. This was important because the Ladegårdsåen Daylighting Project will affect all of these types of people. The respondents utilized a variety of transportation methods to commute to work; most biked or used public transportation, but there were some who walked or drove to work as well. Overall, demographic data showed that the respondents came from a variety of different backgrounds, which meant that the survey data represented the opinions of diverse groups of people.

<b>QUESTION</b>	<b>NUMBER OF RESPONSES</b>	<b>SURVEY DATA STATISTICS</b>
<b>MARITAL STATUS</b>		
MARRIED	5	17%
COHABITATING	10	33%
NOT MARRIED	15	50%
TOTAL	30	
<b>NUMBER OF CHILDREN</b>		
0	21	70%
1	5	17%
2	3	10%
3	0	0%
4	1	3%
TOTAL	30	
<b>EMPLOYMENT STATUS</b>		
EMPLOYED	21	70%
STUDENT	3	10%
UNEMPLOYED	6	20%
TOTAL	30	
<b>CONNECTION TO NØRREBRO</b>		
LIVE IN	23	77%
WORK IN	3	10%
COMMUTE THROUGH	7	23%
OTHER: FRIENDS IN NØRREBRO	1	3%
TOTAL	34	
<b>METHOD OF COMMUTING</b>		
WALK	4	13%
BIKE	21	70%
PUBLIC TRANSPORTATION	10	33%
CAR	3	10%
TOTAL	38	

**TABLE 6: DEMOGRAPHIC DISTRIBUTIONS FOR SURVEY RESULTS**

#### 4.1.1.2 Survey Analysis and Results

Dividing the non-demographic survey questions into five categories allowed for targeted analysis of each topic. The categories were:

- Traffic Pollution Knowledge Levels and Health Effects
- Noise and Air Pollution and Their Causes
- Traffic Removal
- Ladegårdsåen Daylighting Project
- Potential Sign Location

##### 4.1.1.2.1 TRAFFIC POLLUTION KNOWLEDGE LEVELS & HEALTH EFFECTS

The Traffic Pollution Knowledge Levels & Health Effects analysis compared responses to question 9, “What do you know about traffic pollution?” and question 14, “How informed do you feel about the health effects of traffic pollution?” Question 9 was an open response question, and based on the response, the analyst assigned a knowledge level. To eliminate any discrepancies in the level assignments, only one team member assigned the knowledge level. This kept the assignments consistent throughout all the responses. The levels were Unknown, Not Knowledgeable, Slightly Knowledgeable, Relatively Knowledgeable, and Very Knowledgeable. As seen in Figure 17, the survey participants had a normally distributed knowledge of the health effects of traffic pollution. The chart divided each group of ratings in question 14 by the corresponded knowledge level for each respondent. This allowed the team to visualize how the knowledge level compared to the rating for the traffic pollution health effects. There was also a positive relationship between how knowledgeable of traffic pollution the person was and how informed they felt of the associated health effects; people with higher knowledge levels gave a higher rating for question 14. The analysis concluded that while some people are informed about traffic pollution and the associated health problems, there is room for improvement.

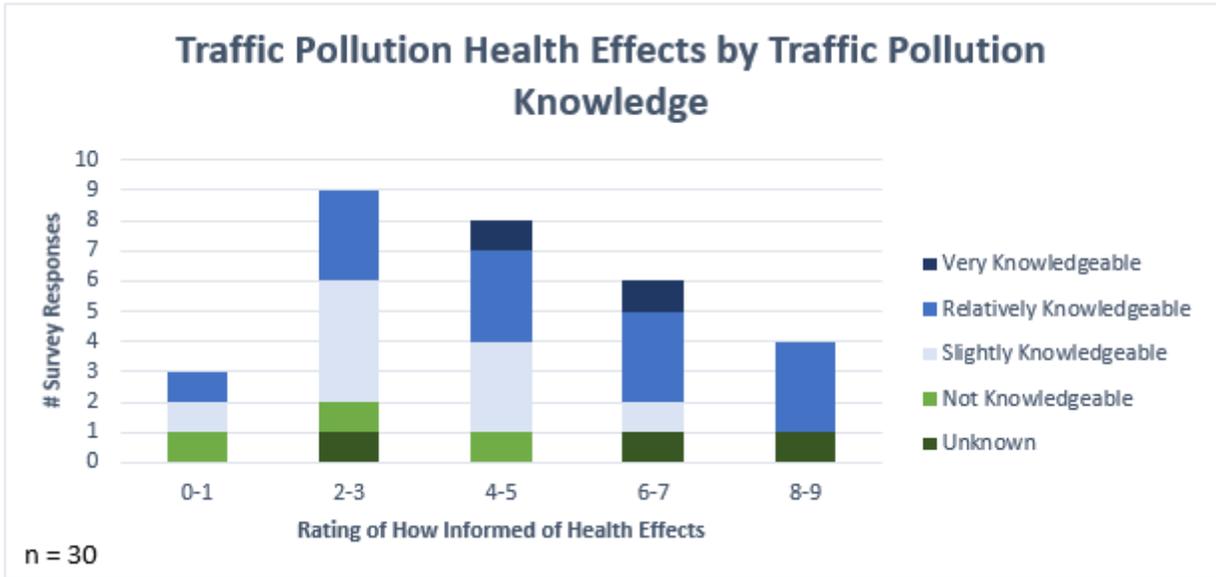


FIGURE 17: SURVEY RESPONSES TO TRAFFIC POLLUTION HEALTH EFFECTS BY TRAFFIC POLLUTION KNOWLEDGE

4.1.1.2.2 NOISE AND AIR POLLUTION AND THEIR CAUSES

The analysis of questions 10 – 13 evaluated the ratings that the survey participants gave for both the noise and air pollution levels in Nørrebro, as well as their associated causes. Each respondent provided a rating from 1 – 10 on both the air pollution (question 10) and noise pollution (question 12) levels in Nørrebro. They then checked off reasons for the respective pollution from a list, which included an “other” category where they had the option to provide a reason that the team had not thought to include in the survey. The survey allowed people to select all of the options that they believed to be true, which meant that the number of responses varied between noise and air pollution. Figure 18 suggests that most people believe that there is a relatively high amount of pollution in Nørrebro. Participants believe that there is a bigger problem with noise pollution than air pollution, as 70% of participants rated the noise pollution as being a six or greater, while only 50% did the same for air pollution. Shown in Figure 19a, when asked to provide reasons for the air pollution in the area (question 11), 86% of the responses attributed it to traffic (cars and trucks). Similarly for noise pollution (question 13), 64% of respondents named traffic as a main contributor (see Figure 19b). The air pollution rating had a mean of 5.7 and a mode of 6, and the noise pollution rating had a mean of 6.1 and a mode of 7. This indicates that the survey participants believed that the overall pollution in the area is above average. Additionally they believe that traffic is the main reason for this pollution.

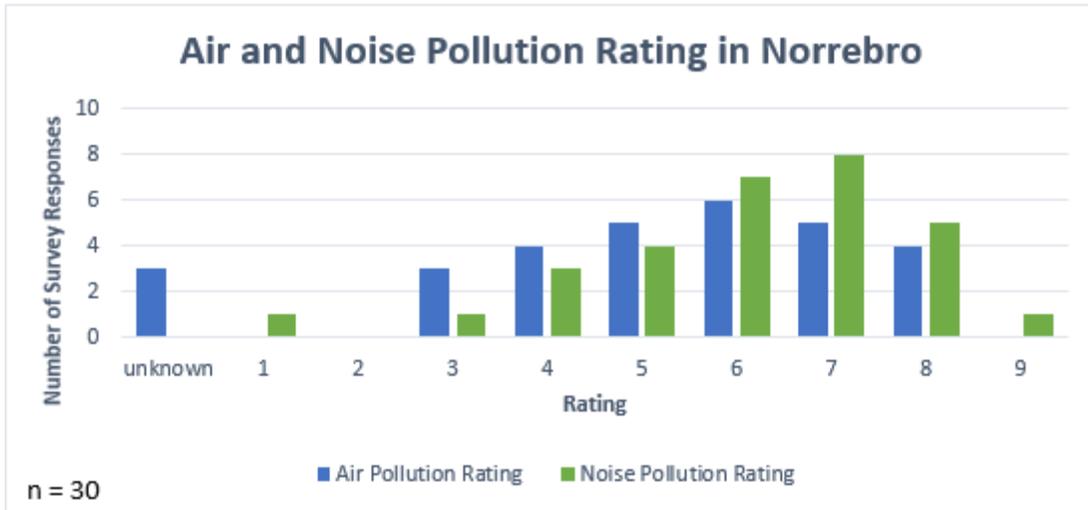


FIGURE 18: SURVEY RESPONSES TO AIR AND NOISE POLLUTION RATING IN NØRREBRO

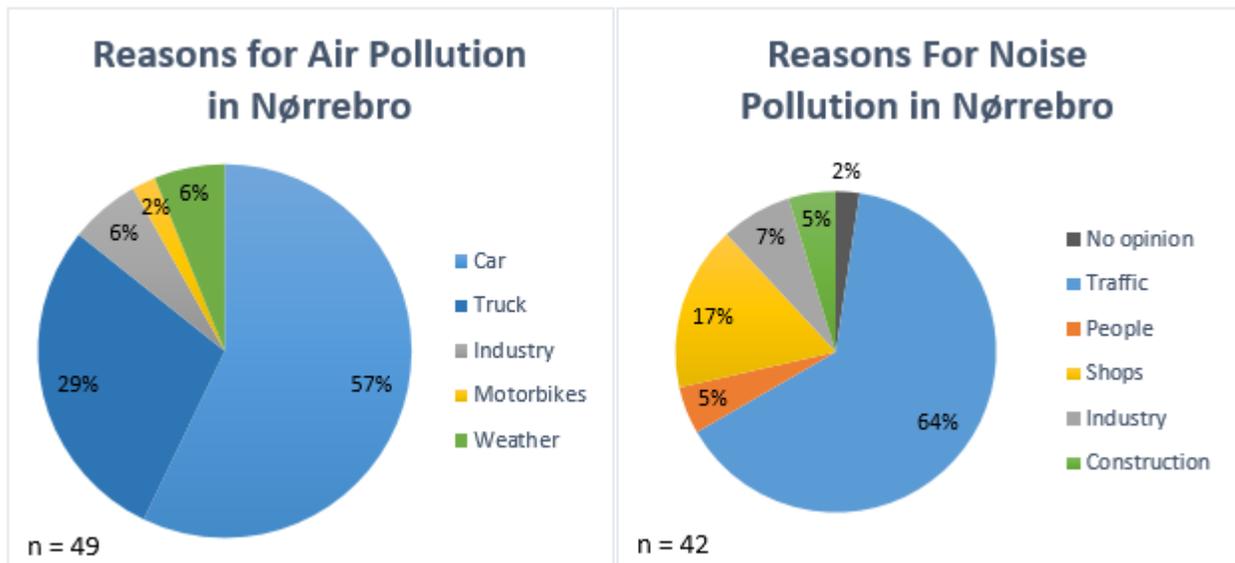
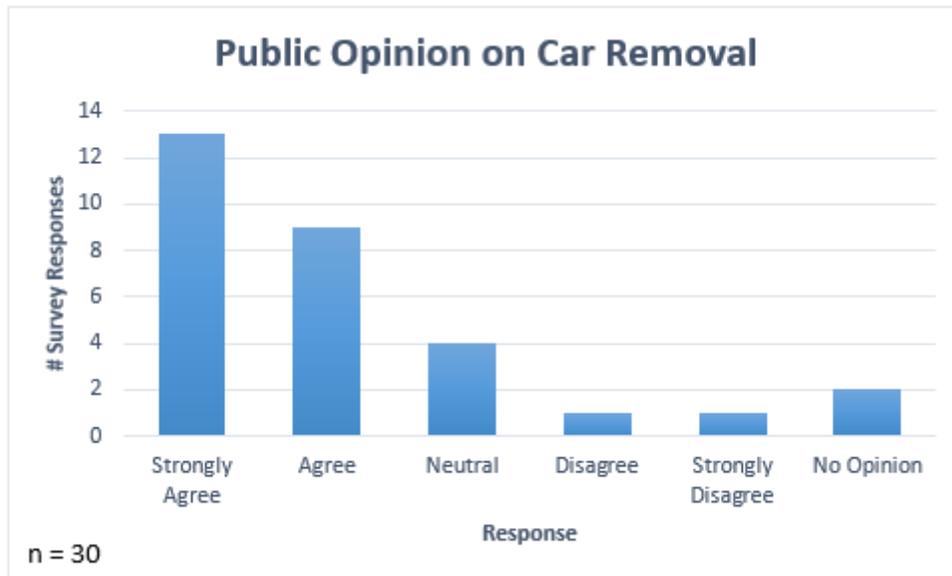


FIGURE 19A AND 19B: SURVEY RESPONSES TO REASONS FOR AIR (19A) AND NOISE (19B) POLLUTION IN NØRREBRO

#### 4.1.1.2.3 CAR REMOVAL ANALYSIS

Question 17 provided participants with the statement “Decreasing the number of cars that drive through Nørrebro is beneficial to the neighborhood.” The survey asked respondents to rank how strongly they agreed with the statement. Shown in Figure 20, of the 30 people surveyed, only two people disagreed, and 9 and 13 people agreed or strongly agreed with the statement, respectively. This showed that 73% of the respondents were in favor of car removal.



**FIGURE 20: SURVEY RESPONSES TO PUBLIC OPINION ON CAR REMOVAL**

#### 4.1.1.2.4 LADEGÅRDSÅEN DAYLIGHTING PROJECT

Questions 15 and 16 asked people if they had heard of the Ladegårdsåen Daylighting Project, and what their opinion of it was. Question 16 also had respondents provide a reason for their opinion. These questions provided the basis for the Ladegårdsåen Daylighting Project analysis. As seen in Figure 21, only 40% of respondents had heard of the project before reading the description in the survey. Of the people who knew about the project, there was no one who was against it, and only one person had no opinion; everyone else who had heard of the project was in favor of it. Of the people who had not heard of the Daylighting Project, only one person disagreed with it. Overall, 67% of the survey responses were in favor of the project. When asked to provide a reason for their opinion on the project, people gave open response answers, which the team later grouped into six categories: Less Pollution, Success of the Århus Project, Segregation of Cars and Pedestrians, Less Noise, Traffic Removal, and More Green Space. Sixteen participants who were in favor of the project did not provide a reason, and depending on the answer, some responses fell into more than one category, so there were 37 responses. Only 3% of the responses were Less Pollution, but Traffic Removal and More Green had 22% and 16% of the responses, respectively (see Figure 22). Forty-three percent of the respondents who were in favor of the project did not give a reason, which meant that the team was unable to gain further insight into their opinion. Although most people are in favor of the Daylighting Project, it is not because they want to lower pollution, but because they want less cars on the streets and more green space in their neighborhoods.

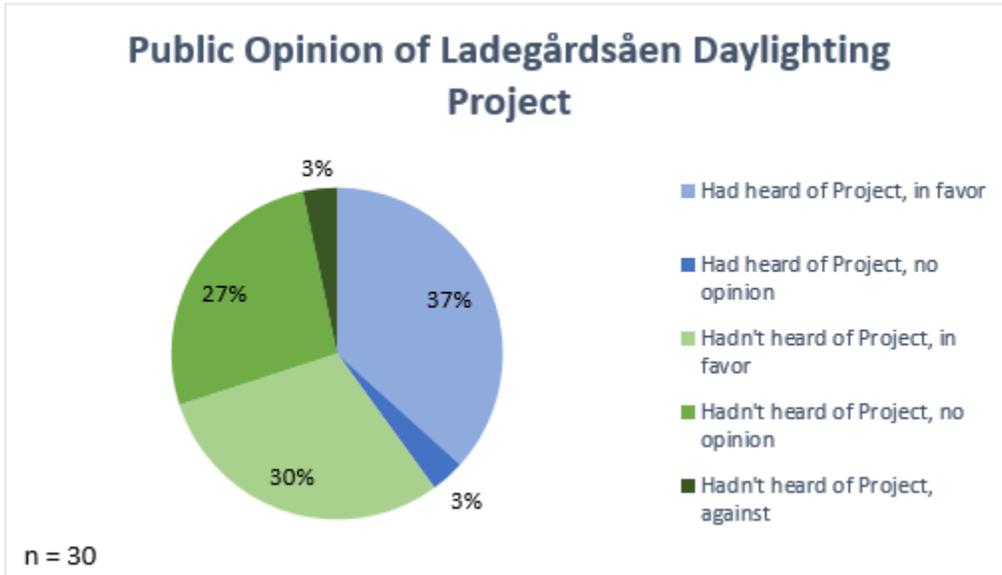


FIGURE 21: SURVEY RESPONSES TO PUBLIC OPINION OF LADEGÅRDSÅEN DAYLIGHTING PROJECT

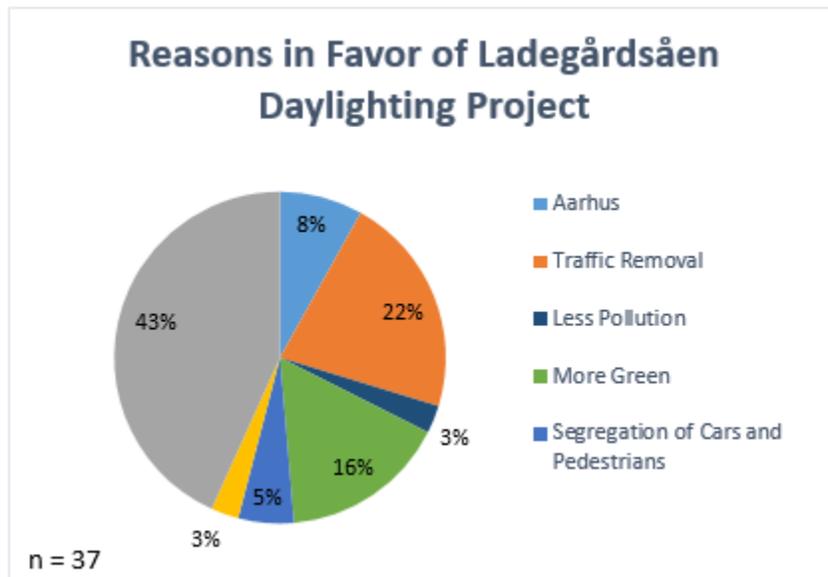


FIGURE 22: SURVEY RESPONSES TO REASONS IN FAVOR OF LADEGÅRDSÅEN DAYLIGHTING PROJECT

#### 4.1.1.2.5 POTENTIAL SIGN LOCATIONS

Question 18 on the Nørrebro Pollution Awareness Survey asked people for pollution sign locations in Nørrebro. Some people provided more than one location, so there were 38 locations suggested. Figure 23 plots the 38 locations chosen by survey respondents, which led to conclusion that either the Nørrebro Runddel or the Dronning Louises Bro would be good choices. Since the project conducted this survey at the Nørrebro Runddel, the team asked the same question during the Community Feedback Charrette,

which took place at both the Nørrebro Runddel and the Dronning Louises Bridge, to eliminate any preference towards the Nørrebro Runddel that came from being there when completing the survey.

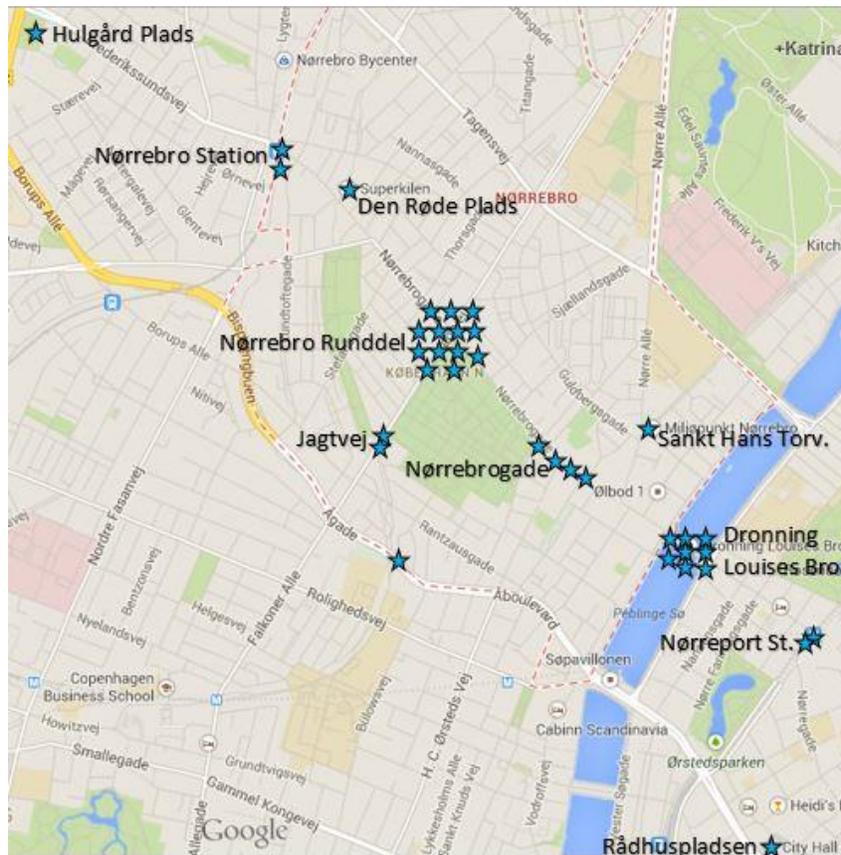


FIGURE 23: MAP OF SUGGESTED SIGN LOCATIONS, SURVEY RESULTS

#### 4.1.2 Community Feedback Charrette Analysis

The Community Feedback Charrette consisted of questioning 40 people in Nørrebro, 20 at the Dronning Louises Bro and 20 at the Nørrebro Runddel, about the three proposed visual displays: the Speedometer, Pie Chart, and Bar Display. The group conducted the charrette on Thursday, April 10, 2014 from 10:00–12:00 at the Dronning Louises Bro and from 13:00 – 15:00 at the Nørrebro Runddel. The team also asked participants to provide comments and recommendations on the various designs. A team member had a conversation with each participant during the charrette and recorded the responses to each question. The team used their responses to determine which design to modify and select as the final design to present to Miljøpunkt Nørrebro.

##### 4.1.2.1 Charrette Data Validation

The Community Feedback Charrette asked each participant thirteen questions, with the first three being demographic questions to check the data for representativeness, similarly to the Nørrebro Pollution

Awareness Survey. Miljøpunkt Nørrebro requested that the demographics be age, gender, and connection to Nørrebro, as those categories would be useful to them in the future. The group used these specific demographics to determine which age groups and gender responded positively to each design, and to establish the representativeness of the data. The age breakdown of the Community Feedback Charrette participants was not as in line with the Nørrebro statistics as the Nørrebro Pollution Awareness Survey responses were (see Table 7), but they still showed that the group obtained a wide spread of ages of participants. The gender of the participants was perfectly in line with the Nørrebro data. The gender breakdown gave legitimacy to the charrette data, as it showed that the responses were in line with Nørrebro Statistics. For connection to Nørrebro, the “Other” category included people who worked in neighboring areas, had friends in Nørrebro, were visiting the area, used to live in Nørrebro, and went to school in Nørrebro. The charrette reached people who had a variety of connections to the neighborhood, which meant that the group appeared to have spoken with all of the types of people who will be affected by the project.

<b>QUESTION</b>	<b>NUMBER RESPONSES</b>	<b>OF SURVEY STATISTICS</b>	<b>DATA NØRREBRO STATISTICS</b>
<b>AGE (YEARS)</b>			
10-19	1	3%	7%
20-29	22	55%	33%
30-39	10	25%	21%
40-49	1	3%	11%
50-59	6	15%	7%
60-69	0	0%	5%
<b>GENDER</b>			
MALE	19	48%	49%
FEMALE	21	52%	51%
<b>CONNECTION</b>			
LIVE	21	51%	-
WORK	3	7%	-
COMMUTE	5	12%	-
OTHER	12	29%	-

**TABLE 7: CHARRETTE DATA DEMOGRAPHICS**

#### 4.1.2.2 Charrette Analysis and Results

Aside from the demographic questions, the group asked each charrette participant six basic questions:

- Which design has the strongest first impression?
- Which design is easiest to understand?
- Which design is hardest to understand?
- Which design would you want to see developed into a communication tool for Nørrebro?

- Would you rather see this information displayed as a sign, website, widget, or app?
- If the chosen design were to be made into a sign, where in Nørrebro would you like to see it installed?

Additionally, the team asked the participants to provide recommendations for changes they would like to see to any of the visual display options. Section 4.3 discusses these comments.

#### 4.1.2.2.1 DESIGN WITH THE STRONGEST FIRST IMPRESSION

The strongest first impression inquiry (question 4) allowed the team to determine which design would draw the public’s attention the most. Of the 40 responses, over half of them said that the Speedometer had the strongest first impression (see Figure 24), while the rest of the participants were divided between the Pie Chart and Bar Display. Interestingly, the Pie Chart seemed to appeal more to the women than it did the men (see Figure 25), as seven women thought that it had the strongest first impression, compared to only one man. The Speedometer still had the most votes for both the men and women, showing that it is the most eye-catching design out of the three options.

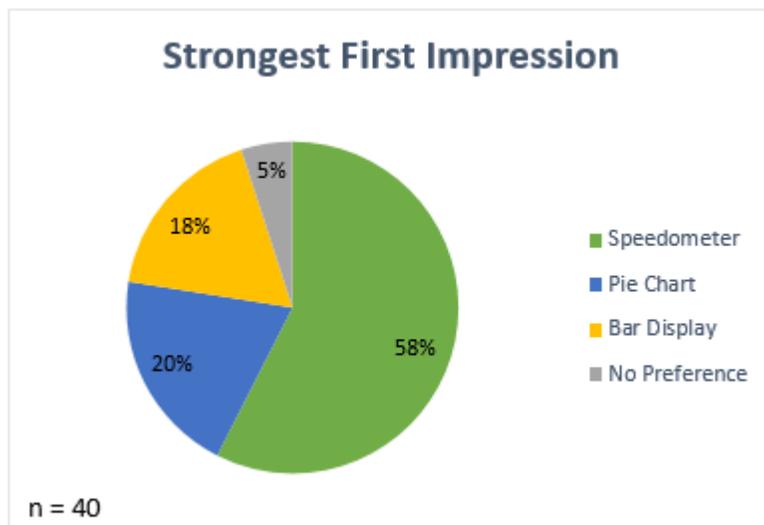


FIGURE 24: CHARRETTE RESPONSES TO STRONGEST FIRST IMPRESSION

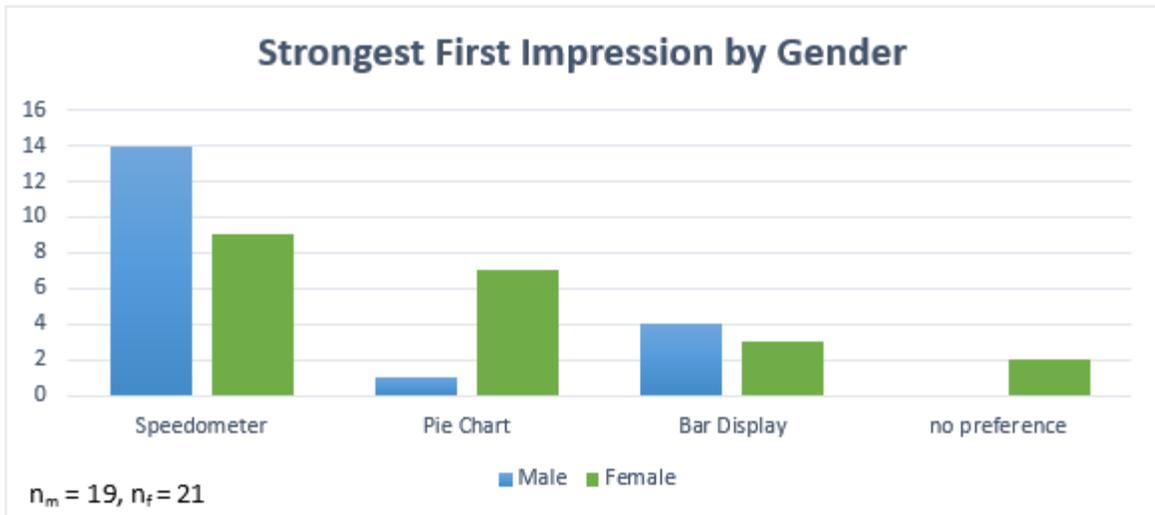


FIGURE 25: CHARRETTE RESPONSES TO STRONGEST FIRST IMPRESSION BY GENDER

#### 4.1.2.2.2 EASIEST DESIGN TO UNDERSTAND

Question 5 asked participants to identify which visual display was the easiest to understand. Similarly to the strongest first impression question, 50% of the responses said that the Speedometer design was the easiest to understand (see Figure 26). If someone could not decide between two designs, their response was “No Preference”. There was no difference between gender, age, or connection to Nørrebro for this question. In every demographic category, the Speedometer was the favorite.

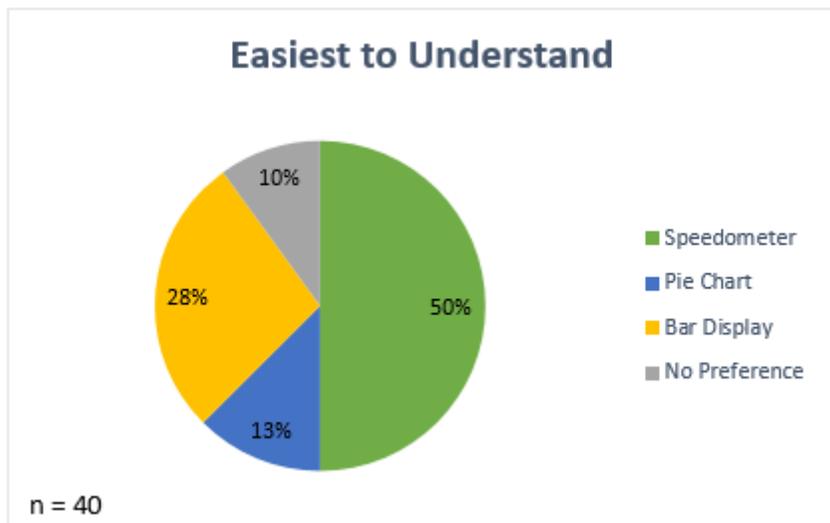
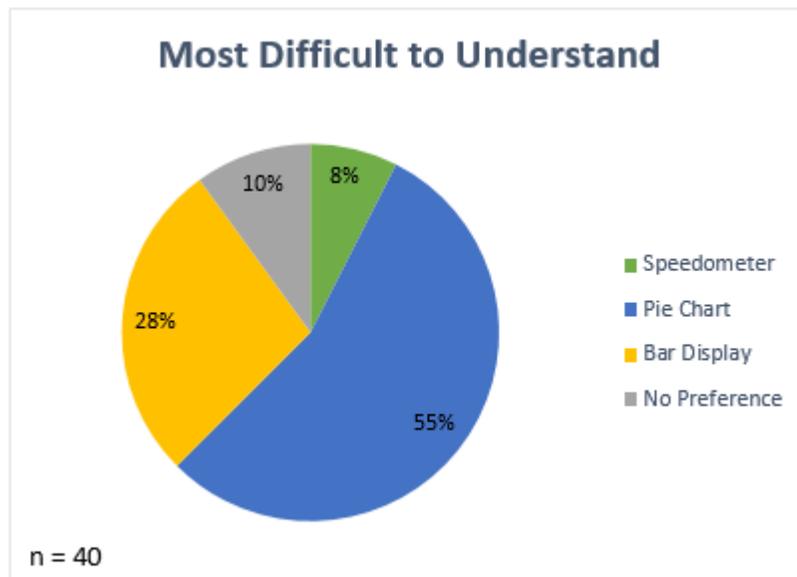


FIGURE 26: CHARRETTE RESPONSES TO EASIEST TO UNDERSTAND

#### 4.1.2.2.3 MOST DIFFICULT DESIGN TO UNDERSTAND

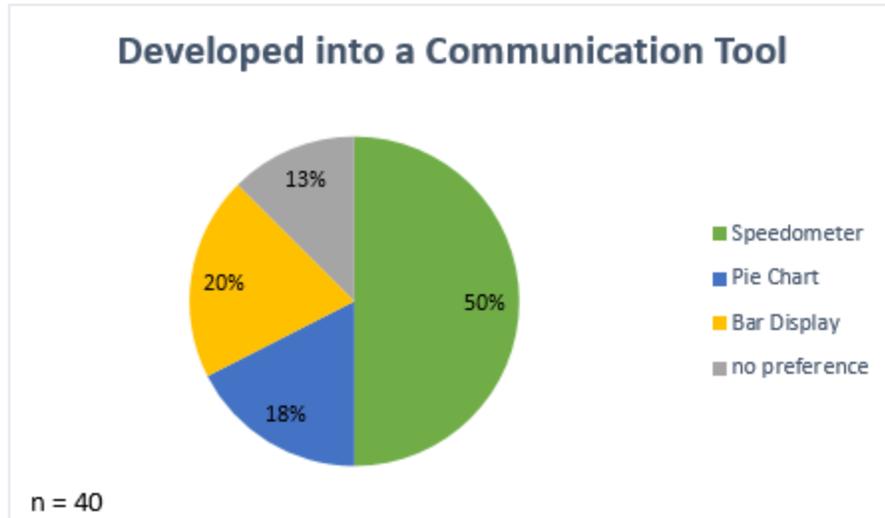
Question 6 had charrette participants identify which design they found to be the most difficult to understand. As seen in Figure 27, 55% of the participants responses said that they thought the Pie Chart design was the most difficult to understand, only 8% of the responses named the Speedometer as the hardest design to understand. From question 5, 50% of the participants did not select the Speedometer as the easiest to understand, but 42% of those people did not believe that it was the hardest to comprehend.



**FIGURE 27: CHARRETTE RESPONSES TO MOST DIFFICULT TO UNDERSTAND**

#### 4.1.2.2.4 DESIGN TO DEVELOP INTO A COMMUNICATION TOOL

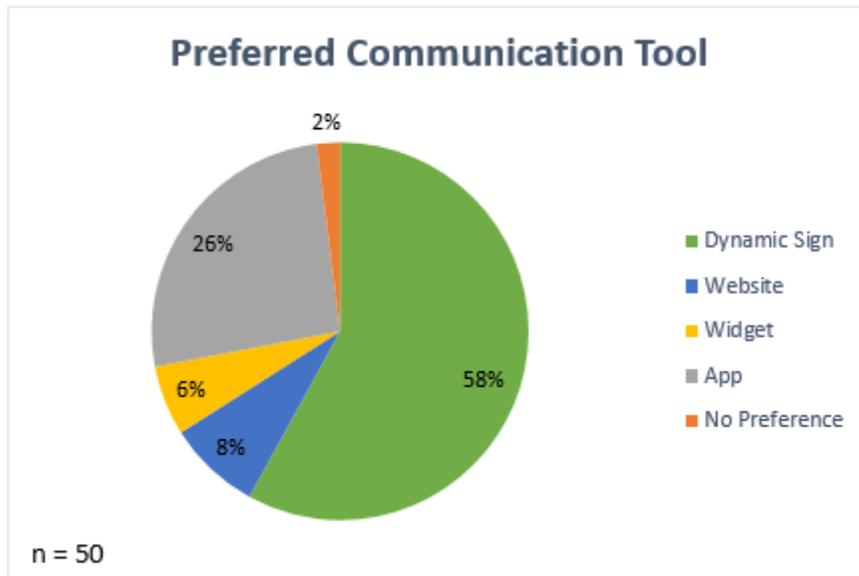
In order to determine which design was the public's favorite, question 7 asked participants to select the design they would prefer to see developed into a communication tool. Consistent with the strongest first impression and easiest to understand, 50% of participants told the team that they preferred the speedometer design (see Figure 28). The Speedometer design was the clear favorite among charrette participants, as participants consistently selected the design for all three positive opinion questions.



**FIGURE 28: CHARRETTE RESPONSES TO DEVELOPED INTO A COMMUNICATION TOOL**

#### 4.1.2.2.5 PREFERRED COMMUNICATION TOOL

In addition to obtaining input about the actual visual displays, question 8 asked the public to select which potential communication tools they would like used with the display. A dynamic sign took 58% of the responses (see Figure 29), and as people could select more than one tool, the 58% accounted for 29 people, which was just under three-quarters of all of the participants. Some people were also very interested in the idea of an app that they could download for their smartphones, which one can see from that fact that it received 26% of the responses. For types of communication tools, a dynamic sign was the clear favorite, with an app being a good alternative.



**FIGURE 29: CHARRETTE RESPONSES TO PREFERRED COMMUNICATION TOOL**

#### 4.1.2.2.6 POTENTIAL SIGN LOCATIONS

In order to see if the suggested sign locations changed depending on where the participants were when asked to name a location, the team had people provide suggestions for sign locations in question 13 of the Community Feedback Charrette. Figure 30 plots the new suggestions (in yellow and orange) on top of the previous responses (in blue). The charrette responses from the Droning Louises Bro are in yellow and those from the Nørrebro Runddel are orange. Of the seven people who selected the Nørrebro Runddel, six of them were at Runddel when they made this suggestion. Ten of the thirteen people who suggested the Droning Louises Bro did so while standing on the bridge. The team concluded that the location that people physically were at influenced their location suggestions, though both locations are highly trafficked areas, so they are still viable sign locations. The Droning Louises Bro has the added benefit of already having a real-time bike counter, and five people suggested putting a potential pollution sign next to the bike counter, as people already look at it on a daily basis.

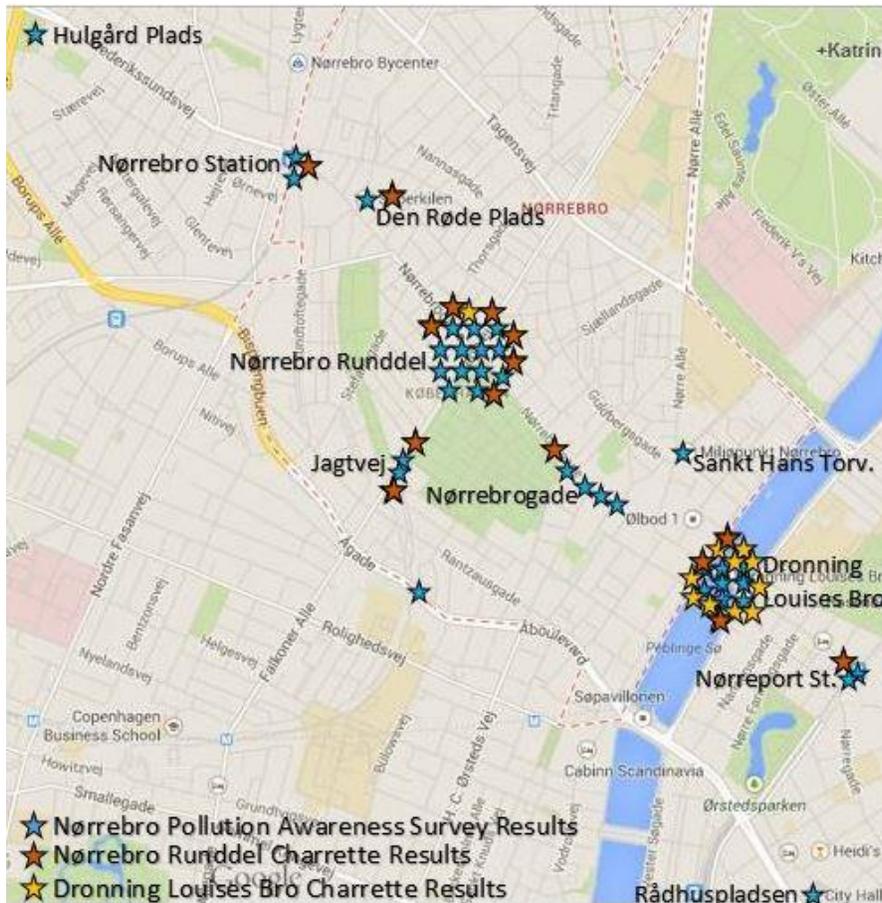


FIGURE 30: MAP OF SUGGESTED SIGN LOCATIONS, CHARRETTE RESULTS

#### 4.2 Developing a Research Case for the Ladegårdsåen Daylighting Project

Both the benefits report and presentation for the Ladegårdsåen Daylighting Project are to act as educational and persuasive tools for Miljøpunkt Nørrebro. Each of the documents goes into detail on the different problems in Nørrebro and discusses how the daylighting project could act as an overarching solution. The report and presentation synthesize findings from the team’s research and community interaction into informational tools that Miljøpunkt Nørrebro can utilize to gain support for the Ladegårdsåen project. While the presentation and report consist of the same data, they offer Miljøpunkt Nørrebro two different methods of informational delivery to suit their needs.

The actual case presented in the report and presentation first lays the groundwork for why Nørrebro needs this project. The group first discusses the lack of green space, lack of storm water management, and high traffic pollution in Nørrebro and then evaluates the impact of the resulting negative effects. After describing the environmental trouble in Nørrebro, research case presents Miljøpunkt Nørrebro’s solution to the problem, the Daylighting of the Ladegårdsåen. The team creates a case for daylighting

citing environmental studies and previous construction projects of similar nature and providing the predicted benefits for such a project in Nørrebro. After discussing the technical foundation for the need for the Daylighting of the Ladegårdsåen, the report and presentation summarize the community opinion on pollution as a whole and the potential daylighting project. The community opinion, gathered from the Nørrebro Pollution Awareness Survey, supports the project. The team presented both the Benefits of Daylighting the Ladegårdsåen report and presentation to Miljøpunkt Nørrebro for use in providing the Nørrebro community with evidence of the positive impacts that the Ladegårdsåen Daylighting Project will have on the neighborhood.

#### 4.2.1 The Benefits of Daylighting the Ladegårdsåen Report

Appendix D contains the benefits report for the Daylighting Project. It is titled “The Benefits of Daylighting the Ladegårdsåen” and roughly 35 pages long. This includes references and the table of contents but excludes the Nørrebro Pollution Awareness Survey data. The survey data is included as an appendix in the benefits report provided to Miljøpunkt Nørrebro, but is not included in Appendix D.

#### 4.2.2 The Benefits of Daylighting the Ladegårdsåen Presentation

Appendix E consists of the Benefits of Daylighting the Ladegårdsåen presentation, along with a suggested presenter’s script. The presentation is a PowerPoint, and the script includes animation cues for the presenter to follow. The presentation and script summarize the important information from the report in a more condensed form. The presentation also provides examples of projects similar to the proposed Ladegårdsåen Daylighting that have been successfully implemented in the past, and the newfound benefits the projects provided to the nearby communities. Miljøpunkt Nørrebro is free to change any and all of the content in either of these to accommodate their changing needs.

### 4.3 Creating the Visual Display

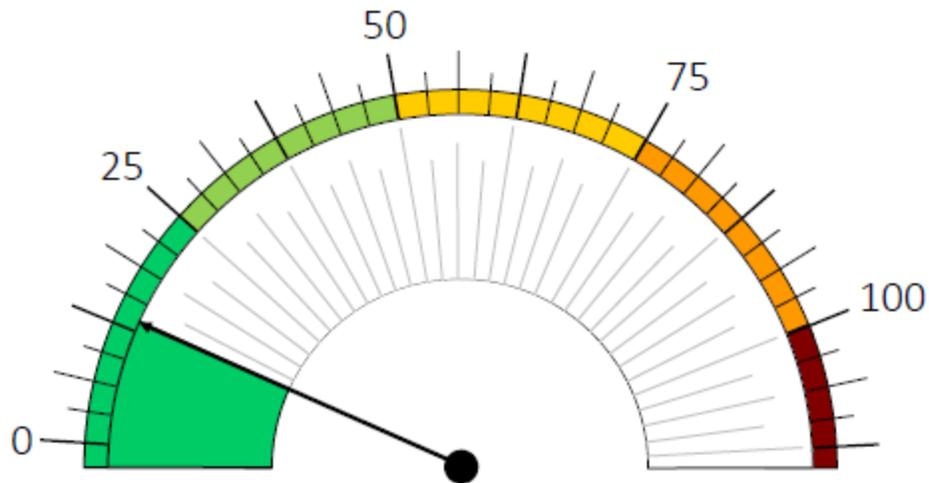
Using the Community Feedback Charrette data, the team selected a final visual display and determined which communication tools Miljøpunkt Nørrebro should attempt to produce. The group also evaluated the pollution sensor data and converted it into a usable format for the display.

#### 4.3.1 Finalizing the Visual Display Design

The selection of the final visual design utilized both the rankings of the visual displays and the comments of the survey respondents. Although the majority of the charrette participants were in favor of one design, the team wanted to make sure that any extra feedback that a person gave on any particular design was taken into account.

During the Community Feedback Charrette, participants had the opportunity to provide a team member with their recommendations for improvement as well as any other comments about all of the visual displays, both individually and collectively. Five comments said that the displays would benefit from clarifying the pollution level scale. In the final design proposal (found in Appendix F), the suggested communication tool contains a small descriptor on what the CAQI (Common Air Quality Index) scale is and what the corresponding numbers mean. The group also received a suggestion that the designs should show comparative information to the pollution levels in other places or the immediate impacts of the current pollution levels. However, the possibilities for something simple such as a dynamic sign are limited; if the communication tool were to be made into a website, widget, or app, more information about comparative pollution levels and in-depth health effects can and should be included.

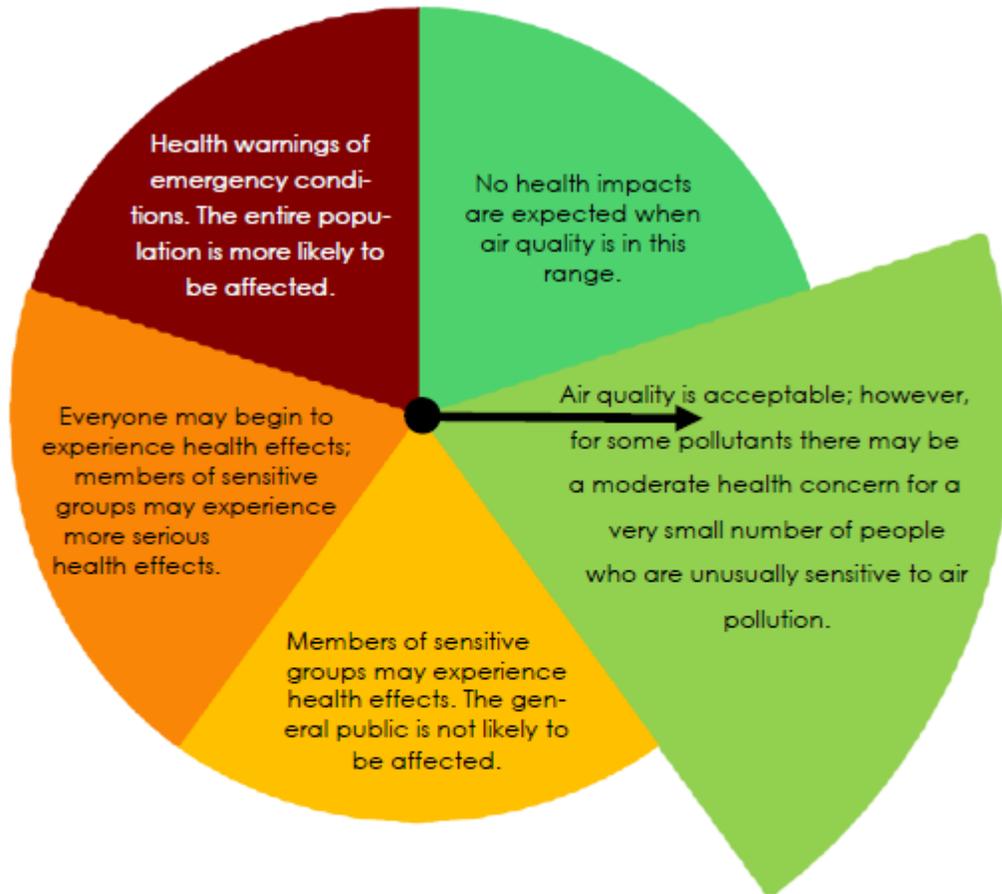
The speedometer design (see Figure 31) had the most positive feedback with 50% of people requesting to see it made into the final design, so the group decided to pursue this option further. A recurring comment for the Speedometer design was to remove the smaller tick marks to make it easier to understand at a quick glance. The team modified the Speedometer design to account for this suggestion, as well as the general suggestions for all of the displays.



Very Low	Low	Medium	High	Very High
0 to 25	25 to 50	50 to 75	75 to 100	> 100
Air quality is considered satisfactory, and air pollution poses little or no risk.	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive.	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.	Health warnings of emergency conditions. The entire population is more likely to be affected.

FIGURE 31: SPEEDOMETER VISUAL DISPLAY DESIGN

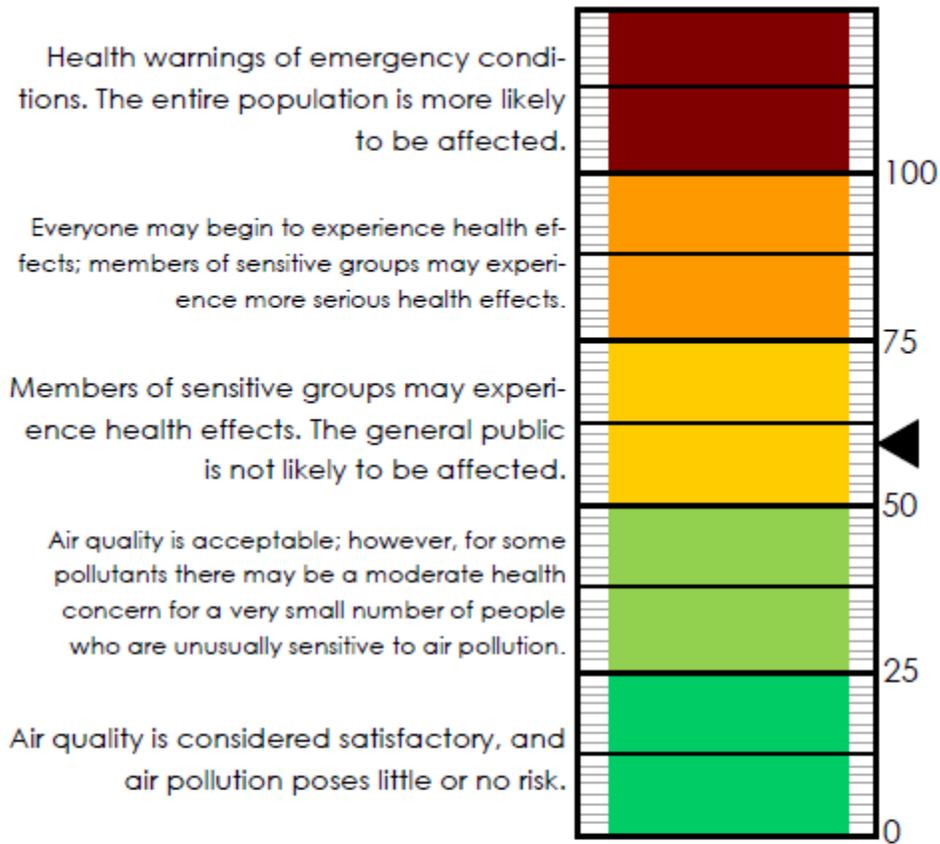
The Pie Chart (see Figure 32) received several comments that it was confusing or hard to read. Most did not like that there was text inside the slices, and it was the only design that had strongly negative feedback from several respondents. For these reasons, the group decided to remove this design from consideration.



Very Low	Low	Medium	High	Very High
0 to 25	25 to 50	50 to 75	75 to 100	> 100

FIGURE 32: PIE CHART VISUAL DISPLAY DESIGN

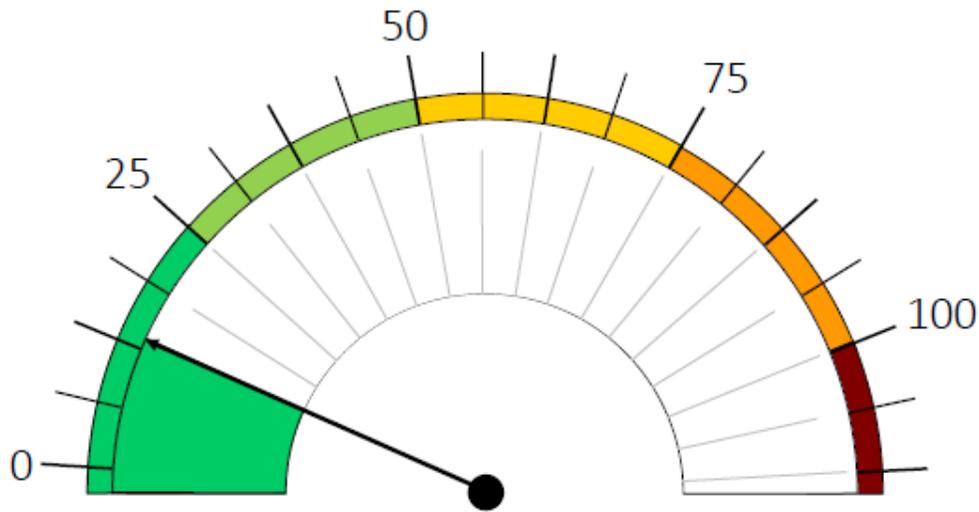
The Bar Display (see Figure 33) received the second highest ratings next to the Speedometer design and had minimal design-related feedback. Though it did not receive as much positive feedback as the Speedometer design, 27% said the design was the easiest to understand and 23% of people still said that they would like to see the design made into a finished product. Since the design was not as widely liked as the Speedometer, the team rejected it and instead chose to recommend the Speedometer display.



Very Low	Low	Medium	High	Very High
0 to 25	25 to 50	50 to 75	75 to 100	> 100

FIGURE 33: BAR DISPLAY VISUAL DISPLAY DESIGN

After modifying the Speedometer design to account for the public’s recommendations, the group presented it to Miljøpunkt Nørrebro as the final design that they should pursue. Figure 34 displays the finalized design. The team presented the final design suggestions in the form of the Visual Display Recommendation Report (see Appendix F).



Very Low	Low	Medium	High	Very High
0 to 25	25 to 50	50 to 75	75 to 100	> 100
Air quality is considered satisfactory, and air pollution poses little or no risk.	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive.	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.	Health warnings of emergency conditions. The entire population is more likely to be affected.

FIGURE 34: FINALIZED SPEEDOMETER DESIGN

### 4.3.2 Analyzing Communications Platforms

The dynamic sign had the most positive feedback, with 58% of respondents saying that they would like to see a sign installed somewhere in Copenhagen. At a 25% response rate, an app is the second choice for communication platform choice. A dynamic sign has the possibility of reaching the largest audience since it would ideally be placed in a highly trafficked area, meaning the information would be readily available to the public. The team did not take into account price or feasibility when making their recommendation and made their recommendation based purely on community feedback.

Though Miljøpunkt Nørrebro has the option of eventually creating more than one communication tool, their efforts should first focus on the installation of a dynamic sign. Although there were a small number

of responses indicating that they would not like to see a sign installed, there was general enthusiasm by respondents regarding the installation of a sign showing the current pollution levels in Nørrebro.

### 4.3.3 Pollution Sensor Data

The team analyzed the data from the pollution sensors in Nørrebro to determine how best to display the data on the final visual design. Since the focus of the display is to promote awareness about traffic pollution, the team evaluated each set of particulate measurements to determine which would have the greatest impact when displayed on the visual display. The three potential pollution options to display with their associated EU standard levels were NO<sub>2</sub> at 40 µg/m<sup>3</sup> daily average, PM10 40 µg/m<sup>3</sup> daily average, and PM2.5 31 µg/m<sup>3</sup> daily average. Figure 35, Figure 36, and Figure 37 display the average daily particulate densities for each of these measurements, as recorded by the sensor on H.C. Anderson Boulevard along with the particulates EU standard level. The team determined that since H.C. Anderson Boulevard is an extension of Ågade and Åboulevard, it provides the most relevant data to the project; therefore, the visual display should utilize this data. As shown in the figures below, NO<sub>2</sub> is the only particulate that is consistently above the EU standard. Motor vehicles are the main reason for NO<sub>2</sub> emissions; consequently, the team chose to use NO<sub>2</sub> as the pollution type to show on the visual display.

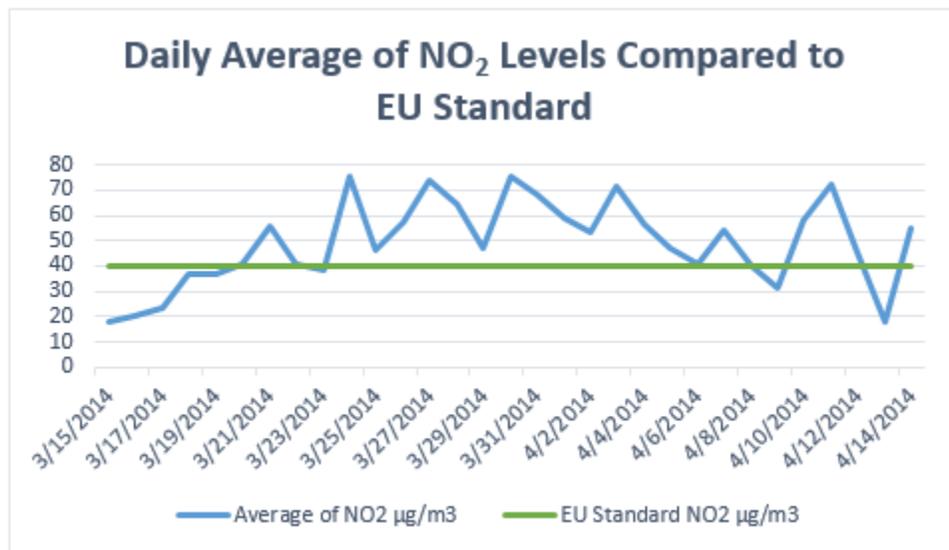


FIGURE 35: DAILY AVERAGE OF NO<sub>2</sub> PARTICULATE DENSITIES COMPARED TO 2014 EU STANDARD

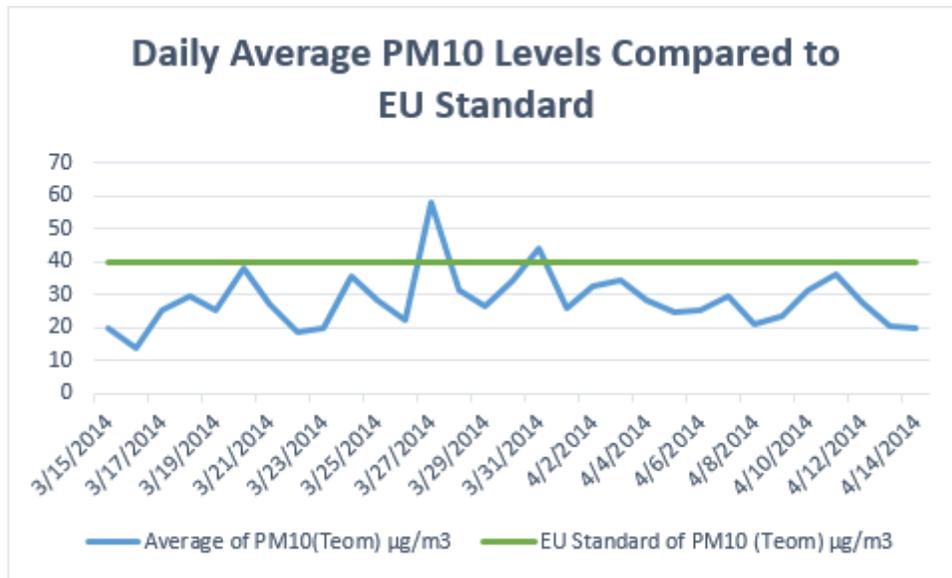


FIGURE 36: DAILY AVERAGE OF PM10 PARTICULATE DENSITIES COMPARED TO 2014 EU STANDARD

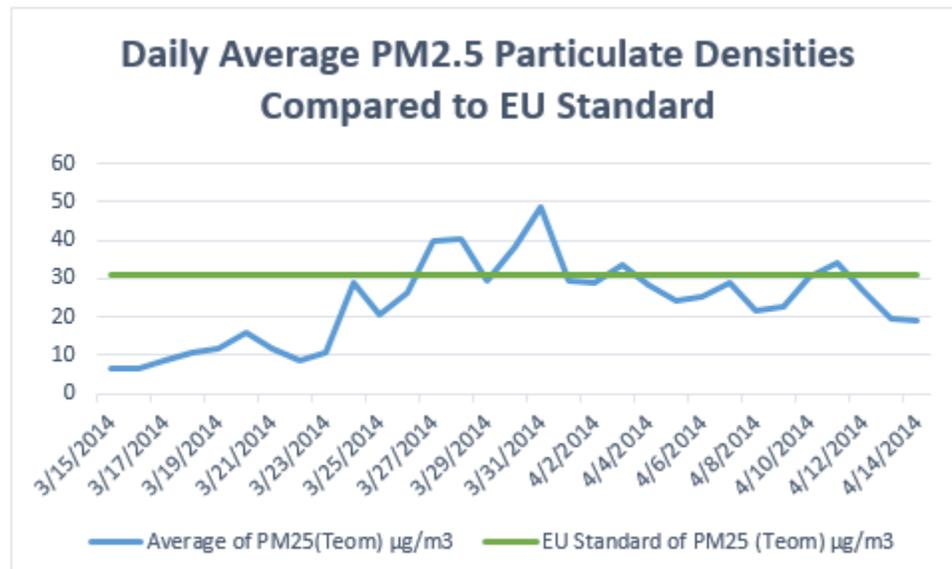


FIGURE 37: DAILY AVERAGE PM2.5 PARTICULATE DENSITIES COMPARED TO 2014 EU STANDARD

#### 4.3.3.1 Weighted Moving Average Calculations

In order to display the real-time pollution data in the form of a visual display, the team took the raw data from the sensors and developed a process to smooth the data. The pollution sensors take the incoming data, average it over a one-hour period, and then output the pollution readings into a spreadsheet which Miljøpunkt Nørrebro can access. Even with this averaging, there are still potential outliers that the team needed to take into consideration. Outliers can occur if a large vehicle idles next to the sensor or if there

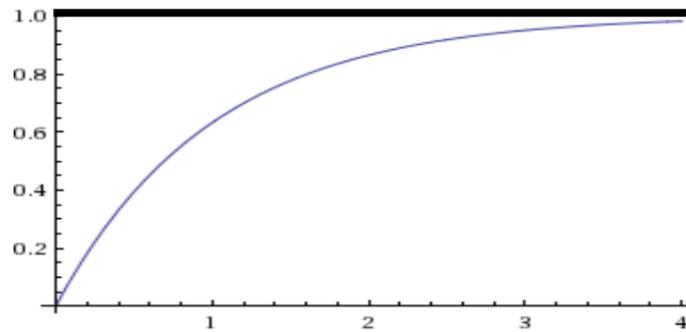
is a momentary outage in the sensor readings. When this happens, it is still necessary to display accurate information. To do this, the team applied moving weighted averages to the data stream. A moving weighted average dampens the outliers but does not eliminate them, which is beneficial to the project as eliminating an outlier would mean that there would be no pollution data to display for an entire hour ("Single Exponential Smoothing," n.d.). The project used a four-point moving weighted average, shown in Equation 1, where "real" is the most recent data received, and "real<sub>m<sub>x</sub>h</sub>" is the value of past data where the variable "x" indicates the age of the measured data is in hours. The team chose this equation because it is roughly approximate to the exponential smoothing function (see Equation 2). As shown in Figure 38, it provides a smooth exponential curve approaching a limit of 1.

$$f(avg) = ((real * 0.64) + (real_{m1h} * 0.235) + (real_{m2h} * 0.09) + (real_{m3h} * 0.035))$$

**EQUATION 1: 4 POINT WEIGHTED MOVING AVERAGE FOR POLLUTION DATA**

$$f(x) = 1 - e^{-x}$$

**EQUATION 2: EXPONENTIAL SMOOTHING FUNCTION**



**FIGURE 38: EXPONENTIAL SMOOTHING CURVE FOR EQUATION 2**

Figure 39 displays the difference in the raw and averaged data. The graph shows where the equation has smoothed the data into a more realistic format to help account for outliers.

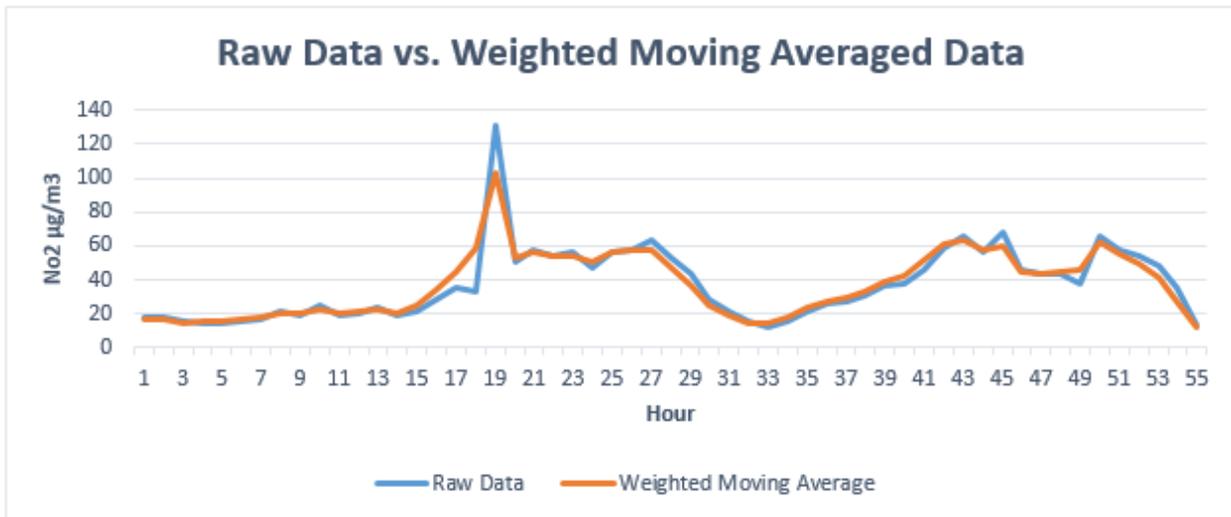


FIGURE 39: RAW DATA COMPARED TO WEIGHTED MOVING AVERAGED DATA

#### 4.3.3.2 Calculating CAQI

After selecting the pollution type and formatting the data to remove outliers, the team then converted the data into the desired air quality index, CAQI. To do this, the group put the real-time data into an Excel spreadsheet containing the CAQI piecewise function for NO<sub>2</sub> (see Equation 3). Table 8 displays the transformation of the raw data, to the weighted moving average data and to the final CAQI levels.

$$f(x) = \begin{cases} .5x & x \leq 100 \\ .25x & 100 < x \leq 200 \\ .125x & 200 < x \end{cases} = \begin{cases} = IF(x < 100, x * 0.5, 0) \\ = IF(x > 200, 0, IF(x \geq 100, 50 + 0.25 * (x - 100), 0)) \\ = IF(x > 200, 75 + 0.125 * (x - 200), 0) \end{cases}$$

EQUATION 3: PIECEWISE FUNCTION FOR NO<sub>2</sub> CAQI

Date	Time	NO <sub>2</sub> µG/M <sup>3</sup>	NO <sub>2</sub> Moving Average	CAQI
4/14/14	15	45.85	49.1468	24.5734
4/14/14	14	55.98	54.81295	27.40648
4/14/14	13	52.55	53.1904	26.5952
4/14/14	12	54.8	54.9728	27.4864
4/14/14	11	48.7	56.475	28.2375
4/14/14	10	65.64	70.9401	35.47005
4/14/14	9	72.82	80.90755	40.45378
4/14/14	8	95.08	94.34525	47.17263
4/14/14	7	93.16	92.1053	46.05265
4/14/14	6	102.13	88.5132	44.2566
4/14/14	5	68.85	62.709	31.3545

TABLE 8: POLLUTION DATA TRANSFORMATION TO CAQI

#### 4.3.3.3 Identifying Trends in Pollution Data

Miljøpunkt Nørrebro can also use the sensor data to create historic databases in order to identify long-term trends. The group has started this database in the hopes of providing Miljøpunkt Nørrebro with a base of hard evidence to back up their pollution claims. There are both long term and short-term benefits of this type of database; unfortunately, due to the time constraints of this project, the team did not have time to collect enough data to analyze long-term trends, but in the short amount of time the group had to collect the hourly data from the pollution sensors, the team has already found daily trends from day-to-day pollution in Nørrebro. Presently there is not adequate historical data to draw meaningful conclusions on the changes in pollution levels throughout the week, but it is possible to examine daily trends from the hourly data. From the NO<sub>2</sub> data gathered, the group determined that the highest pollution levels were consistently during peak traffic times, such as morning rush hour (see Figure 40). Over time, more pollution data will be gathered and Miljøpunkt Nørrebro will have a database of quantitative data to use when presenting about the pollution problems in Nørrebro and the solution.

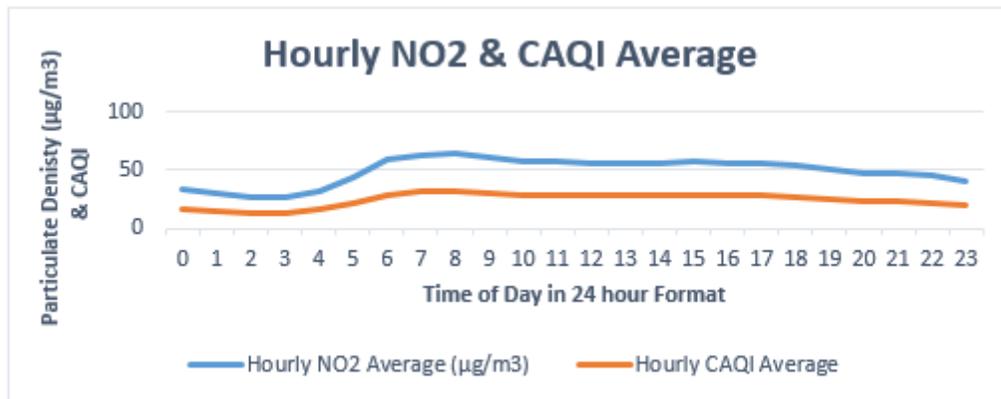


FIGURE 40: HOURLY NO<sub>2</sub> AND CAQI AVERAGE IN MONTH OF MARCH 2014 FROM HC ANDERSON BLVD

## 5.0 Recommendations

The project provided Miljøpunkt Nørrebro with three deliverables: the Benefits of Daylighting the Ladegårdsåen report, the Benefits of Daylighting the Ladegårdsåen presentation, and the Visual Display Recommendation. The team recommends that Miljøpunkt Nørrebro use the report, presentation, and recommendation to gain support for the Ladegårdsåen Daylighting Project.

## 5.1 Benefits of Daylighting the Ladegårdsåen Report Recommendation and Report

The team created an in-depth benefits report for the Ladegårdsåen Daylighting Project. The report provides a detailed explanation of the benefits of the project; it also uses the Nørrebro Pollution Awareness Survey Data to analyze the Nørrebro community's opinion of the project. The group recommends Miljøpunkt Nørrebro use the Benefits of Daylighting the Ladegårdsåen report, in Appendix D, when seeking funding and support for the Ladegårdsåen Daylighting Project. Miljøpunkt Nørrebro should utilize this report as a resource containing detailed specifics of the various aspects of the Ladegårdsåen Daylighting Project. They can show the report to politicians, interested community members, potential project funders, and anyone who is looking to gain in-depth knowledge about the project.

In addition to the benefits report, the team recommends using the Benefits of Daylighting the Ladegårdsåen presentation (in Appendix E) to gain support for the project. The presentation summarizes the Ladegårdsåen Daylighting Project and should be used by Miljøpunkt Nørrebro when educating community members and potential project sponsors. The presentation is less detailed than the report, but acts as a brief overview of the problems Nørrebro is dealing with and how the solutions for many of them are in the Ladegårdsåen Daylighting Project. The team recommends using the presentation for the majority of future community education efforts, because it succinctly provides an audience with understandable information about the project. Miljøpunkt Nørrebro can use the presentation whenever they need to provide a project stakeholder with an overview of the project, as it is not as detailed as the benefits report. Similarly to the report, these stakeholders can be politicians, community members, and potential project sponsors.

## 5.2 Visual Display Recommendation

The team recommends that Miljøpunkt Nørrebro try to obtain funding to create a dynamic sign in Nørrebro. If they can receive adequate funding for this project, they should install the sign either next to the bike counter on the Dronning Louises Bro, or in the Nørrebro Runddel. If Miljøpunkt Nørrebro is not able to get sufficient funding, the team recommends that they develop a smartphone application instead. The smartphone application could be an intermediate step for a dynamic sign; it could be used to gain support for the endeavor before building a sign. If this were to happen, the app and dynamic sign could both be used together to educate the community of Nørrebro about the pollution levels in the area. Regardless of the communication tool, the team recommends that Miljøpunkt Nørrebro use the

Speedometer Display as the design, and that they use the pollution sensor data from H.C. Anderson Boulevard sensor. They should also use the moving weighted average smoothing and CAQI methods described to format the pollution data into a universally understood format. With these recommendations, the team hopes that Miljøpunkt Nørrebro will be able to create an effective communication tool for education the community about the air pollution levels in the neighborhood. Appendix F contains the full Visual Display Recommendation report that the team gave to Miljøpunkt Nørrebro.

### 5.3 Recommendations for Next Steps

In terms of actually gaining public support for the Ladegårdsåen Daylighting Project, Miljøpunkt Nørrebro needs to make an active effort to educate the Nørrebro community about the project. Since Nørrebro Pollution Awareness Survey data showed that of the 60% of the respondents who had not heard of the project, half of them were in favor of it, there needs to be an active push to make the public aware of the proposed project. The team recommends for Miljøpunkt Nørrebro to be more aggressive in their community education efforts. For the municipality to approve the Ladegårdsåen Daylighting Project, they need to be convinced that the community wants the project, but this cannot happen if the public does not know about it. While Miljøpunkt Nørrebro can use the Benefits of Daylighting the Ladegårdsåen report and presentation to convince the public of the positives of the project, they first need to make them aware that this proposal exists.

Additionally, Miljøpunkt Nørrebro needs to start focusing on the reasons why people are already in favor of the Ladegårdsåen Daylighting Project. The survey results shows that the most popular reasons that people liked the project were because it will remove traffic and add more green space to the area. This investigation provided evidence of the benefits of the Ladegårdsåen project, but it did not emphasize the aspects that were import to the community. In the future, the team recommends conducting a more thorough analysis of the extent of the traffic removal and the addition of green space in the area. If possible, Miljøpunkt Nørrebro should estimate the decrease in traffic that would result from the proposed solution, and determine what benefits this would have on Nørrebro. They should do the same in regards to green space, and determine how much green space the project will add and stress the improvements that this would bring to the area.

Of the people the team surveyed, more people were concerned about Nørrebro's noise pollution problem, rather than air pollution. However, the team chose not to display noise pollution on the visual display because there is currently no system in place to measure real-time noise pollution in the area.

Since people believed that noise pollution is a bigger problem than air pollution, it would be beneficial if there were a method of measuring real-time noise pollution, similar to the air pollution sensors. One suggestion is to install noise sensors throughout the neighborhood, specifically in the same locations as the current air pollution sensors. If this were to happen, it might be possible for a future project to incorporate this data into a communication tool of their own, or to add it to the one that this team has recommended.

## 5.4 Conclusion

The team presented Miljøpunkt Nørrebro with the Benefits of Daylighting the Ladegårdsåen report, the Benefits of Daylighting the Ladegårdsåen presentation, and the Visual Display Recommendation. Using with these tools, there needs to be an increased effort of community outreach, as the public needs to be more informed of the Ladegårdsåen Daylighting Project before Miljøpunkt Nørrebro can expect them to support it. When spreading awareness of the project, community outreach efforts need to focus on topics that are important to the Nørrebro community, such as traffic removal, additional green space, and noise pollution. It is the team's hope that their deliverables and recommendations will help Miljøpunkt Nørrebro gain long-lasting support for the Ladegårdsåen Daylighting Project.

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# Appendix A: Gantt Chart of Project Timeline

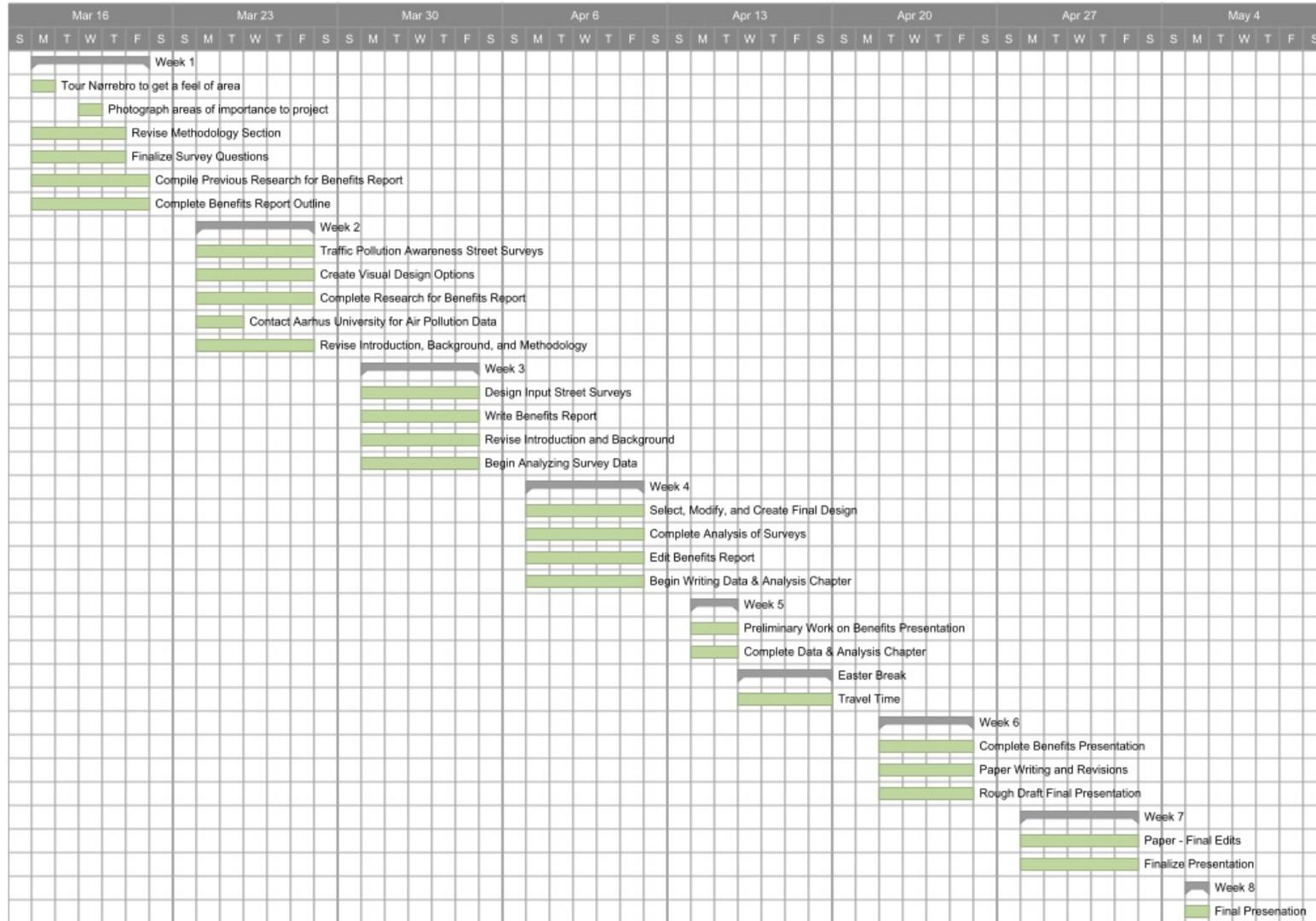


FIGURE 41: APPENDIX A GANTT CHART OF PROJECT

## Appendix B: Nørrebro Pollution Awareness Survey

### Nørrebro Pollution Awareness Survey

*We are students from Worcester Polytechnic Institute in Massachusetts, USA, and we are working on a research project in collaboration with Miljøpunkt Nørrebro. We would like to invite you to participate in a research study which aims at collecting data about the current level of public knowledge about the pollution levels in Nørrebro. This survey is voluntary and the data collected is strictly confidential. All participants will NOT be identified individually and you have the option not to answer a particular question. The data collected will be analyzed and used to identify any gaps in public knowledge which can then be addressed as appropriate. Please note that if you don't know the answer or don't want to answer a particular question than leave it blank. You agree to take part in this survey by completing the questions below.*

- Vi er studerende fra Worcester Polytechnic Institute in Massachusetts, USA og arbejder på et research projekt sammen med Miljøpunkt Nørrebro
- Denne undersøgelse handler om at indsamle data omkring viden om forurening fra trafik på Nørrebro
- Deltagelse er selvfølgelig frivillig og den indsamlede data behandles fortroligt og individuelle deltagernes identitet er ikke identificerbar.
- Data vil blive brugt til at identificere områder der ikke er tilstrækkeligt viden og som derefter kan forbedres.
- Hvis der er spørgsmål du ikke ønsker at svare på end kan svare på, blot svare blankt.

#### Demographics:

1. Age / Alder: \_\_\_\_\_
2. Gender
  - a. Male / Mand
  - b. Female / Kvinde
  - c. Other / Andet: \_\_\_\_\_
3. Marital status
  - a. Married / Gift
  - b. Cohabiting/ Samlever
  - c. Not married / ugift

4. Do you have children? Har du nogle børn?: \_\_\_\_\_
  - a. If yes, how many? / Hvis ja, hvor mange?: \_\_\_\_\_
5. Employment status / Arbejdssituation
  - a. Employed / I Arbejde
  - b. Unemployed / Arbejdsløs
6. Do you own a car? / Har du bil?: \_\_\_\_\_
7. Connection to Nørrebro / Forbindelse til Nørrebro
  - a. Live in neighborhood / Bor du på Nørrebro
  - b. Work in neighborhood / Arbejder du på Nørrebro
  - c. Commute through / Pendler du gennem Nørrebro
  - d. Other / Andet: \_\_\_\_\_
8. How do you commute to work? / Hvordan pendler du til arbejde?
  - a. Walk / Går
  - b. Bike / Cykler
  - c. Public transportation / Offentlig Transport
  - d. Car / Bil

Survey Questions:

9. What do you know about traffic pollution? / Hvor meget ved du om forurening fra trafik?
- 

10. Rate the current level of air pollution in Nørrebro. Use scale 1 to 10, where 1 is minimal to no pollution and 10 is severely polluted. / Niveau af forurening fra 1 – 10

Unknown	1	2	3	4	5	6	7	8	9	10
Ukendt	Low									High

11. What makes you think this? Check all that apply / Hvorfor tror du dette?

- Car pollution / Bil forurening
- Truck pollution / lastbil forurening
- Industry/manufacturing pollution / Industri forurening
- Pollution due to weather / Vejr forurening
- There is no air pollution in Nørrebro / Der er ingen af forurening

Other: \_\_\_\_\_ / Andet: \_\_\_\_\_

12. Rate the current level of noise pollution in Nørrebro. Use a scale 1 to 10, where 1 is minimal to no pollution and 10 is severely polluted. / Niveau for støj forurening fra 1-10

Unknown	1	2	3	4	5	6	7	8	9	10
Ukendt	Low									High

13. What makes you think this? / Hvorfor tror du dette?

Traffic noise / trafik støj

Noise from surrounding shops, restaurants, homes / støj fra nærliggende bygninger

Noise from industry/manufacturing / støj fra industri

There is no noise pollution in Nørrebro / Der er ingen støj forurening

Other: \_\_\_\_\_ / Andet: \_\_\_\_\_

14. How informed do you feel about the health effects of traffic pollution? Rate this on a scale from, 1 – 10, where 1 is completely unformed and 10 is highly informed. / Hvor stor er din viden om sundheds skader fra trafik forurening fra 1-10?

Unknown	1	2	3	4	5	6	7	8	9	10
Ukendt	Low									High

15. Have you heard about the Ladegårdsåen Daylighting Project? This project involves bringing the Ladegårdsåen canal above ground and constructing a tunnel for Ågade and Åboulvarden to move car traffic underground. / Har du hørt om Ladegårdså projektet?

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16. Do you think that it is a good idea? / Synes du det er en god idé?: \_\_\_\_\_

a. Why or why not? / Hvorfor eller hvorfor ikke?

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17. Decreasing the number of cars that drive through Nørrebro is beneficial to the neighborhood." How much do you agree with this statement? / "Sænkning af antallet af biler der kører igennem Nørrebro vil blive en fordel for bydelen". Hvordan stiller du dig til denne udtalelse ?

a. Strongly agree / Meget enig

- b. Agree / Enig
- c. Neutral / Neutral
- d. Disagree / Uenig
- e. Strongly disagree / Meget uenig

18. As part of our project, we are creating a visual representation of real-time pollution data in Nørrebro. This will aide in an effort to keep the public more informed about the pollution levels in their own neighborhood. Where in Nørrebro would you like to see this type of sign installed? / Hvis der skal placeres en interaktivt stander der informerer om niveauet af forurening. Dette vil forbedre mulighederne for at informere beboere I bydelen om niveauet for luft forurening. Hvor så du den gerne placeres?

---

19. Would you be interested in being contacted to participate in a focus group or a presentation regarding your thoughts on a dynamic sign? / Vil du kunne være interesseret I at deltage I en præsentation og focus gruppe om udformningen af en interaktiv stander?

- b. If yes, can we have your name and email? / Hvis ja, kan vi få dit navn og e-mail?

Name / navn: \_\_\_\_\_

e-mail / e-mail: \_\_\_\_\_

## Appendix C: Community Feedback Charrette Questions

### Community Feedback Survey

*We are students from Worcester Polytechnic Institute in Massachusetts, USA, and we are working on a research project in collaboration with Miljøpunkt Nørrebro. We would like to invite you to participate in a research study that aims at gathering information about the public's response to various visual display designs.. This survey is voluntary and the data collected is strictly confidential. All participants will NOT be identified individually and you have the option not to answer a particular question. The data collected will be analyzed and used to identify any clear winners or changes in the designs. Please note that if you do not know the answer or do not want to answer a particular question than leave it blank. You agree to take part in this survey by completing the questions below.*

- ***Vi er studerende fra Worcester Polytechnic Institute i Massachusetts, USA, og vi arbejder på et forskningsprojekt i samarbejde med Miljøpunkt Nørrebro.***
- ***Vi vil gerne invitere dig til at deltage i dette, som har til formål at indsamle oplysninger om deltagernes reaktion på forskellige visuelle display designs.***
- ***Denne undersøgelse er frivillig, og de indsamlede data er strengt fortrolig. Alle deltagere vil IKKE kunne identificeres individuelt, og du har mulighed for ikke at besvare et bestemt spørgsmål. De indsamlede data vil blive analyseret og brugt til at identificere det foretrukne design eller ændringer i design.***
- ***Bemærk, at hvis du er usikker på svaret eller ikke ønsker at besvare et bestemt spørgsmål kan du bare lade det stå tomt. Du accepterer at deltage i denne undersøgelse ved at udfylde nedenstående spørgsmål.***

*The images you will be shown are potential designs for a communication tool displaying the current traffic pollution levels in Nørrebro. The tool has the potential to take the form of a road sign, a website, an app, or a widget. Regardless of the type of communication tool that is eventually created, the design will display real-time data regarding the traffic pollution in Nørrebro.*

De billeder, du bliver vist er mulige design for et kommunikationsværktøj der viser den aktuelle forureningsniveauer fra biler på Nørrebro. Værktøjet har potentiale til at tage form af et vejskilt, et website, en app eller en widget. Uanset hvilken type kommunikation værktøj, der i sidste ende skabte vil udformningen vise real-time data om trafik forurening på Nørrebro.

1. Age / Alder: \_\_\_\_\_
2. Gender
  - a. Male / Mand
  - b. Female / Kvinde
  - c. Other / Andet: \_\_\_\_\_
3. Connection to Nørrebro / Forbindelse til Nørrebro
  - a. Live in neighborhood / Bor du på Nørrebro
  - b. Work in neighborhood / Arbejder du på Nørrebro
  - c. Commute through / Pendler du gennem Nørrebro
  - d. Other / Andet: \_\_\_\_\_
4. Which design has the strongest first impression? / **Hvilke design har givet det stærkeste første indtryk ?**
  - a. Speedometer
  - b. Pie Chart
  - c. Bar Display
5. Which design is the easiest to understand? / **Hvilke design er det nemmeste at forstå ?**
  - a. Speedometer
  - b. Pie Chart
  - c. Bar Display
6. Which design is the most difficult to understand? / **Hvilke design er det sværeste at forstå ?**
  - a. Speedometer
  - b. Pie Chart
  - c. Bar Display
7. Which design would you like to see developed into a communication tool for Nørrebro? / **Hvilke design vil du helst se udviklet til et kommunikations værktøj for Nørrebro ?**
  - a. Speedometer
  - b. Pie Chart
  - c. Bar Display

8. Would you rather see this information displayed as a sign, website, widget, or app? / **Hvordan vil du helst oplysninger om forurening ?**
- a. Dynamic Sign / **Som et dynamisk skilt I det offentlige rum ?**
  - b. Website / **Som en hjemmeside ?**
  - c. Widget / **Som indhold på andre hjemmesider ?**
  - d. App / **Som en app til smartphone ?**

9. Would you recommend any changes for the speedometer design? If yes, state them below: / **Vil du foreslå ændringer I design Speedometer. Hvis ja, skriv her:**

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---

10. Would you recommend any changes for pie chart design? If yes, state them below: / **Vil du foreslå ændringer I design Pie Chart. Hvis ja, skriv her:**

---

---

11. Would you recommend any changes for bar display design? If yes, state them below: / **Vil du foreslå ændringer I design Bar Display. Hvis ja, skriv her:**

---

---

12. Do you have any other comments that you would like to share with us about any of the designs? Please state them below: / **Har du yderligere kommentarer du gerne vil dele med os om de enkelte design ? Skriv herunder:**

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13. If the chosen design were to be made into a sign, where in Nørrebro would you like to see it installed? / **Hvis det valgte design bliver virkeliggjort som et dynamisk skilt, hvor ser du det helst placeret ?**

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# Appendix D: Benefits for Daylighting the Ladegårdsåen Report

## 1.0 Introduction

For the last few years, cities around the world have started to daylight their rivers. Daylighting is the process in which rivers that were previously put into a pipeline below ground are restored to their original state above ground and exposed to the sunlight. In places as varied as Seoul, South Korea and Yonkers, New York, cities are daylighting bodies of water to beautify the area and provide natural spaces for their citizens. Cities also use daylighted rivers for stormwater management during times of heavy flooding. There is currently a proposed daylighting project to restore the Ladegårdsåen in Copenhagen, Denmark (Ruddy et al., 2012). The canal resides under the Ågade and Åboulevard, two roads that form the southern border of Nørrebro, one of Copenhagen's ten districts.

The plan is to strip the two roads and free the stream from its pipeline, making it a normal canal once again. A tunnel will then be built underneath the Ladegårdsåen to accommodate the displaced traffic. In case of heavy rain, the city will be able to use one side of the tunnel for stormwater storage while leaving the other side open to traffic. The Ladegårdsåen Daylighting project solves multiple problems with its one solution: it will manage stormwater, assist in flood prevention, provide natural green space in Nørrebro, and reduce the traffic pollution in the area.

The purpose of this paper is to provide evidence that the Ladegårdsåen Daylighting project will be beneficial, with many long-term positive outcomes. Due to the uniqueness of this project, there are no examples of daylighting a river and rebuilding the stripped road as a tunnel underneath it. Since the project involves stripping a road, daylighting a river, building a tunnel, creating floodwater storage, and providing green space, this report will detail each of these various components which have been seen in previous construction projects, including their impact on pollution levels in the area.

This report begins by detailing the Ladegårdsåen Daylighting Project in chapter 2. Chapter 3 provides background information on pertinent topics. The topics include traffic pollution, green space, and tunnels. Following the background research, chapter 4 examines relevant case studies about roadways, tunneling roads, storm water managements, daylighting rivers, and construction projects. The report ends with Chapter 5, which summarizes the benefits and examines the public opinion of the Ladegårdsåen Daylighting Project.

## 2.0 Ladegårdsåen Daylighting Project

On July 2, 2011, a cloudburst dumped 6 inches of water within a two hour period on Copenhagen, Denmark, heavily flooding the streets (see Figure 42). According to the city's Parks and Nature Department, the flash storm caused an estimated 6 billion Danish Kroner (DKK) in damage (Gerdes, 2012). To prevent billions more kroner worth of damage from storms, Copenhagen has put 42 million DKK towards researching innovative solutions. There have been about twenty small projects proposed, such as the renovation of Amagerbrogade to reduce car traffic, and flood protection of St. Annae (Jensen, 2012). The largest of these proposed projects is the Daylighting of the Ladegårdsåen (Ruddy et al., 2012).



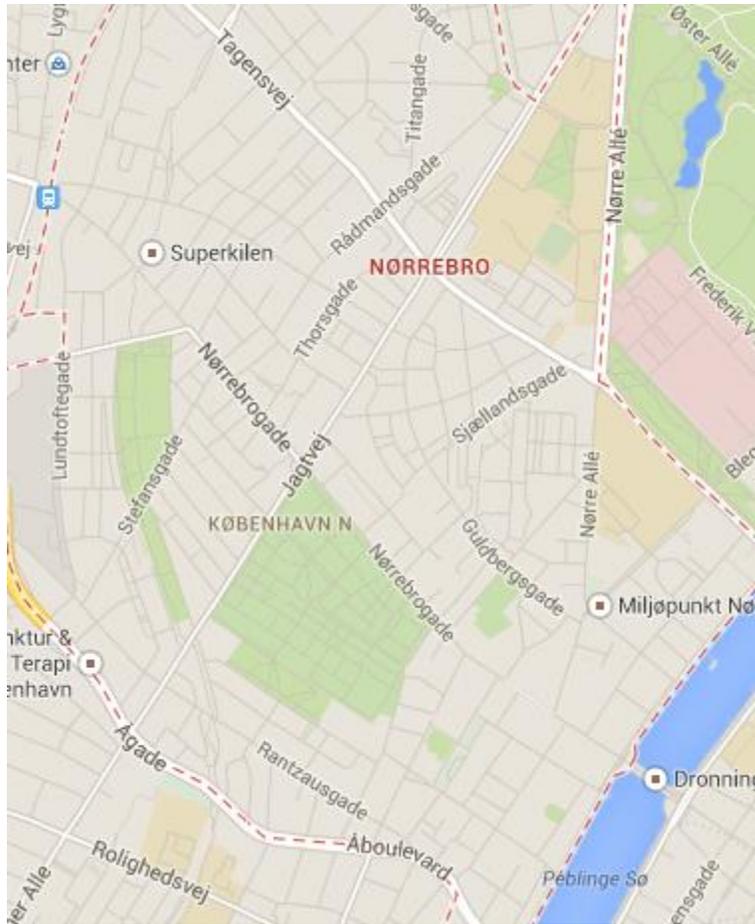
**FIGURE 42: APPENDIX D 2011 FLOODING (JENSEN, 2012)**

Prior to the 20<sup>th</sup> century, the Ladegårdsåen was a canal that was central to life in Nørrebro. It began in Damhussøen and emptied into the Lakes, five rectangular bodies of water located along the edge of Nørrebro. Local residents used it to cook, clean, bathe, and play in. In 1897, the city of Copenhagen redirected the river into a pipe and paved over it to adapt to the rapidly expanding population, which needed more roadways. Today, these roads are known as Ågade and Åboulevard (Ruddy et al., 2012).

Following the flooding in 2011, a group of students from Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts worked with Miljøpunkt Nørrebro to develop a solution to the flooding problem, which ultimately became the Ladegårdsåen Daylighting Project. The plan is to remove Ågade

and Åboulevard, daylight the Ladegårdsåen, remove the Bidspeengbuen Bridge that leads into Ågade from the west, direct traffic underground into a stormwater management and traffic tunnel, and cultivate the surface around the river into a lush park for residents to enjoy (Ruddy et al., 2012).

The project gained publicity in the fall of 2013 after Miljøpunkt Nørrebro acquired 11,500 signatures for a petition in support of it. Lord Mayor of Copenhagen, Frank Jensen, fully supports the Daylighting Project. He has approved 1 million DKK of exploratory funding over 2014 and 2015 to research the feasibility of the project. Jensen believes in the project because it is a practical solution to multiple problems that Copenhagen is facing, and it will be aesthetically pleasing (Chistensen, 2013). The City of Copenhagen is working with the Danish engineering consulting company, Ramboll, to estimate both the financial cost of the project and gauge the effect it will have on traffic during and after construction. Ramboll had previously estimated the cost to be 10-15 billion DKK, but has since changed the estimate to 4 billion DKK, due to a change in the construction plan. The tunnel was originally supposed to be a bored tunnel, but the plans have changed to be a cut-and-cover tunnel. This change was made in order to redirect the canal, but it has the added benefit of reducing the construction costs to a more feasible level. Ramboll believes that Copenhagen will see traffic reductions in the surrounding streets, particularly those that currently intersect Ågade and Åboulevard. The most important of these streets is Jagtvej, a road that connects three main roads in Nørrebro that all run in parallel: Åboulevard, Nørrebrogade, and Tagensvej (Chistensen, 2013). Figure 43 shows how Jagtvej runs through Nørrebro and its three main parallel roads. Cutting off Åboulevard from intersecting traffic will mean that there will be minimal traffic on Jagtvej between Åboulevard and Nørrebrogade.



**FIGURE 43: APPENDIX D MAP OF NØRREBRO DISPLAYING JAGTVEJ, ÅGADE, NØRREBROGADE, AND TAGENSVEJ**

The main purpose of the Ladegårdsåen Daylighting Project is to manage stormwater runoff, and prevent another cloudburst from causing extensive damage to local homes and businesses. The design of the canal is meant to be both aesthetically pleasing and effective in preventing damage. The canal has a stepped, double profile design, as shown in Figure 44, that allows water to be captured from the streets and rooftops. The municipality can use this water as semi-clean water for flushing toilets, for heating, and washing. This will reduce stress on sewers and the drinking water supply (Ruddy et al., 2012). When the canal is not being used to hold floodwater, the public can use the steps along the canal for biking, walking, and enjoying the park. The proposed design is four meters wide (2 meters for the canal, and one meter on each side for the steps), but the space left by clearing the roads will provide enough room to create a park alongside the canal. The park will help manage floodwater as well as provide a beautiful, natural area for the residents to enjoy.

The tunnel that will run under the Ladegårdsåen Canal will become the primary mode of transportation for through-traffic in Nørrebro, and it is designed to aid in floodwater control as well. It is designed as a six-lane rectangle that will be divided in the middle to be two three-lane tunnels, with a smaller section in the middle. Each side of the tunnel will be for a different direction of traffic. A pair of pipes stacked on top of each other will reside in the middle section of the tunnel. The top pipe is designed to recycle the canal water by carrying from the end of the canal back to the beginning in order to keep the water flowing during dryer periods. The bottom pipe will transfer extra water to the harbor and machines that use semi-clean water. When the water in the canal gets too high, it will be placed in the bottom pipe. When that is not enough, the top pipe can also be used for storage. If the amount of stormwater is still too much for the canal and both pipes to handle, it can be diverted into one of the traffic tunnels. The tunnel used for storing floodwater will be closed from traffic, and the open tunnel will be converted to a small, two-way tunnel, with two lanes for one direction and one lane for the other direction (Ruddy et al., 2012). With the construction of this tunnel, there will no longer be a need for Bidspeengbuen, the bridge that connects to Ågade from the west and brings in large amounts of through-traffic. The tunnel will start from before the bridge and the road will go down into the tunnel, eliminating the need for the elevated highway.

Figure 44 is a cross-section of the tunnel and river. The canal is at the top, with its double stepped design, each step a meter wide. Beyond the two steps is greenery, which is currently dubbed Åpark. Underneath is the design for the tunnel. In the middle are the two pipes that carry water back and forth between the source and outlet of the river. The two rectangles on either side are the tunnels for traffic, with the one on the right filled up with water to demonstrate how the tunnel can store stormwater.

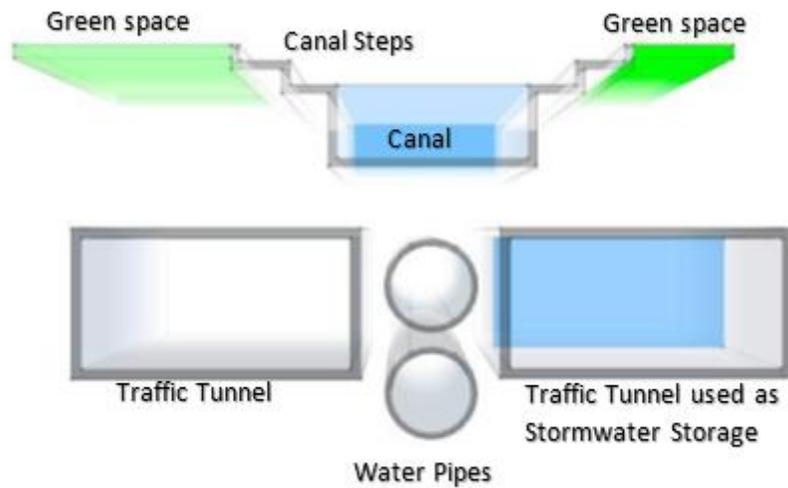


FIGURE 44: APPENDIX D CROSS SECTION OF PROPOSED TUNNEL DESIGN (RUDDY ET AL., 2012)

While preventing floods and the billions of kroner of damage they cause is the primary motive behind this project, the environmental impact is crucial as well. The project will also have a critical impact in regards to traffic pollution. As a result, the level of air and noise pollution in Nørrebro will decrease and the overall health of the community will increase. The majority of this report is dedicated to providing evidence of the benefits of the Ladegårdsåen Daylighting Project by using peer-reviewed studies and analyzing previously completed projects.

### 3.0 Background Research

#### 3.1 Traffic Pollution

Traffic is a normal occurrence in any heavily populated urban area, and it is one of the main reasons for the typically high levels of pollution, compared to less populated areas. Heavy automobile traffic results in two forms of pollution: air and noise pollution. Air pollution is a result of the fuel emissions given off by the exhaust pipes in a car. Sounds such as car horns, emergency vehicle sirens, construction on the roads, etc., can cause noise pollution. These heavy levels of pollution can negatively affect the lives of those who experience it, as prolonged exposure to both air and noise pollution can be detrimental to both a person's physical and mental well-being. In Denmark alone, pollution from traffic kills 4000 people a year, compared to 400 a year from traffic accidents (Glaser et al., 2013). Nørrebro experiences a particularly severe level of traffic-related pollution, leading to the exploration of its associated health effects.

### 3.1.1 Air Pollution and Health Effects

There are four types of air pollution: gaseous pollutants, persistent organic pollutants, heavy metals, and particulate matter. The combustion of fossil fuels, in both stationary and mobile combustion sources, creates gaseous pollutants. They consist of chemicals such as SO<sub>2</sub>, NO<sub>2</sub>, ozone, and Volatile Organic Compounds (VOCs). The majority of this pollution type comes from combustion that occurs in transportation vehicles, when exhaust emissions give off VOCs. Persistent organic pollutants are a group of toxic chemicals that include pesticides, dioxins, furans, and PCDs. Created in any industrialized process including combustion; dioxins make up the largest part of these pollutants. People living in more industrialized areas tend to have higher levels of dioxins in their systems (Schechter et al., 2006). Persistent organic pollutants tend to enter food sources, which magnifies their negative health effects every time they move up the food chain due to a process called bio-magnification. Heavy metal pollution includes elements such as lead, mercury, chromium, nickel, and other heavy metals, which come from the earth's crust and are indestructible. They can enter the earth's water and food supply by traveling through air and combustion reaction and manufacturing facilities can introduce additional metals to the atmosphere. Particulate matter pollution consists of pollution particles that are suspended in the air that people breathe. These particles come from factories, automobiles, construction sites, and many other places. Many things make up particulate matter, including metal, organic compounds, reactive gases, ozone, and ions. It can also be a variety of sizes, ranging from 1 µm to 10 µm, and smaller particles tend to be more hazardous than larger ones. Most particulate matter is labeled as PM10 and PM25. PM10 refers to particles that are below 10 micrometers, and PM25 refers to particles that are below 2.5 micrometers (Kampa & Castanas, 2008; Katsouyanni, 2003). A vehicle's combustion system produces gaseous pollutants, heavy metal pollutants, particulate matter, and persistent organic pollutants, and then releases them through the exhaust pipe. The examination of all forms of air pollution is necessary in order to fully understand the severity of the health problems associated with traffic pollution.

#### 3.1.1.1 EFFECT OF AIR POLLUTION ON THE RESPIRATORY SYSTEM

Exposure to air pollution can have a severe impact on the respiratory system. Noise and throat irritation are symptoms of exposure to gaseous and heavy metal pollutants. Particularly harmful pollutants include nitrous oxides, ozone (O<sub>3</sub>), sulfur dioxide, arsenic, and nickel. They can increase the risk for chronic bronchitis, asthma, emphysema, and lung cancer, as well as worsen pre-existing conditions such as lung lesions or lung diseases (Kampa & Castanas, 2008; Künzli & Tager, 2005). At 25 million diagnosed patients, the United States currently has a huge problem with asthma (NRDC, 2014).

Studies have shown a strong correlation between respiratory health and air pollution. Researchers in Switzerland, tracked pollution and respiratory illnesses in the area over an 11-year period. The research showed that as the air pollution in the area decreased, so did the reported cases of chronic coughing, wheezing, and breathlessness in adults and children (Kelly & Fussell, 2011). Air pollution also exacerbates symptoms of pre-existing Chronic Obstructive Pulmonary Disease (COPD). Those who have COPD do not develop it from air pollution, but their symptoms worsen when exposed to particulate matter. There have also been reports of decreases in pulmonary function, increased frequency of bronchodilator use, and higher mortality in COPD patients who moved to areas with higher air pollution (Kelly & Fussell, 2011).

#### 3.1.1.2 EFFECT OF AIR POLLUTION ON THE CARDIOVASCULAR SYSTEM

The cardiovascular system is extremely susceptible to the negative effects of air pollution. Heavy metal pollution can increase blood pressure and tachycardia, which is a faster than normal heart rate. Particulate matter can affect blood clotting and lead to angina or myocardial infarctions (Kampa & Castanas, 2008). Increased levels of air pollution can also result in higher risks for arrhythmia, thrombosis, and strokes (Künzli & Tager, 2005).

#### 3.1.1.3 EFFECT OF AIR POLLUTION ON THE URINARY AND NERVOUS SYSTEMS

Heavy metal pollution negatively affects both the nervous system and the urinary system. Exposure to these metals can result in neurotoxicity, which can cause memory loss, sleep disorders, tremors, fatigue, blurred vision, and slurred speech. Mercury, in particular, causes certain types of neurological cancer. Heavy metals can also cause kidney damage, increase the risk of kidney stones, and increase the risk of renal cancer (Kampa & Castanas, 2008).

#### 3.1.1.4 THE OVERALL HEALTH RISKS OF AIR POLLUTION

A study conducted in Austria, France, and Switzerland showed that air pollution causes 6% of the combined total deaths in these countries every year. Half of these fatalities were caused by traffic-related air pollution (Künzli et al., 2000). Specifically within Denmark, approximately 3400 people die each year from medical conditions as a result of traffic air pollution (Glaser et al., 2013). Exposure to air pollution results in more deaths than traffic accidents. For every  $10 \mu\text{m}/\text{m}^3$  increase in daily air pollution exposure, there is 0.5% increase in the number of associated respiratory or cardiovascular-related deaths (Künzli & Tager, 2005). Living in areas with high levels of air pollution shortens a person's life expectancy by 1-2 years, which is relatively large compared to other environmental factors (Brunekreef & Holgate, 2002).

Each element of air pollution has specific chemical reactions with the body that can be very dangerous. Carbon Monoxide (CO) causes many health problems, the worst of which is death when exposed to very

high amounts of CO. When carbon monoxide is inhaled, it enters the blood stream and binds to hemoglobin, the oxygen-carrying chemical in red blood cells, to form carboxyhemoglobin. The binding strength between carbon monoxide and hemoglobin is 210 times stronger than oxygen and hemoglobin, which means that carbon monoxide blocks red blood cells from being able to utilize any oxygen that a person inhales(Hamilton & Harrison, 1991). This effect is similar to that of severe anemia. After 5% of hemoglobin becomes to carboxyhemoglobin, the symptoms begin to appear. With increasing intensity, symptoms include headaches, loss of vision, impairment of judgment, nausea, coma, convulsions and death. Death occurs when 70% of a body's hemoglobin converts to carboxyhemoglobin. Smokers are at an increased risk of suffering from CO poisoning because they already have approximately 7-9% converted hemoglobin from cigarettes alone. The chronic effects of exposure to low levels of carbon monoxide are not well understood and there has been much debate over them, though some studies have shown links between cardiovascular disease and carbon monoxide(Hamilton & Harrison, 1991).

Nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>) are two gases released from vehicles during combustion; they are usually grouped together with other compounds and called NO<sub>x</sub>. Nitric oxide is by far the more abundant, but has little to no effect on human health. Combustion produces very low quantities of nitrogen dioxide, but is harmful to the respiratory systems of several animal species, including humans(Henry, Ehrlich, & Blair, 1970). Although it is not harmful on its own, nitric oxide reacts with oxygen in the air to form nitrogen dioxide, which both removes oxygen from the air as well as replaces it with a toxic gas that contributes to smog and harms humans. Prolonged exposure to NO<sub>2</sub> causes irritation of air passages, lowers resistance to bacterial infections, and reduces respiratory function in mice, rats, guinea pigs, dogs, squirrel monkeys, and humans (Henry et al., 1970).

### 3.1.2 Noise Pollution and Health Effects

Noise pollution is any loud or disruptive sound caused by airplanes, automobiles, trains, etc. that is annoying and/or detrimental to the health of the people who experience it ("Noise Pollution," n.d.). Theoretically, anything that can make a sound can contribute to noise pollution, including everyday things such as a neighbor playing their stereo too loud or emergency sirens passing by a building (Bronzaft, 1996). Noise pollution tends to occur more in higher populated and urban areas, such as cities and airports, due to the increased volume of automobiles, low-flying planes, and other key contributors to noise pollution. Poor urban planning can also contribute to higher noise pollution levels. In places where residential and industrial buildings are situated close to each other, increased levels of noise pollution can be experienced by the people living in the residential area ("Noise Pollution," n.d.). Noise pollution can have a surprisingly

detrimental effect on a person's health. In Denmark alone, it kills 600 people each year because of the consequential health effects that noise has on the human body (Glaser et al., 2013).

#### 3.1.2.1 THE EFFECT OF NOISE POLLUTION ON SLEEP

Noise pollution can have a serious effect on a person's ability to get a good night's sleep, which can lead to adverse psychological and physiological health effects. Sleep is an essential part of resting after a long day, and without proper recuperation during sleep, one may be unable to refresh his or herself, which can be detrimental to both one's physical and mental health. Sleep loss from noise disturbance can result in poorer task-performance and can make a person less attentive during the day, which can make one more accident prone, as they are less aware of potential danger around them. Studies have also shown that people who were exposed to high levels of noise pollution while sleeping tended to be unhappier the next day and more irritable overall. Nighttime noise disturbances can change people's sleep patterns, as well as increase their heart rate and blood pressure (S. Stansfeld & Matheson, 2003). People who live in noise-polluted areas are more likely to use sleep aids such as tranquilizers regularly, which can lead to many other negative health effects as well (Bronzaft, 2002).

#### 3.1.2.2 THE PSYCHOLOGICAL EFFECTS OF NOISE POLLUTION

A major human reaction to noise pollution is annoyance, and this increase in annoyance can lead to psychological effects, which can ultimately decrease a person's mental health. People exposed to higher amounts of noise pollution are more likely to get into aggressive disputes with their neighbors and react violently to stressful situations. In addition, people tend to ignore others around them when walking in a noisy urban area, even if they are asking for help (Bronzaft, 1996). Exposure to noise pollution can slow a person's memory rehearsal and affect their memory's selectivity, as well as decrease their ability to pick up on normal social cues (S. Stansfeld & Matheson, 2003). K. Hiramatsu and her associates conducted a study on the people who reside near the Kadena Air Base in Ryukyu, Japan, an area with a large amount of air pollution from the heavy air traffic near the base. These researchers conducted a survey asking people about their perception of their mental well-being. Those who lived closer to the air base, and thus experienced higher levels of noise pollution, reported that they felt more mentally unstable, depressed, and nervous than those who lived further away, showing the negative correlation between noise pollution and mental health (Hiramatsu et al., 1997). There is also evidence that a change in a person's environment that leads to higher levels of noise pollution can aggravate pre-existing mental and emotional health problems, leading to psychologist intervention for a problem that a potential patient would have normally been able to handle on their own (Bronzaft, 2002).

### 3.1.2.3 THE PHYSIOLOGICAL EFFECTS OF NOISE POLLUTION

Researchers have most convincingly linked exposure to high levels of noise pollution to harmful effects on the cardiovascular system. This can be attributed to the stress that a person undergoes while experiencing high levels of noise pollution, as high stress levels have been proven detrimental to a person's health, most notably to the cardiovascular system (Bronzaft, 1996). Studies have definitively shown that people who regularly experience noise levels of 85 dB have significantly higher blood pressure than those who experience less noise.

High levels of noise exposure can lead to treatment for hypertension and other heart problems. Although there have also been studies done that have shown relations between noise pollution and effects on cholesterol levels, total triglycerides, blood viscosity, platelet count and glucose levels, these relationships have not been conclusively proven (S. Stansfeld & Matheson, 2003). Each year in Denmark, 200-500 people die from cardiovascular problems that can be traced back to noise pollution from traffic (Glaser et al., 2013).

Noise pollution can affect other parts of the human body such as the gastrointestinal and circulatory systems, hearing, and any other weakened area of the body. People who chronically experience noise pollution are more likely to have hearing loss than those who do not. A study comparing a typical United States population and Maaban tribesmen proved that repeated exposure to moderate to high levels of noise can lead to an increase in hearing loss ("Noise Pollution," 2012). Exposure to high noise levels in industry settings can cause increased levels of noradrenaline and adrenaline secretion. People who experience regular noise pollution have reported that they feel like they are in worse health than those who have very little noise pollution in their everyday lives. People have also reported that high noise levels render them unable to do normal activities such as having conversations, watching TV, and opening windows, as the noises around them were too disrupting to partake in these activities.

### 3.1.2.4 THE EFFECT OF NOISE POLLUTION ON CHILDREN

Noise pollution affects children the most, because they are the most vulnerable demographic. Similar to noise-exposed adults, noise-exposed children are at the same risk for increased stress levels, detrimental cardiovascular effects, and raised adrenaline and noradrenaline levels. A notable study examined the effects of noise pollution on primary school children within four 32-floor apartment buildings on a busy road. The researchers assumed that children living on the lower floors would experience more noise disturbances from the road than those living on higher floors. They tested Seventy-three children for

reading comprehension and auditory discrimination and it concluded that the children living on the floors closer to the road had significantly lower scores for these tests.

Children exposed to chronic noise have a harder time concentrating than children who are more often in quieter settings. There is evidence suggesting that noise exposure negatively affects a child's cognitive functions such as central processing and language comprehension. Noise pollution also affects children's performance on standardized tests and their memory for high processing problems. Regular noise exposure decreases a child's motivation. Studies have found that children are more likely to give up on difficult puzzles if they have been exposed to high noise levels (S. Stansfeld & Matheson, 2003). Linear correlations exist between road and air traffic noise and children's annoyance levels, reading comprehension, and recognition memory (S. A. Stansfeld et al., 2005).

### 3.3 Green Space

Green space is defined as open land protected and valued for its natural processes and wildlife, aesthetic beauty, and public benefits (Agriculture, n.d.). In the 19<sup>th</sup> and 20<sup>th</sup> century, there was an influx of people moving into cities as the world entered the modern era. To accommodate the population increase, cities expanded outwards and upwards, leaving little open space. Green space was a luxury that cities could not afford as they tried to maintain their growing infrastructure. Now, in the 21<sup>st</sup> century, cities are rethinking their design and realizing the need for more public green space.

Green space can add value to urban landscape in multiple ways. Greenery's ability to reduce pollution has been documented on different occasions. Carbon dioxide is one of the biggest components of air pollution, produced by transportation, industry, homes, and humans. The only practical way to reduce carbon dioxide in the air is by planting trees, which use carbon dioxide in photosynthesis and release oxygen in to the air, and then use the remaining molecules to create carbon-based cellulose (Rowntree & Nowak, 1991). On top of this, certain bacteria in soil have the ability to eat oil. A study of six different petroleum products absorbed into soil over 14 plots of 5.1 m<sup>2</sup> land showed that the bacteria in the soil could reduce the amount of oil from 50-90% depending on the type of product (Raymond, Hudson, & Jamison, 1976). In total, green space purifies air, works as a rainwater storage system, improves and creates microclimates, absorbs noise pollution, and helps ensure socioenvironmental stability (W. Y. Chen & Jim, 2008).

In addition to the significant environmental benefit, green space also provides a psychological benefit to people, which in turn results in physiological benefits. Currently, half the world's population lives in cities, isolating them from natural landscapes (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007). Restoring

green space to a city improves the residents' well-beings significantly, as it promotes recreation and physical health while relieving mental and physical stresses (Zhou & Rana, 2012). A study conducted in the United Kingdom investigated the effects of walking in green space on stress levels and self-esteem. Researchers went to multiple parks and surveyed visitors before and after they walked through the trails. The researchers used the Rosenberg Self-Esteem Scale, a system widely used in popular clinical psychology, and qualitatively and quantitatively assessed the psychological effects of experiencing nature. They found a strong correlation between walking through the parks and increased self-esteem. Even many of the people who already had high self-esteem saw a slight increase. The data also found a decrease in negative emotions such as anger or sadness, and an increase in overall energy (Barton, Hine, & Pretty, 2009). However, these therapeutic effects only work if the green space has rich variety, as would be seen in true nature. A study of 15 green spaces in Sheffield, England showed that visitors' well-beings were most affected primarily by plant species richness, then bird species richness, and then insect species richness, in this case richness meaning the number of unique species (Fuller et al., 2007). Mental health effects such as lower stress levels have physical manifestations as well, including lower blood pressure and lower risk of cardiovascular disease (Zhou & Rana, 2012).

### 3.4 Tunnels

Tunnels are considered safer to the health of local residents because the particulate pollution does not directly enter the air and affects those who live around them; however, there are still pitfalls to consider. Traffic jams can be very dangerous in a tunnel, as carbon monoxide can build up at a rapid rate. Nørrebro has high levels of through traffic and its main roads are prone to traffic jams, so it is important to consider the various methods of safeguarding a tunnel against potential traffic-related hazards (Larsen, 2014). Simulations and measurements of the Melbourne Tunnel in Melbourne, Australia showed that even with the fans working at maximum power, carbon dioxide and carbon monoxide built up at a dangerous rate (Bari & Naser, 2010). If the power was to be interrupted or the ventilation system unexpectedly stopped working during a traffic jam, the tunnel would need to be evacuated. Except in the case of extreme circumstances, the level of pollution within a tunnel is perfectly manageable.

The Norwegian Public Roads Administration has developed guidelines for determining the pollution management requirements for a tunnel. The first step is to construct an impact analysis based on traffic patterns and check the pollution levels against the standards of the area. Ventilation systems for carbon monoxide are mandatory in case of emergencies or other situations in which there would be a traffic backup; however, the vents can consist of a very simple airway with a jet stream that allows the carbon

monoxide to escape. An air jet alone helps dilute and purify the air escaping the tunnel (NRPA, 2004). Depending on the layout of the airways, there are potential noise pollution concerns due to the jets that need to be taken into account along with the noise pollution from the traffic.

In situations with regularly high traffic that causes hazardous pollution levels, further measures are necessary. Filters can be placed within the exhaust shafts to collect particulate matter. Electrostatic filters can be highly effective, cleansing 80-95% of particles. These filters can also be installed in side tunnels as an overlaying installation. When installed in smaller side tunnels that run alongside the main tunnel, a special thermally activated carbon formation can be used to absorb NO<sub>2</sub> (Zhang, Bagreev, & Rasouli, 2008). If the problem cannot be solved using any of these methods, another more extreme method of pollution management involves the use of a cleaning plant that takes any and all pollution out of the tunnel and treats it using a scrubbing technique that pumps the exhaust into a water-based solvent that dissolves specific pollutants (NRPA, 2004).

One of the added benefits of building a tunnel is the control of noise pollution. As long as the tunnel is built properly, the sound from traffic stays within the tunnel instead of disturbing the lives of local residents. In a situation where the tunnel is not constructed properly, the noise reduction effect occurs only around the main body of the tunnel. A study found that the noise pollution does not simply disappear just because it is below ground; instead, the sound reverberates within the tunnel until it leaves out either end. The noise pollution is relocated and concentrated at the openings of the tunnel (Woehner, 1992). The only truly effective technique to reduce noise pollution is by using sound-absorbing material. Workers must place the material inside the walls in the understructure of the tunnel in order for it to be effective; when placed on the walls themselves, the material has almost no effect. Though expensive, the material actually reduces noise pollution instead of simply redirecting it (Herman et al., 1999).

## 4.0 Case Studies

While the previous chapter illustrated the health effects of air and noise pollution, including how and why they are so harmful, this chapter illustrates the effect that the various aspects of a large daylighting and tunneling project would have on pollution levels. Because there is no identical project to compare to, the different pieces of the project have been split up and individual case studies will be done for each component. These components are: the removal of roadways, building a large tunnel, using it for stormwater management, and daylighting a river.

## 4.1 Roadways

Major roadways create substantial levels of pollution for the surrounding area. Eleven percent of US households live within 100 meters of a major 4-lane highway. In the United States, governments only monitor and regulate pollution at a regional level, and ignore the increased exposure to pollutants at the community level for those living nearby. After 1000 meters, the effects are relatively homogeneous, but within 100m of a highway, the amount of pollution exponentially increases. The concentration of particulate pollution is five times higher in the first 30m within a highway than the next 30m (Brugge et al., 2007).

In the 1940's and 1950's, Americans began moving to the suburbs after World War II. Families found new wealth after the Great Depression and moved into homes that were less closely packed together than cities but more concentrated than the countryside. This appealed to people looking to be a part of a close community but avoid the squalor and chaos of cities. To compete with the clean and clear roadways of suburbs, U.S. cities built highways that helped commuters who had to travel from the suburbs to the cities every day. This resulted in freeways within cities that helped maximize traffic flow. In her seminal book, *The Death and Life of Great American Cities*, activist Jane Jacobs challenged this practice in urban development, criticizing it for cutting up cities and being completely opposed to the goal of connecting people (Jacobs, 1961). While highways were originally built to reduce traffic congestion for those needing to travel long distances at high speeds, traffic engineers studying travel habits concluded that access to highways induced greater overall traffic, since people bought more cars since space for them seemed more available. This induced traffic that kept the level of congestion the same, and cities were left with an infrastructure that split communities, degraded the environment, and displaced homes and businesses during construction (Bocarejo, LeCompte, & Zhou, 2012).

### 4.1.1 The Embarcadero Freeway

Many cities are finding it far more effective to remove elevated highways, and replace them with boulevards, tunnels, or remove them altogether and create a park. The Embarcadero Freeway in San Francisco, California was an elevated highway that blocked off the view of the shore and made the whole area more depressing. An earthquake in 1989 collapsed the freeway and left it in shambles. Instead of fixing it, the city government decided to completely dismantle the rest of the elevated highway. San Francisco replaced it with a boulevard lined with trees, large sidewalks, and green areas where people could sit and bathe in the sun as they looked out on the bay (Bevilacqua, 2012). The city began construction in 1991 and officially completed the renovations in 2000.

#### 4.1.2 Public Roads in the Redwood Forest

In the U.S, there is an effort to remove roads in public land. Public land consists of national parks, reserves, and other federally owned land. While the American interstate highway system has been called one of the largest public works projects in history at 69202 miles of freeways, public roads total 13 times that length (Havlick, 2002). In the past, science and engineering worked towards the goal of laying better roads, now teams are focusing on the ecological effects of constructing roadways.

One example is the Redwood National Park in northern California. The United States Congress designated the area as a protected national park in 1965. When timber companies heard this, they knew Congress would eventually mark neighboring territories as national parks, shrinking the effective land available for logging. In a rush, they went through and cut down as many trees as possible. In doing this they laid hundreds of kilometers of road to in order to transport lumber, tools, and people. By the time Congress finished marking regions as national parks in 1978, logging companies had already removed much of the newly added land, leaving only 36 of the new 200 km<sup>2</sup> untouched. As such, there were hundreds of kilometers of road throughout the park that was damaging the surrounding land (Havlick, 2002).

Mike Sanders, known in the industry as the “road killer”, was called in in 1995 with an initial allocation of 33 million USD to remove 300 km of logging roads. His team saw that when roads are built, they often change the contouring of the land. This contour change disturbs the flow of nearby streams and creeks, and loosens the soil, leading to landslides. At first, Sanders’s team attempted to treat the land around the roads, restore the contours, and minimize any impact. Eventually, they realized that the only way to fully restore the ecology was to remove the roads entirely. The presence of the roads disrupted streams and displaced many species of fish. The removal itself was difficult and cost 750,000 USD to remove 2.5 km of road and 150,000 m<sup>3</sup> of soil and introducing the danger of landslides with the newly exposed loose soil that had been underneath the road. Years after, many of the species of insects and fish returned to the site of the park, and the landscaping needed to fix the loose soil ended up being very cheap(Havlick, 2002).This increase in species was also seen during the daylighting of the Cheonggyecheon, which is discussed in section 4.5 (A. C. Revkin, 2009). The removal of Ågade and Åboulevard and the subsequent daylighting of the Ladegårdsåen could potentially lead to an increase in the number of species in the vicinity.

#### 4.1.3 Roadways and Traffic Pollution in Lithuania

The introduction of traffic to a road drastically increases the amount of noise and air pollution, and can even further damage the water and land around it. A study in Vilnius, Lithuania showed that the majority

of air pollution came from traffic, and 60-80% of noise pollution in cities was from traffic, depending on the time of day (Baltrenas, Kaziukoniene, & Kvasaukas, 2004). Another study of pollution in Lithuania took place in the Kaunas district, the second largest city of Lithuania. Researchers found that the noise pollution persisted at its peak for three hours, from 3-6pm. Furthermore, this peak noise pollution was 5-6 times higher around highways, especially elevated highways, than on the quieter side streets of the city. Public transportation only caused 3 percent of this noise pollution, compared to 17 percent from trucks alone. This has to do with how traffic speed and density affect noise pollution. A tripling in traffic speed doubles noise pollution, while it takes ten times the traffic density to double noise pollution. Public transport tends to travel more slowly, which is why even though the engines for buses are loud, they do not cause as much noise (Bendokiene & Grazuleviciene, 2009). Removing Ågade and Åboulevard would remove this traffic from the surface and redirect it underground, where it can be controlled as mentioned in section 3.4.

#### 4.1.4 Roadway Expansion in India

India is still undergoing a period of heavy urban expansion to accommodate their rising population and industrial change, which has occurred over the last few decades. As the country continues to build cities and the connecting highways, they are studying the environmental impacts of such projects in order to ensure a long lasting infrastructure. India is attempting to avoid finding a quick solution that is not fully thought out, and could potentially lead to problems in the future.

One of these studies looked at a bypass in northern India. National Highway 2 connects Delhi and Kolkata, two large economic and cultural centers in the north. In 2008, there were plans to build the Allahabad Bypass (see Figure 45) near Kokhraj, and divert some of the traffic north until it connected back to the highway at Handia. The researchers looked at traffic patterns along the stretch of NH-2 that was to be bypassed, and at the populations of Kokhraj and Handia, and ran the numbers through a simulation. They found that by 2024, the air pollution at Kokhraj and Handia would be at staggering levels. The availability of long-distance travel for the two cities, which are both highly populated, would induce greater traffic. Initially, the traffic congestion would improve, traffic speed would increase, and air pollution would go down.

In the end, the greater induced traffic would revert the traffic situation back to what it was before the bypass, but also now introducing greater pollution to the area the bypass would go through (Basu, Srivastava, & Vaishya, 2008). Removing roadways decreases pollution and adding roadways increases pollution, showing that pollution in an area is directly related to the presence of traffic.

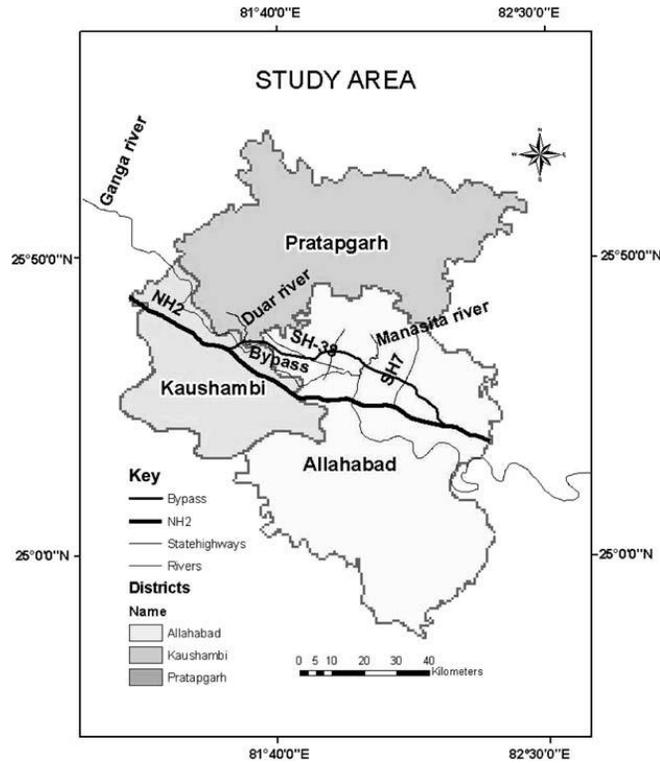


FIGURE 45: APPENDIX D ALLAHABAD BYPASS, INDIA (SRIVASTAVA 2008)

## 4.2 Tunneling Roads

In the earlier part of the 20th century, urban centers in the United States were rapidly expanding with brand new infrastructure. Large projects began in New York City, Philadelphia, Los Angeles, Boston, and other major U.S. cities. Around the world, major cities have begun to recognize the effectiveness of moving large roadways underground when trying to reduce traffic pollution and congestion. This section will explore two major tunneling projects, the Central Artery/Tunnel Project in the US and the Madrid M30 project in Spain, and the challenges and benefits that arose from both.

### 4.2.1 Central Artery/Tunnel Project

One of these large projects was the elevated highway at the end of I-90 in Boston, which led to Logan International Airport, known as the Central Artery. It was an eyesore and the pollution made the property values in the area drop drastically. The construction of the Central Artery highway was poorly planned, rushed, and went over budget; it destroyed and relocated 900 businesses and 100 residences in Boston due to the road expansion (Vernick, 2009). A proposal was made in the 1970's to remove all of the elevated highways going through downtown Boston and place them in an underground tunnel where expansion would not displace hundreds or thousands of residents. Officially named the Central Artery/Tunnel Project (CA/T), it is more commonly referred to as the Big Dig (Gelinas, 2007).

The various statistics concerning the Big Dig, such as person-hours and material used, are more comprehensive than any other infrastructural renovation in recent decades. Due to the minimal space restrictions and not needing to worry about expansion displacing homes and businesses, the architects planned for the tunnel to be between 8 and 10 lanes, in comparison to the original 6-lane highway. Altogether, it is 161 miles of single lane road, and with 14 on-off ramps, it is significantly sleeker than the original Central Artery's complex network of 27 on-off ramps that did not have merging lanes or proper signs. The research and fieldwork that went into planning the Big Dig is still currently the largest geotechnical study performed in North America (Massachusetts, 2014). When construction began, workers had to dig out 16 million cubic yards of dirt, some of which was then used to cap dumps and create parks. This large cavity was replaced with 26,000 linear feet of steel-reinforced concrete slurry tunneling, the largest amount ever used for a single project, set 120 feet below the surface (Massachusetts, 2014).

Boston has already started to notice the long-term benefits of the CA/T. The elevated highway created wasted space; not only did it not leave room for parks or recreational areas, but it destroyed homes, businesses, and urban development. The Big Dig created space for 300 new parks, filled with 2,400 new trees and 26,000 new shrubs (Massachusetts, 2014). The expansive tunnels allow traffic to travel at a smoother pace, decreasing congestion at peak hours by 42-74 %. This reduction in traffic congestion has led to a 12% reduction in carbon monoxide emissions (Massachusetts, 2014). The City of Boston was also able to utilize the 16 million cubic yards of displaced dirt. When the tunnel itself was capped, they created 26 acres of new green space in the middle of the city. They also created an island of green space with the dirt, a 105 acre area called Spectacle Island. Furthermore, they capped a landfill and created the 100 acre West Roxbury Millennium Park (Vernick, 2009). Overall, the Big Dig has led to less pollution, less traffic, and more green space, very similar to the goals of the Ladegårdsåen Daylighting Project. Figure 46 shows the visual difference between Boston before and after the Big Dig.



**FIGURE 46: APPENDIX D BEFORE AND AFTER OF BIG DIG, BOSTON, MA (MASSACHUSETTS, 2014)**

While the long-term benefits of the CA/T project include decreased pollution in the surrounding neighborhoods, the construction itself caused a significant amount of pollution. Construction vehicles are not subject to the same environmental regulations as normal vehicles because of their heavy-duty use. The pollution created from 70 of the construction vehicles was equivalent to 1,300 diesel buses, which was the type of pollution that the Big Dig aimed to reduce (Allen, 1998). The constant construction also generated excessive noise pollution, further disturbing residents in the area and lowering property values (Kim et al., 2007). The city of Boston placed filters on the construction vehicles to reduce the short term cost of pollution of the Big Dig and keep the project in line with the desired long term benefits (Allen, 1998).

#### 4.2.2 Madrid M30

Madrid's highways are set up in ringed interconnected layers. Each layer is an elevated highway that runs in a circuit centered around the center of the city. The four rings from outermost (largest radius) to innermost (smallest radius) are the Autopista Circunvalación M50, M45, M40, and M30. The M30 motorway was the subject of a major reconstruction project in 2004 when the city determined that it was more of a hindrance than a help for moving around the city. It was originally in need of serious repairs, but after considering the roadway's effect on the local air quality and the adjacent Manzares River, the

city council decided to move it underground (RTTM, 2014). The project consisted of 15 separate projects each contracted to multiple companies, all working towards the goal of removing a large section of the M30 and reducing pollution. The construction equipment companies worked together to fulfill an order for the world's largest tunnel boring machine, capable of tunneling at a rate of 0.665m/min, which is the fastest speed for any boring machine today. The machine used an earth pressure balance shielding system, which prevented the soft ground from collapsing and kept it in tact before it was covered by concrete and steel supports("Madrid M30," n.d.).

The construction happened in pieces, project by project, with the city opening another section every month. The city completed the M30 Tunnel in 2007 at a final cost of 5 billion USD. During the construction, the city organized a landscaping competition for companies to design the park that would be built on the land above the tunnel where the elevated expressway used to be. The parks were finished in 2007; they included thousands of planted trees, a wading pool for toddlers, and a grand plaza. Although it was more expensive than anticipated, the project returned the Manzanares River to its original elegance (Kimmelman, 2011).

## 4.3 Stormwater Management

### 4.3.1 SMART Tunnel

Flooding problems affect many cities around the world, especially in areas that experience monsoons and typhoons on a regular basis. Kuala Lumpur, Malaysia, located in a tropical climate, has flooding problems. Floods in 1926 and 1971 were previously the only floods that caused destruction to Kuala Lumpur's city center. Urbanization and expansion of Kuala Lumpur has narrowed rivers that run through the city, lessening their ability to collect stormwater and allowing major floods to occur on an almost annual basis. The Malaysian government has attempted to increase water channel capacity and create pools to hold water, but none of these have significantly decreased the flooding (Darby, 2007).

In 2001, the government of Kuala Lumpur began accepting proposals for a large scale tunnel solution that would allow for a flood to occur over a three to six hour timespan without inundating the city center. The Malaysian company Gamuda worked with engineering consultants around the world to come up with a cost effective tunnel, called the Stormwater Management and Road Tunnel (SMART Tunnel). Since floods are a rare occurrence, they decided to use the tunnel to remove traffic from the surface as well. This way, the city could solve two problems with one well organized solution (Darby, 2007).

The tunnel's design has two channels, one north bound and the other south bound. There are toll plazas at either end, stacked on top of each other, and an extra channel underneath for water to fill during times of flooding (Hill, 2014). The roadways only run for the center four kilometers of the entire 9.7 km channel; the channel underneath contains the majority of the tunnel's flood capacity. The tunnel also contains large ponds on either end, one, the Berembang Holding Basin, is able to hold 0.6 million cubic meters of water and the other, the Taman Desa Storage Reservoir, can hold 1.4 million cubic meters; they both slowly drain into rivers through the Kuala Lumpur Flood Mitigation System. During periods of no rain, the tunnel works in Mode 1 (see Figure 47), where both tunnels are opened for car traffic and the channel underneath is empty. When it initially starts raining, and water flows into the holding basin and storage reservoir. For heavier rainfall, water is moved through the channel underneath (Mode 2), keeping the tunnel open for traffic. When the rain gets too heavy and flooding is predicted, Mode 3 is activated. Commuters are warned and the tunnel is closed to traffic and opened up to store more flood water, up to a total of 3 million cubic meters. If, after 2 hours, the rain is not predicted to end within the next 8 hours and the entire tunnel capacity is necessary to manage flood water, the tunnel will remain closed to traffic (Mode 4). The road will reopen up to 4 days after all the water has been drained ("Operation Modes of the SMART Tunnel," 2011). Within the first three years, the SMART tunnel prevented seven potentially disastrous floods from ruining the city center in Kuala Lumpur (Hill, 2014).

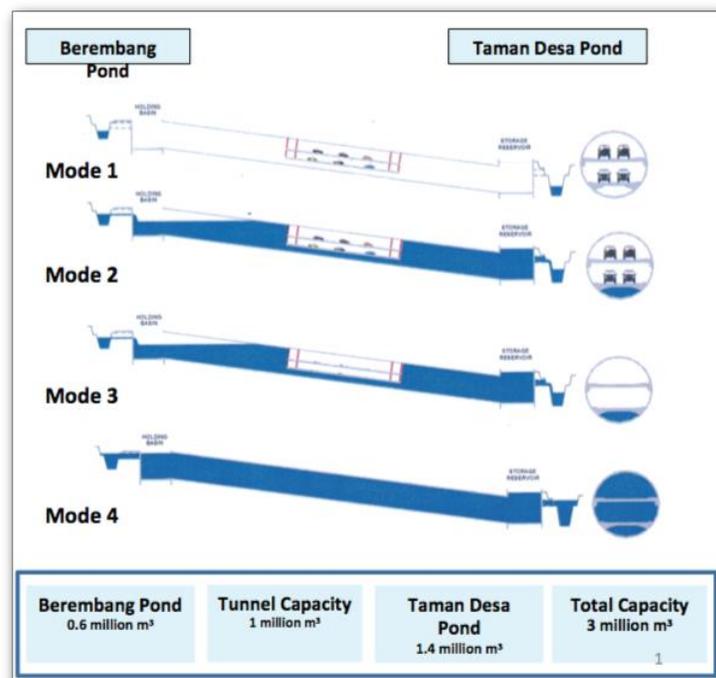


FIGURE 47: APPENDIX D PHASES OF OPERATION FOR SMART TUNNEL, MALAYSIA

## 4.4 Daylighting

Copenhagen is not the only city to bury its rivers to make way for urban expansion. All across the world, major cities are discovering rivers long forgotten in steel pipes underneath the sprawling expanses of metropolitan development. The Ladegårdsåen is just one of many rivers in consideration for daylighting in modern city planning.

### 4.4.1 Daylighting of the Cheonggyecheon

Seoul, South Korea recently released a river from its use as a conduit for sewage and converted it into a tourist attraction, beautifying the city. The Cheonggyecheon is central to the history of Seoul. Over 600 years ago, a king in the Choson dynasty came to Seoul and declared it the capital of South Korea after seeing the Cheonggyecheon (A. Revkin, 2009). By the end of the Korean War, the river had become a rank open sewer. South Korea was going through explosive expansion to make an economic recovery in the second half of the 20<sup>th</sup> century. The city's top priority was to build roads and buildings, and any empty space was filled with concrete and asphalt. The only open space left was in temples that were not allowed to be touched. Along with the unappealing state of the river, this led to the Cheonggyecheon being put into a pipeline that was paved over, and in the late 1960's an elevated highway was built on top of that (Lee & Anderson, 2013). In the 21<sup>st</sup> century, Seoul has become the most populous city proper and the second most populous metropolitan area, next to Tokyo. The city proper contains a fifth of South Korea's population at 10 million, and the metropolitan area contains half of South Korea's population at 25.6 million.

In 2002, Seoul elected Lee Myung-bak, a former CEO of Hyundai Construction, as the city's first conservative mayor. He ran on the platform of new development that would turn Seoul from a "car-oriented city to a human oriented city" (Lee & Anderson, 2013). In 2003, he announced the daylighting of the Cheonggyecheon. The area above the river was known for having high levels of pollution, with noise and air pollution being far above the average for Seoul, an already densely populated and polluted city. Those who lived in the neighborhood were twice as likely to suffer from respiratory ailments. According to the Korean Society of Civil Engineering, the elevated highway over the piped river would require \$92 million in repairs over the next 10 years.

The city of Seoul began daylighting of Cheonggyecheon River in 2003 and successfully completed the project in 2006 (see Figure 48). Within years, the positive effects of the project could be seen. The area saw a 15 percent decrease in particulate matter almost immediately, while neighboring areas saw a 16 percent increase in particulate matter on average (Lee & Anderson, 2013). The small particle pollution

was lowered from 74 micrograms (mcg) per cubic meter to 48 mcg per cubic meter, a 35% reduction. With the restoration of natural space, various animals that were pushed out by the roads have returned. A mere four years after, the number of fish species has increased from 4 to 25; the number of bird species increased from 6 to 36; the number of insect species increased from 15 to 192. Summer temperatures around the Cheonggyecheon are 5 degrees cooler than neighboring areas. With the walkways and beautiful scenery, the river attracts 90,000 pedestrians daily. Consequentially, businesses have been doing very well and property values have gone up 30-50 percent (A. Revkin, 2009).



**FIGURE 48: APPENDIX D CHEONGGYEcheon DAYLIGHTING (NY TIMES)**

#### 4.4.1.1 REDIRECTION OF TRAFFIC

A main concern during the proposal of this Cheonggyecheon Daylighting Project was the future of traffic in the area. Unlike the plans for Daylighting the Ladegårdsåen, there was no plan for a tunnel. Miles of road were stripped, and those who had previously commuted using the elevated highway had to find

another way to get to work. Critics of the project were afraid that removing the road would make cars travel through other routes and increase traffic elsewhere in the city. Researchers found that changing the availability of transportation induces a change in the demand for roadways. In several cases, when roadways were removed, the traffic in alternate routes spiked initially and then decreased to previous levels. For example, the removal of a major roadway in Manchester, UK resulted in an immediate increase in traffic congestion, followed by a change in travel times and eventual decrease in traffic. (Chung, Hwang, & Bae, 2012). On the other hand, adding a road can increase traffic congestion, as seen with a case in Bogota, Colombia (Wright, 2002). This phenomenon is known as self-compliance, where commuters change their behavior due to a change in the availability of traffic routes. All around the world, there are examples of this effect. There will be a loss in road capacity, an initial spike immediately after, a behavioral shift of travelers, and the result is no long-term increase in traffic condition. Similarly, Seoul saw an initial spike in traffic in surrounding areas, but only two weeks after construction began in 2003, 11 percent of those who used to drive over the Cheonggyecheon and were displaced still drove to work but drove at a different time to avoid congestion. 6.2 percent of commuters eventually changed their mode of transportation to adapt to the construction. By the end of 2003, a couple months after construction began, traffic had reverted to its state prior to the displacement of the Cheonggyecheon commuters (Chung et al., 2012). Copenhagen, being a city notable for alternate modes of transportation, has the appropriate infrastructure to allow for an induced change in traffic. Construction will affect traffic for a short amount of time, but it will not be a long-term problem. Once the project is complete, Copenhagen will have a new, beautiful attraction that will benefit the environment.

#### 4.5 Construction

Various construction projects have happened or are in planning that are meant to combat traffic emissions and global climate change. Unfortunately, the problem with these projects is just that: they are construction projects. As such, they can be a significant source of pollution and disruption for citizens. Even with the long term benefits of these projects, the construction alone would turn people away from supporting the project. The Cheonggyecheon's daylighting is an example of a project that was successful because it received the support of the public to the point where they felt as though they had a part in the project. The Cheonggyecheon daylighting was publicized through a string of speeches that were meant to make the citizens of Seoul take pride in their city and feel as though the project was an improvement to their lives (Chung et al., 2012). While the problem of losing public support because of construction is a very complicated issue for which the solutions are too far and too varied to be detailed here, the issue of

pollution produced by project sites can be categorized and managed accordingly to reduce emissions from construction vehicles and other damages to the local environment.

#### 4.5.1 The Effects of Construction on Air and Noise Pollution

An overview of the types of jobs performed at a construction site makes the risk of pollution clear. Clearing of land, use of heavy machinery, mechanical drilling or demolition, metal welding and brazing, and application of industrial chemicals are among the many activities that take place on a construction site ("Air Quality Guidance Note: Construction Sites," 2013). The main aerosol pollutant from construction is PM10, which is usually dust from excavation, as well as diesel vehicle exhaust (Gray, 2013). On top of this, diesel fuel vehicles also release high levels of carbon monoxide, carbon dioxide, hydrocarbons, NO<sub>x</sub>, soot, sulfates, and silicates. All of these particles are collectively known as Diesel Particulate Matter (DPM) and combine with other toxins in the air to form an unhealthy atmosphere. In Manchester and Warrington, UK, 13% of all NO<sub>x</sub> emissions were found to be from construction, with 33% from other industry, and 40% from road traffic (Peace, Owen, & Raper, 2004). On top of air pollution, construction creates a significant amount of noise pollution from the use of heavy duty vehicles, high powered equipment, and workers shouting or playing music while working. In most cities, Construction is cited as the reason for more noise complaints than any other source. (Gray, 2013).

#### 4.5.2 Chemicals and Construction

The other issue with construction is chemical spillage and runoff into the water supply and/or ground water. There are many chemicals used on construction sites such as cleaners, thinners, paint, and adhesives. These chemicals, if not properly managed and handled, can end up spilling while in use and soak into the ground, contaminating ground water and damaging the land ("Air Quality Guidance Note: Construction Sites," 2013). Cleaning ground water is much more difficult than cleaning surface water, as it requires sophisticated tools and precise planning. Fortunately, there are methods of dealing with many of these sources of pollution.

#### 4.5.3 Limiting Construction Pollution

A lot of the particulate matter can be eliminated by routinely spraying construction sites down with a fine mist of water. It follows the same principle as rain; reducing the levels of pollution by absorbing pollutants and bringing them down to the ground. One caution with water spraying is that attention must be paid to the strength and direction of the wind; not doing so can ruin the effectiveness of it and render the efforts useless. Using a fine mesh screen in addition to covering up rubble can prevent dust from escaping the construction site and polluting the air around civilians.

An interesting method of reducing all forms of pollution is scheduling the work so that the pollution is more spread out and thus the concentration at any given time is below a pre-set threshold. The technique is a Genetic Algorithm Enhanced Leveling Technique, which takes several factors into account and uses a quantitative algorithm that moves various activities around, taking their constraints into consideration (a certain activity may have to be done before others can proceed), and provides a even schedule that ensures the noise and air pollution levels do not exceed limits, which is one of the constraints. The technique was tested on the construction of a building in Shanghai in 2000 that was projected to have very low amounts of activity on some weeks and very high amounts of activity on other weeks. Before putting the activities (such as using a jackhammer, excavating, drilling, etc.) through the algorithm, noise and air pollution levels were projected to be far above safe levels for three weeks straight around the middle of the schedule. After the algorithm, at no point did any week go beyond tolerable levels, and the time to complete construction went from 20 to 22 weeks. When the construction actually occurred, the pollution levels strongly matched the prediction of the algorithm. Break weeks were eliminated, peak activity weeks were spread out, and activities with high emissions were spread out so that there would be time for the pollutants to disperse or be filtered, leading to a very slight increase in schedule time with a significant reduction in peak pollution levels (Z. Chen, Li, Wong, & Love, 2002).

## 5.0 Conclusions

### 5.1 Benefits of the Project

To review, the aspects of daylighting the Ladegårdsåen include stripping away Ågade and Åboulevard, exposing the underground Ladegårdsåen, demolishing the Bispeengbuen, constructing a tunnel that can manage stormwater and traffic, and developing the land around the daylighted river into green space. Each step has its benefits, which are extracted from the research above.

The first step in daylighting a river under a road is to strip away the road. As Mike Sanders's team saw when treating the land around roads in Redwood National Park, the presence of a road alone causes damage to the surrounding ecosystem. After treating the land, removing the road was the only solution to restoring the contour of the land, which allowed for better movement of water and species of fish and insects return to their homes without the road in the way. With species richness playing a large factor in the effectiveness of green space, and removal of the road allowing species to return, this first step alone will be a crucial first step in setting the stage for Åpark, the proposed green space along the canal. The road removal will allow more species to live in Nørrebro, enhancing the green space and bringing more nature to the city.

Removing a road also means removing the traffic that would normally travel over it. Automobile traffic causes a large amount of pollution, more than any other source of pollution in some areas. The health effects of this pollution set in slowly over a long period of time, but include respiratory, cardiovascular, neurological, urinary, and mental issues. Large amounts of air pollution can damage airways and increase the risk of bacterial infection in the esophagus and lungs. Heavy metal and particulate matter can build up over time and increase blood pressure and the chance of heart disease while decreasing respiratory function. This can especially be harmful to children and the elderly whose bodies are not fully developed or are aged and already losing function. Air pollution can also heavily exacerbate existing conditions such as asthma or C.O.P.D. Noise pollution from thousands of cars driving at high speeds increases stress levels and stunts childhood development mentally and physically. Increased stress can increase the risk of heart disease, and further irritate conditions already present.

Heavy road traffic creates heavy traffic pollution, which causes all the issues listed above. These are not small obstacles to an otherwise healthy life; the pollution is so heavy that it can lead to a premature death. From India, to San Francisco, to Lithuania, automobile traffic causes pollution levels high enough to see the eventual lethal health effects. Those within 100 meters of major roadways are exposed to an even greater risk. All these risks and issues can be significantly reduced by removing the road, keeping traffic and thus pollution away from the surface entirely. Local residents will not have to deal with smog-filled air slowly damaging their body, which is a great benefit to the city.

Once the asphalt is peeled back and the pipe exposed, the river can be daylighted. With some work, the land and river can be properly restored to its original state. The reason for the increase in destructive floods in Kuala Lumpur that originally created the need for the SMART Tunnel was the narrowing of rivers and green space, which left little capacity for holding floodwater. Introducing what is essentially a new river to the surface created a large amount of new space for floodwater to go. To put it more clearly, daylighting can prevent floods.

As seen with the Cheonggyecheon in Seoul, rivers can add a lot of aesthetic value to a city that is engulfed in concrete and steel. The daylighted river gave citizens a way to connect with the natural, historic beauty lying beneath the city. When the green space is developed around it, the river will be the centerpiece, enhancing the therapeutic effects of walking through the park.

When Ågade and Åboulevard are removed, there will no longer be a need for the Bispeengbuen, the bridge that goes into Borups Alle on the southern border of Bispebjerg and forms a major commuting

route. The Bispeengbuen is similar to an elevated highway in its structure, though it's only 1km in length. Jane Jacobs argues against elevated highways in her book, *The Death and Life of Great American Cities* because of how contrary they are to the purpose of a city. Cities are meant to connect people and allow for freedom of movement. Elevated highways place cars at a higher priority and divide communities. In Copenhagen, a city that promotes walking and biking, an elevated highway like this simply does not make sense. It makes it difficult to travel from Nørrebro to Bispebjerg, restricting access in a city focused on pedestrian access.

The most difficult, expensive, and time consuming part of the project will be digging out land and constructing the tunnel that will serve as the new Ågade and Åboulevard, and transport water back and forth when necessary. The construction of the tunnel is also the riskiest part of the project. It will cost billions of kroner and take years to complete, although at 3 km in length, it is much shorter than the SMART Tunnel and the Big Dig, meaning the cost will not run as high. One complaint about a tunnel is that the noise pollution is not removed, it is just diverted to the openings. This is only true if there is no sound absorbing material placed within the walls of the tunnel. Most tunnels are constructed outside cities to allow highways to pass through large hills and mountains, where noise pollution is not a concern. In a city, noise pollution is an issue, and the relatively inexpensive solution of sound absorbing material will come in handy in preventing noise pollution from the tunnel. In other words, moving the road below into a tunnel will reduce the problem of noise pollution.

A tunnel can easily manage air pollution. The advantage of a tunnel over a road is that the pollutants are contained within a closed off system with two exits. Contained air is easier to work with, and it can be ventilated off to a cleaning plant that will remove pollution and release clean air. Once again, a tunnel equipped with the proper technology will eliminate the problem of air pollution. The drawback here is the cost, as these additional measures will require upkeep and maintenance. Powerful fans would need to be installed and maintained, and most of all a cleaning plant or ventilation tower would have to be built at a distant location. Although this can add significantly to the construction and maintenance costs, there are positive benefits, leading to a measurable difference in quality of life for the residents of Nørrebro.

The final step in the project is to create the park around that canal, which will make the area more visually appealing. As shown in previous research, many studies have concluded that contact with nature has many benefits that improve the body and mind. Walking through natural scenes relieves stress and increases opportunities for exercise and recreation, which improves overall health. Rivers intensify the benefits and therapeutic effects of green spaces. Developing a lush green space with a variety of species

costs little compared to the tunnel, but goes a long way in improving lives of children in the area, and is a good way to purify and manage the environment. Bacteria in soil can digest oil at a reasonable rate, which helps in cleaning up the runoff from automobiles. Soil also absorbs water, meaning it will help the river manage stormwater and prevent flooding. Green space is very versatile in cleaning the environment, preventing flooding, and relieving stress for residents.

## 5.2 Survey Data

The group wanted to understand how informed the population of Nørrebro was about pollution and the Ladegårdsåen Daylighting Project, as well as their stances towards each. As mentioned in section 4.6, successful projects generally have public support, so it was important to determine the level of public support that already existed for the project. The team distributed surveys to individuals passing through Nørrebro Runddel at the intersection of Jagtvej and Nørrebrogade, which is considered the center of Nørrebro. The group consists of American English speakers, so an accompanying representative of Miljøpunkt Nørrebro helped translate and speak to residents walking by the Runddel. In total, the survey reached 30 respondents of varying ages and contained questions covering three main topics: demographics, pollution, and the Ladegårdsåen Daylighting Project. The specific format and order of the survey questions, as well as the responses is in Appendix A. Summaries and conclusions of the data will be covered here.

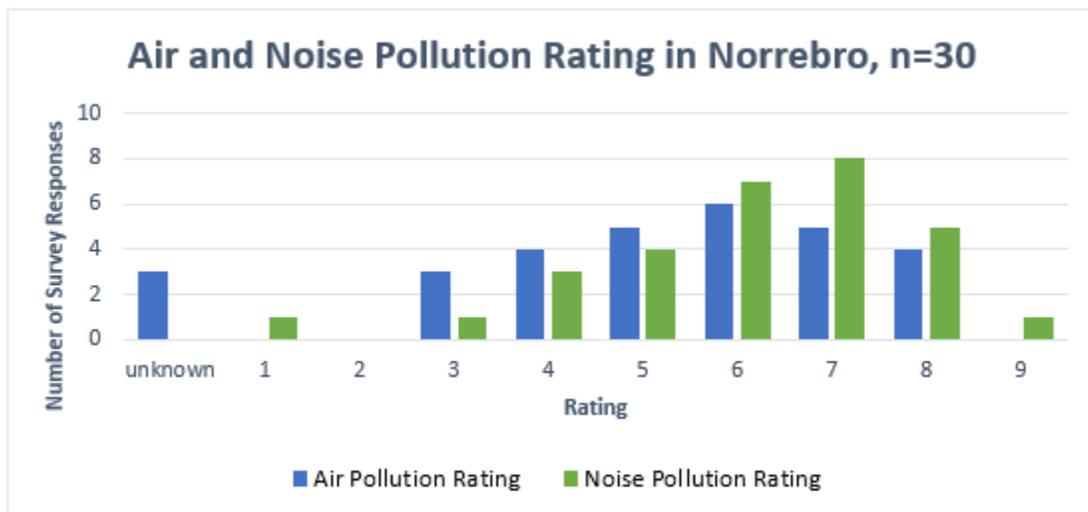
The team collected demographic data to show that while there were only 30 respondents, the people surveyed were a good representation of Nørrebro’s population. The age, gender, and car ownership distribution shown in the results closely matches that of Nørrebro’s statistics (see Table 9) The small discrepancies in age are owed mostly to the fact that Nørrebro has a sizeable population below 18, and the group avoided handing the survey to minors. Another important statistic in the demographics section was travel habits, including car ownership. Car ownership among the respondents was 13%, while the actual car ownership in Nørrebro is 13%.

<b>QUESTION</b>	<b>NUMBER OF SURVEY DATA RESPONSES</b>	<b>STATISTICS</b>	<b>NØRREBRO STATISTICS</b>
<b>AGE (YEARS)</b>			
10-19	2	7%	7%
20-29	14	47%	33%
30-39	7	23%	21%
40-49	3	10%	11%

50-59	2	7%	7%
60-69	2	7%	5%
<b>GENDER</b>			
MALE	18	60%	49%
FEMALE	12	40%	51%
<b>CAR OWNERSHIP</b>			
OWNS CAR	4	13%	13%
DOES NOT OWN CAR	26	87%	87%

**TABLE 9: APPENDIX D SURVEY DATA DEMOGRAPHICS COMPARED TO NØRREBRO STATISTICS**

The next section of the survey asked passersby how knowledgeable they were about pollution in the area. When asked how much they felt they knew about traffic pollution in general, 57% of people responded with either “None” or “Not much”, 33% of people said they knew “A medium amount” or “A lot”, and 10% said they did not know where they were on the scale. When asked how bad they thought air and noise pollution in Nørrebro were on a scale from 1-9, responses averaged 5.7 and 6.1, respectively (see Figure 49). What this means about the residents of Nørrebro is that many of them know that Nørrebro has a high level of pollution, but many of them are not aware how much of an effect that pollution has on their health beyond being somewhat unpleasant.



**FIGURE 49: APPENDIX D SURVEY RESPONSES TO AIR AND NOISE POLLUTION RATING**

The third section asked volunteers their thoughts on the Ladegårdsåen project and associated topics. When presented with the statement “Decreasing the number of cars that drive through Nørrebro is

beneficial to the neighborhood,” the overwhelming majority of participants answered with “Agree” and even more so “Strongly Agree,” confirming the hypothesis of the research team that the residents of Nørrebro are interested in decreasing traffic, even if they are not fully aware of the ill effects traffic pollution can cause. The survey then asked the public about their opinions on the Ladegårdsåen project to gauge the public’s awareness and support for it. Figure 50 summarizes the responses. The blue shades represent those who had heard about the project prior to taking the survey, and the orange shades represent those who did not know about the project until it was described to them. The lightest shades correspond to those in favor of daylighting the Ladegårdsåen, the medium shades correspond to those without an opinion, and the darkest shades represent those who were against the project. The majority of participants, two-thirds, were in favor of the project. Even those who had not heard of the project were in favor, and nobody who had heard of the project was against it.

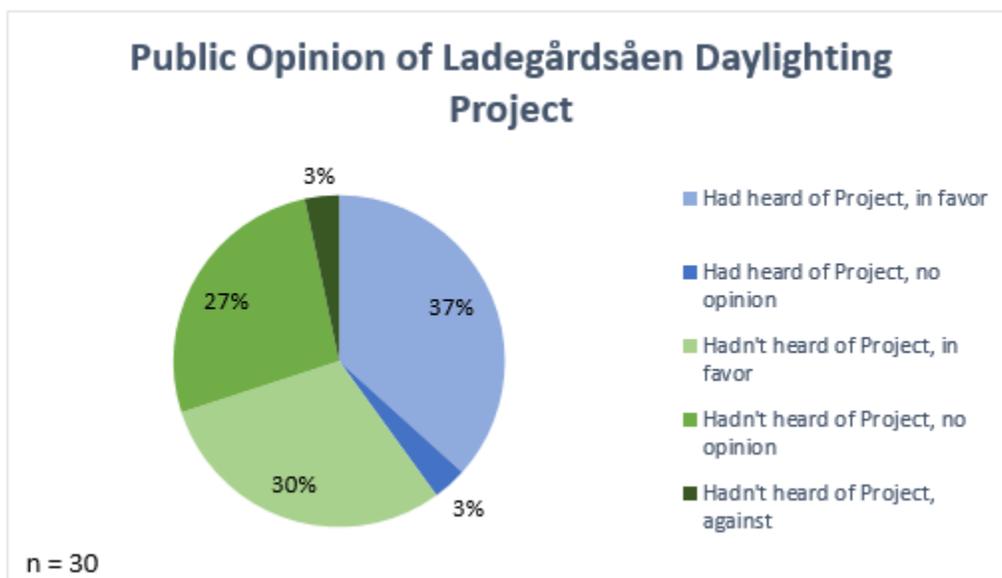


FIGURE 50: APPENDIX D SURVEY RESPONSES TO OPINION ON LADEGÅRDSÅEN DAYLIGHTING PROJECT

### 5.3 Need for Daylighting the Ladegårdsåen

The Ladegårdsåen Daylighting Project will bring many positive changes to the Nørrebro community. It will decrease the amount of visible through-traffic in the neighborhood, as the project will redirect traffic into the tunnel. This will help to lower both the air and noise pollution levels in the neighborhood. The tunnel will also serve as a stormwater management system, which will help to contain floodwater during heavy storms. The daylighted canal will also help contain excess rainwater, and it will become another recreational area for Nørrebro. The addition of the park along the canal will bring much needed green space to the area, along with its associated health benefits. While construction increases the pollution in

the area, with appropriate scheduling it can have a smaller effect on the environment. As previously shown, the long-term benefits of the project outweigh any negatives from the construction process.

The Nørrebro community supports the project, as they believe that there is a need to remove pollution from the neighborhood and add green space to the area. This project may have started as a way to prevent floods, but it has transformed into a way to save lives and improve the health of the community. The benefits of stopping floods from destroying businesses and homes can be measured in currency, but the damage done by pollution can be measured in lives, as traffic pollution kills 4000 people in Denmark each year.

Bringing back the river also means bringing back a part of history. Copenhagen is a city rich with history, spanning over a thousand years since the Middle Ages, but a piece of that history is buried underground and is currently being used as a sewer. Daylighting the Ladegårdsåen will put Copenhagen's history back above ground for everyone to enjoy. Almost every part about this project is a direct benefit to the people of Nørrebro, and can help Copenhagen become an inspiration for smart, green technology around the world

# Appendix E: Benefits for Daylighting the Ladegårdsåen Presentation

## Presentation

Slide 1



MILJØPUNKT  
AGENDA 21 - FOR ET BÆREDYGTIGT KBH



NØRREBRO

Miljøpunkt Nørrebro

# Ladegårdsåen Daylighting

Slide 2

## Cloudburst



Flooding in Copenhagen in 2011

- 2 July 2011
- Over 160mm in 2 hours, 6 billion kr. in damage
- 42 million kr. for solution

2

Slide 3

## Stormwater Management



Sectional view of SMART Tunnel in Kuala Lumpur

- SMART Tunnel in Kuala Lumpur, Malaysia
- Manages stormwater, diverts traffic

3

Slide 4

## Ladegårdsåen



Traffic on Åboulevard at 3pm

- Ågade and Åboulevard
- Ladegårdsåen
- 60,000 cars per day

4

Slide 5

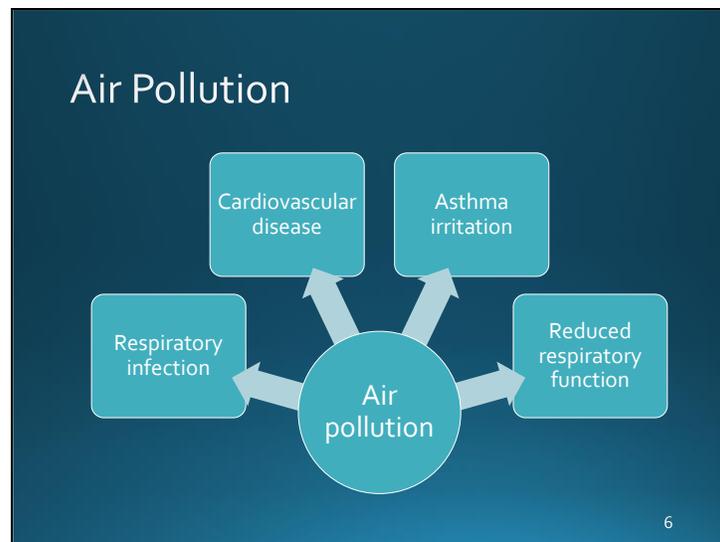
## Pollution

- Pollution reduction is key
- Pollution is more than just “unpleasant”
- 4,000 deaths/year in Denmark alone

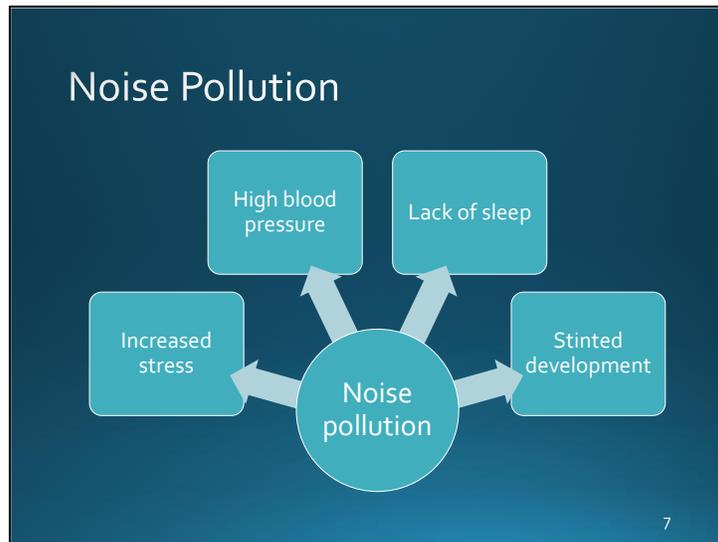


5

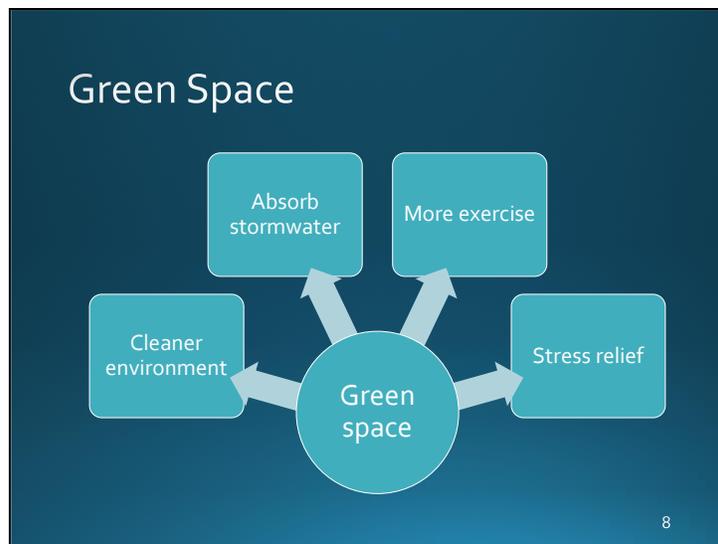
Slide 6



Slide 7



Slide 8



Slide 9

## Roadways and Pollution



- Traffic creates pollution
- Removing roads *always* reduces pollution
- Addition of roads *always* increases pollution

9

Slide 10

## The "Big Dig," Boston



Before and after of Central Artery

- Largest construction project in North America
- 231 acres new park
- -15% carbon monoxide
- Decreased peak congestion by up to 75%

10

Slide 11

## Madrid M-30



Before and after of M30

- Madrid M-30 moved underground
- Learned from Big Dig
- 5 billion USD 2004-2007

11

Slide 12

## Cheonggyecheon, Seoul Daylighting

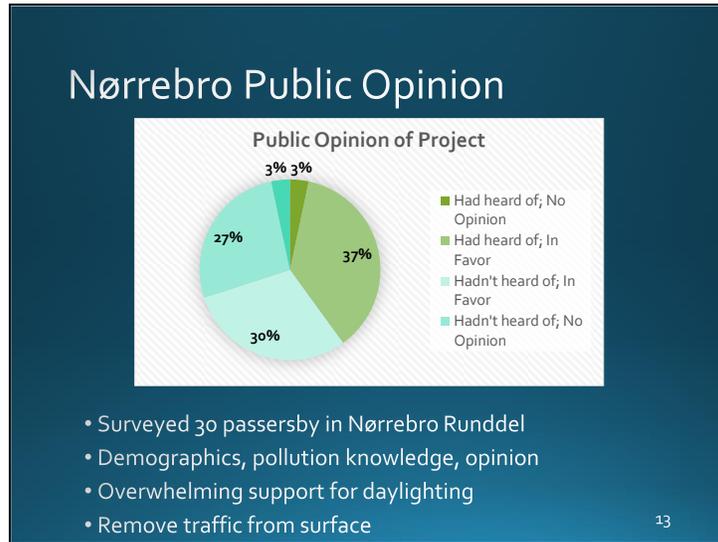


Before and after of Cheonggyecheon

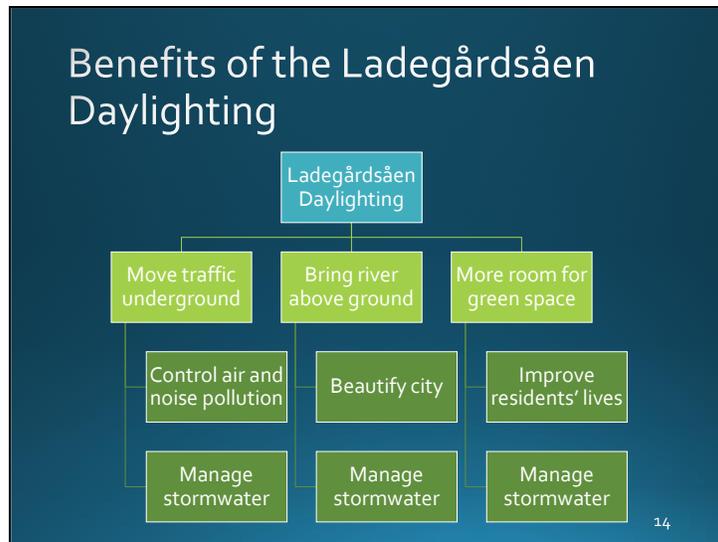
- Stripped major roadway
- Revealed historical river
- Decreased pollution, temperature
- Increased pedestrians

12

Slide 13



Slide 14



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15

## Questions?



16

## Presenter's Script

MEETING ROOM, TITLE SLIDE UP ON SCREEN

PRESENTER

(Say whatever introductions are necessary, representing Miljøpunkt Nørrebro etc.)

Move on to slide 2

PRESENTER

On July 2nd, 2011, Copenhagen experienced a cloudburst, which is what it sounds like. It was as if a giant water balloon exploded above the city, raining over 160mm in under 3 hours.

Motion towards picture

PRESENTER

The pictures and videos show a small glimpse of how heavy the rain was during the cloudburst. The streets were flooded instantly because the water had nowhere to go.

(Possibly add a personal experience about how bad flooding was)

In the end, that storm alone is estimated to have caused 6 billion kroner in damage to homes and businesses. Since then, the City of Copenhagen has been looking for solutions to this flooding problem, and has allocated 42 million kr. to finding one.

Move on to slide 3

PRESENTER

One of the ways in which similar flooding has been handled elsewhere is the construction of a stormwater management

tunnel in Kuala Lumpur, the capital of Malaysia. Kuala Lumpur is in an environment that is prone to monsoons. The large rivers and forests would be able to handle the water normally, but urban development has transformed the landscape and made it less absorbent. Greenery was paved over and the rivers were narrowed by concrete. The number of floods from these monsoons has increased dramatically. Destructive floods used to happen once every decade, but from the mid-80's onward, they have happened almost every year. To prevent the weather from continuing its barrage on the city center, Kuala Lumpur had a tunnel built to store floodwater.

Motion towards picture

PRESENTER

This illustration shows the tunnel during an early stage of a flood. You can see there are two unidirectional levels, one on top of the other, and a channel underneath. When a storm begins, the water can go into this bottom channel. If the storm continues, the roads are closed to traffic and used to store water until the storm passes. Once the water has been pumped out, the tunnels are reopened and traffic continues underground. In this way, the tunnel manages traffic \*and\* prevents floods, as it has done 7 times within the first three years.

Move on to slide 4

PRESENTER

Similarly, we have come up with a project to solve our flood problems. Agade and Aboulevard are two streets, one connected

into the other, that form the southern border of Nørrebro. These streets see an average of 60,000 cars daily, increasing the amount of pollution in the neighborhood. Underneath these streets is the historical Ladegårdsåen, which used to be open for public use as the center of Nørrebro until it was paved over for urban expansion at the turn of the 19th century. Our idea involves restoring this river and bringing it up to the surface, in a process called daylighting. In doing so, we will remove the streets above it, the Agade and Boulevard, and construct a tunnel underground, one similar to Kuala Lumpur's SMART Tunnel. In doing so, we can solve multiple problems with one project. We can prevent flooding, decrease pollution, and increase the public green space in Nørrebro. Obviously flooding is a problem that absolutely needs to be solved as soon as possible, but perhaps it's not immediately clear why the other two are so critical.

Move on to slide 5

#### PRESENTER

Reducing pollution is key to helping the residents of Nørrebro lead healthier lives. With the City of Copenhagen's attempt to be carbon neutral by 2025 and their desire to be the greenest city, we need to explore solutions that solve multiple problems at once. Pollution is more than just unpleasant. The health effects of air and noise pollution lead to 4,000 deaths \*every year\* in Denmark.

Animation of people lined up

PRESENTER

That's a daily average of 11 people. People in Denmark are dying, 11 \*every day\*, and we need to do something about it. Every step we take towards reducing pollution is a step towards keeping the Danish people safer.

Move on to slide 6

PRESENTER

Air pollution consists of gaseous exhaust and particles emitted from cars including carbon monoxide, nitrogen dioxide, particulate matter, ozone, and heavy metal particles. You may already recognize some of these as harmful to humans. At high enough levels, they can cause...

Animation of first item

PRESENTER

...respiratory infection...

Animation of second item

PRESENTER

...cardiovascular disease...

Animation of third item

PRESENTER

...asthma irritation...

Animation of fourth item

PRESENTER

...and reduced respiratory function. They damage airways and lungs and hearts, leaving them more susceptible to a bacterial infection. Studies show that those with asthma or heart disease are more likely to

have worsening symptoms the closer they are to a roadway because of the traffic pollution. On top of that, cars can create a lot of noise.

Move on to slide 7

PRESENTER

This is what we call noise pollution. While air pollution is the silent killer, noise pollution is anything but. The constant noise from many cars going by at high speeds takes a bigger toll on the body than you'd think. The average level of noise around Agade and Aboulevard is above 60dB, which is considered very high. At these levels, the noise from traffic can cause...

Animation of first item

PRESENTER

...increased stress...

Animation of second item

PRESENTER

...high blood pressure...

Animation of third item

PRESENTER

...lack of sleep...

Animation of fourth item

PRESENTER

...and stunted development. Studies have shown that children who live around areas with high noise pollution are more likely to develop learning disabilities. The constant noise distracts children from learning and

people from sleeping, which leads to greater stress and blood pressure. As many of you may already know, a large amount of stress and high blood pressure can lead to a great number of other problems.

Move on to slide 8

PRESENTER

On the other hand, green space has many positive impacts on the surrounding area. Planting trees reduces pollution and creates a cleaner environment, the soil can absorb stormwater, the availability of natural scenery gives people an incentive to exercise, and simply viewing greenery reduces stress. Studies have shown that patients recovering from surgery recovered much faster when they had a view of a forest as opposed to concrete and brick walls. It's very simple, green space is good for people.

Move on to slide 9

PRESENTER

While the project we're proposing is very unique, many different aspects of it have been done in multiple other projects. The first step is removing the road. This alone will reduce traffic immensely. I showed you before the health effects caused by air and noise pollution if they get to high enough levels. Research has shown time and time again that the amount of traffic Agade and Boulevard see creates that much pollution. Every time roads have been removed, the locals have seen a large reduction in pollution. It's a simple cause and effect. Remove a road, remove traffic, remove

traffic pollution, and keep people healthy. The road we're working with will not just be removed, but rebuilt underground as a tunnel.

Move on to slide 10

PRESENTER

This has been done before, most famously in Boston, USA. The Big Dig is the largest construction project in North America in recent decades. They took a very congested elevated highway and moved it underground. In doing so, they were able to create 231 acres of new parks, decrease carbon monoxide emissions by 15%, and reduce the traffic density during peak hours by up to 75%. However, the project was notorious for going several times over budget and taking years longer than anticipated. Fortunately, those involved learned from their mistakes and tried it again, this time with very few problems.

Move on to slide 11

PRESENTER

Madrid tried the same thing with one of their highways, the M-30. It is an elevated highway that runs in a ring around the inner section of the city, and contributed quite a bit of pollution. They managed to take the entire southern section and move it underground. Unlike the Big Dig, it only took under 4 years and was well within the budget.

The next part of the Nørrebro project is daylighting the river and restoring it.

Move on to slide 12

PRESENTER

This too has been done before in Seoul, South Korea. At 10 million people, Seoul is the most populous city in the world, containing a fifth of the entire country's population. History tells us that the city was originally chosen as Korea's capital by an ancient king because of the beauty of the Cheonggyecheon (pronounced Chong-yay-chon). The river had historically been the centerpiece of Seoul until post-war times, when the city expanded to where it is today. Just like the Ladegardsaen, the Cheonggyecheon was put into a pipeline and paved over to make room for heavy traffic. About a decade ago, the city's mayor proposed to restore the river and bring back a piece of Korean history. By 2007, the river had been fully restored, pumping in water from the Han River. Within a year, temperatures in the area dropped, pollution went down, and there were many more pedestrians.

Move on to slide 13

PRESENTER

The public opinion of the project is extremely important, as their support can make or break the project. A group of American students working with us surveyed at Nørrebro Runddel about various topics. They asked them questions about pollution, the project, and some questions to get a sense of demographics. They found an overwhelming amount of support for the project. The orange section is for those who

hadn't heard of the project before the survey, and the blue section is for those who had heard of the project. The lighter colors for each correspond to people who supported the project, the primary reason given being traffic removal.

Move on to slide 14

PRESENTER

This project can be simplified by breaking it down into three easy pieces. That is...

Animation of first item

PRESENTER

...moving traffic underground...

Animation of second item

PRESENTER

...bringing the river above ground...

Animation of third item

PRESENTER

...and creating more room for greenspace. Moving traffic underground will...

Animation of first effect

PRESENTER

...control air and noise pollution. As we saw before, the removal of traffic means the removal of pollution. When you put it into a tunnel, you put it in a controlled space where you can manage the pollution through various filters. Bringing the river above ground...

Animation of second effect

PRESENTER

...will beautify the city and restore a part of its history. The Ladegårdsåen is an important part of Nørrebro, it always has been. Bringing it back to the surface for everyone to enjoy is a victory for everyone. With the river above ground, the rest of the surface will be for Apark. This park will...

Animation of third effect

PRESENTER

improve the lives of everyone around Nørrebro. Nørrebro is in need of more public green space, more places for people to bike and walk their dogs and enjoy a relaxing day in a natural area. And of course, as you can see, all three of these measures, combined in one single project, will manage stormwater. The tunnel, the river, and the park are three areas that can store large amounts of rain and prevent flooding and the billions of kroner of destruction we've seen happen recently. These are all things that have been done before, and they've been done before successfully. Nothing here is really new, it is all known technology that we could see vastly improve Copenhagen for decades ahead.

End presentation, make any necessary closing remarks, take questions,  
move on to slide 15

## Appendix F: Visual Display Recommendation for Miljøpunkt Nørrebro

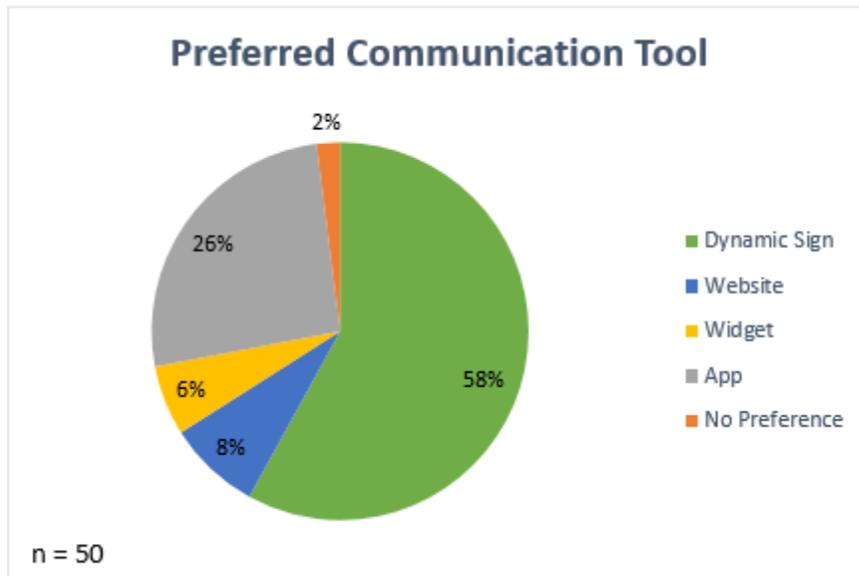
Nørrebro has high levels of traffic pollution, which the public is aware of, though they currently do not have an accurate sense of the problems that this causes. The team conducted research on dynamic visual displays and communication tools so that they could provide a recommendation on the best communication tool for Miljøpunkt Nørrebro to use to display pollution levels and subsequent health effects to the public. The team held a Community Feedback Charrette where they received input on various communication tools and visual display designs from the Nørrebro community. The team made their recommendations using the results of the charrette, as the public's opinion was the most important factor that the group considered when making their recommendation. The following report provides the recommendations and the reasons behind the choices. It does not provide a concrete timeline for implementing a communication tool; it is meant to act as a background plan while attempting to acquire funding and as a reference guide in the event of funding acquisition.

### Selection of Communication Tools

In order to provide an option for various levels of funding, the team proposes two different mediums for a communication tool. Option 1 is the more desirable of the two options, but needs substantial funding while option 2 requires minimal expenses. By recommending two different options to Miljøpunkt Nørrebro, the team hopes give them a plan that they will be able to implement, regardless of political roadblocks or the ability to obtain funding.

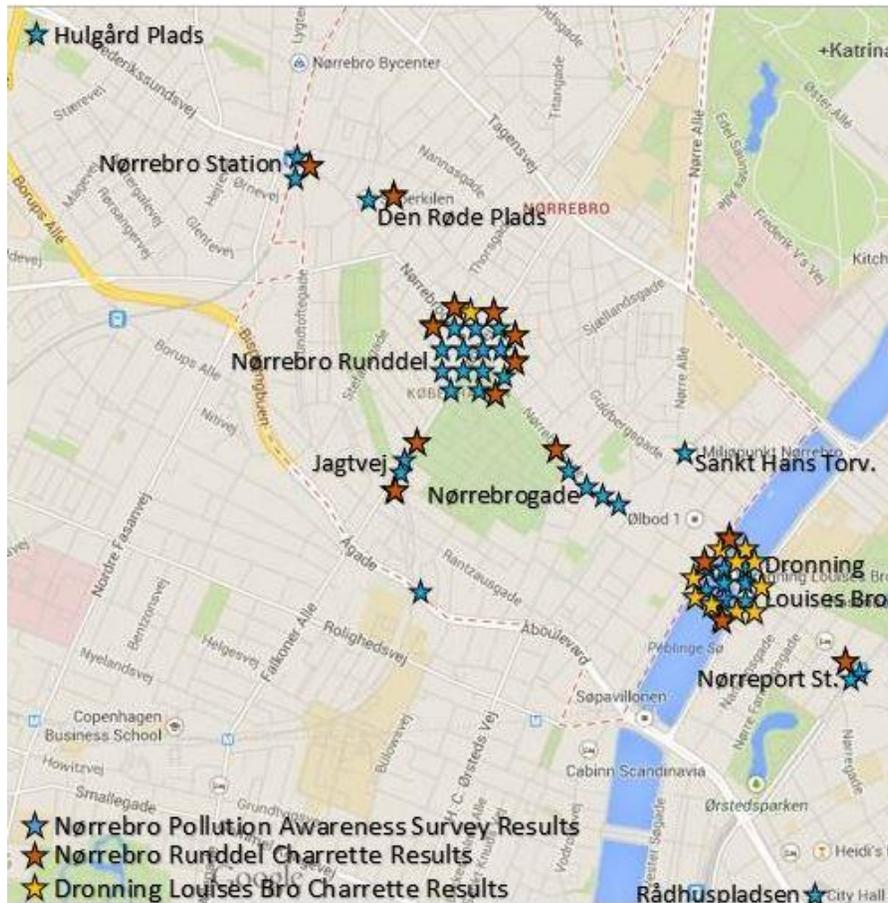
#### Option 1: A Dynamic Sign

Option 1 is a dynamic sign, which is only feasible if Miljøpunkt Nørrebro can obtain substantial funding, as a physical display is the most expensive option. During the charrette, 58% of participants said that they would want to see a dynamic sign installed in Nørrebro (see Figure 51), making it the tool most favored by the public. Because of its high visibility, a sign would best fit Miljøpunkt Nørrebro's goal of increasing awareness of pollution-related health effects throughout Nørrebro. From background research, it has become apparent that, if feasible, the addition of a dynamic element to the display would be highly beneficial. By adding a moving element, people are more likely to notice the sign and become more aware of the air pollution in the area.



**FIGURE 51: APPENDIX F CHARRETTE RESPONSES TO PREFERRED COMMUNICATION TOOL**

The team analyzed potential dynamic sign location recommendations, since a location needs to be chosen if Miljøpunkt Nørrebro can secure funding. The group used feedback obtained from the charrette, as well as a survey conducted earlier in the project, to make their recommendations. Figure 52 displays each participants’ responses plotted on a map of Nørrebro. The blue stars indicates a response given during the first survey, conducted at the Nørrebro Runddel, and the yellow star represents a suggestion made during the Community Feedback Charrette, which occurred at both the Runddel and the Dronning Louises Bro. The team is recommending two potential sign locations, as the two locations reach different types of audiences and because the number of people in favor of each was almost tied, at 21 and 20 votes each. By providing two potential sign locations, the team hopes to provide Miljøpunkt Nørrebro with options to present to potential funders.



**FIGURE 52: APPENDIX F PROPOSED DYNAMIC SIGN LOCATIONS FROM COMMUNITY**

The first location suggestion, with 21 votes, is on the Dronning Louises Bro near, or in conjunction with, the dynamic bicycle counter. This location is ideal because of the heavy pedestrian and bicycle traffic. Coupled with the fact the everyday passersby on the bridge are already familiar with a dynamic sign (the bike counter), this location has much potential. Commuters on the Dronning Louises Bro who check the bike counter as they go past it, so they should be able to quickly adapt to checking the pollution sign as well.

The second proposed location, with 20 votes, is the Nørrebro Runddel. The Runddel acts as the center of Nørrebro and receives large amounts of foot traffic every day. There is also heavier vehicle traffic here than at the Dronning Louise Bro, meaning more people who drive cars would see it. This is beneficial as the goal of the sign is to educate people on traffic pollution, which is caused by motor vehicles. By installing the sign in a location with heavy car traffic, there is the potential of changing a driver's mind about using their car every day.

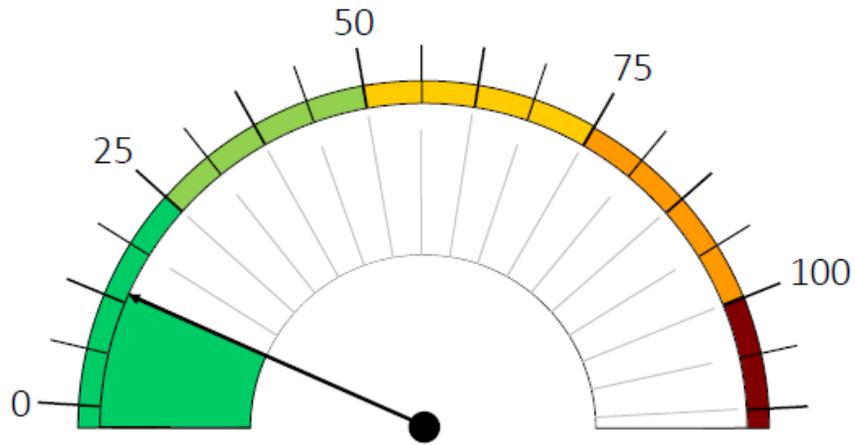
## Option 2: A Smartphone Application

The second communication tool option is a smartphone application, or app, which will be less costly than a dynamic sign. The team considered other low budget options, such as a website and a widget, but rejected them due to a lack of public interest in either option, as collectively they were only preferred 14% of the time. Twenty-six percent of all responses were in favor of an app, making it the runner-up communication tool from the Community Feedback Charrette. An app has the ability to reach people who are not in a specific location, as they can download it and have it with them at all hours of the day, wherever they are.

During the charrette, multiple people suggested having both a dynamic sign and an app that worked together. They recommended having the dynamic sign provide a link for where to download the app. The app could have more detailed information than the dynamic sign, so people who wanted to learn more about the health effects for the current state of pollution could go to the app and find additional information. If this is not immediately possible, the app could work as an intermediate solution for Miljøpunkt Nørrebro. The app could be developed and then its success could be used as leverage in obtaining funding for a dynamic sign that would work with the app to educate the community of Nørrebro about the air pollution in the area.

## Selection of Visual Display Design

The group recommends that Miljøpunkt Nørrebro use the Speedometer Display (see Figure 53), regardless of whether they are able to create a dynamic sign or an app. In the design, the Speedometer would move up and down as the pollution levels fluctuated. Each section of the Speedometer corresponds to an air quality index category while the bottom half of the sign displays information about the health risks associated with each speedometer range. The display can function as either a dynamic sign or an app, and if Miljøpunkt Nørrebro is able to receive funding for both tools, it could be used in both. The group recommends the Speedometer Display, as 53% of the charrette participants preferred it to the other two design options (see Figure 54), the Pie Chart and Bar Display. The speedometer design was the easiest to understand and it had the strongest first impression. Many participants told the team members that they gravitated towards the Speedometer Display due to its association with cars and traffic. They stated that because of the speedometer, they immediately knew that the pollution levels shown were specifically traffic pollution levels. The Speedometer Display was the most preferred visual display, and as it has the most direct relation to traffic pollution, the team recommends that Miljøpunkt Nørrebro use it in the pollution communication tool.



Very Low	Low	Medium	High	Very High
0 to 25	25 to 50	50 to 75	75 to 100	> 100
Air quality is considered satisfactory, and air pollution poses little or no risk.	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive.	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.	Health warnings of emergency conditions. The entire population is more likely to be affected.

FIGURE 53: APPENDIX F SPEEDOMETER DISPLAY

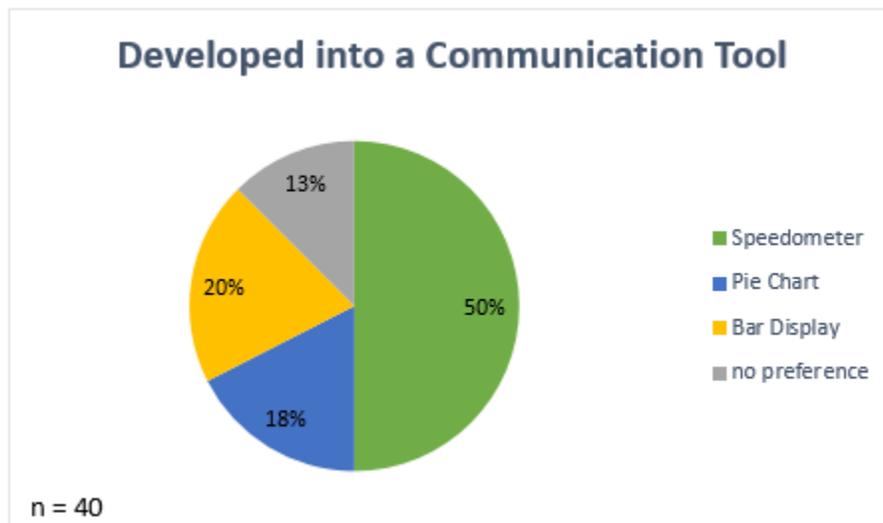


FIGURE 54: APPENDIX F PREFERRED DISPLAY FROM CHARRETTE PARTICIPANTS

## Pollution Sensor Data

The group recommends Miljøpunkt Nørrebro utilize pollution data from the Danish Department of Environmental Science. The government agency receives their data from sensors placed around Nørrebro (see Figure 55). Miljøpunkt Nørrebro has access to the data from these sensors, which will allow them to incorporate this information into the communication tools. The sensor data is real-time with a one-hour delay of pollution levels including NO<sub>2</sub>, NO, and CO<sub>2</sub>. Of the three pollution sensors, Miljøpunkt Nørrebro should use the data from the sensor on H.C. Anderson Boulevard, as it is the extension of Ågade and Åboulevard, the roads that Miljøpunkt Nørrebro aim to focus on. These roads are central to the Ladegårdsåen Daylighting Project, which is a public works project in which Miljøpunkt Nørrebro is invested. H.C. Anderson Boulevard experiences similar traffic, and therefore similar traffic pollution as Ågade and Åboulevard, which means that it provides the most accurate pollution data for the roads. The use of the sensor on H.C. Anderson Boulevard will show the need for the Ladegårdsåen Daylighting Project and the need to reduce traffic in Nørrebro as a whole.

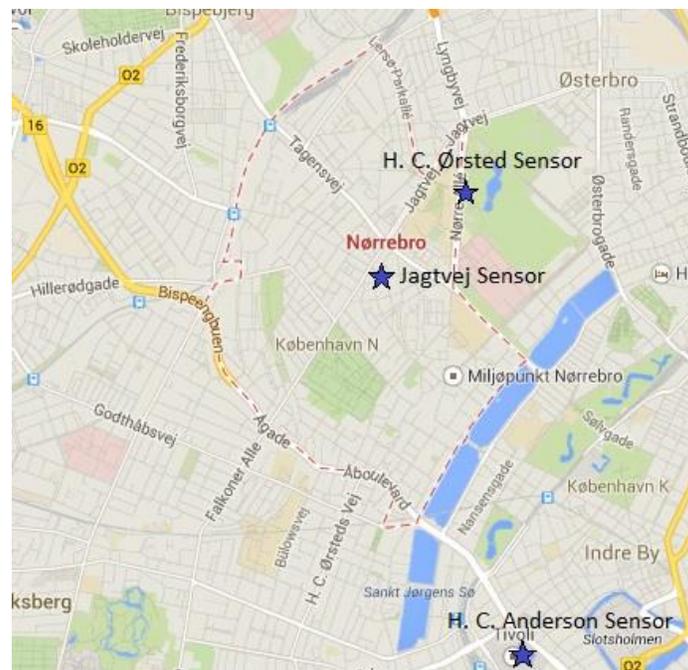


FIGURE 55: APPENDIX F MAP OF NØRREBRO WITH POLLUTION SENSOR LOCATIONS

## Weighted Moving Average

In order to display the real-time pollution data in the form of a visual display, the team recommends that Miljøpunkt Nørrebro put the data through a smoothing process. The pollution sensors take the incoming data, average it over a one-hour period, and then output the pollution readings into a spreadsheet that

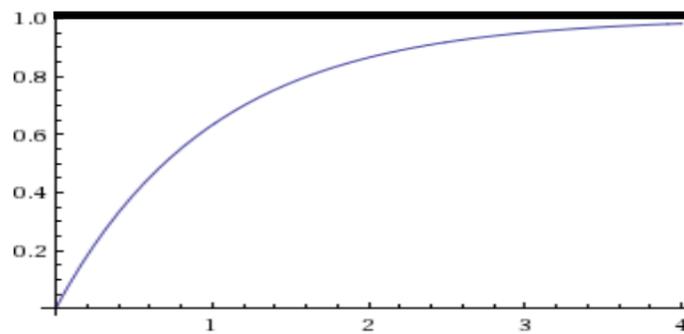
Miljøpunkt Nørrebro can then access. Even with this averaging, there are still potential outliers that they need to take into consideration. Outliers can occur if a large vehicle idles next to the sensor or if there is a momentary outage in the sensor readings. When this happens, it is still necessary to display accurate information. To do this, the team applied moving weighted averages to the data stream. A moving weighted average dampens the outliers but does not eliminate them, which is beneficial as eliminating an outlier would mean that there would be no pollution data to display for an entire hour. Miljøpunkt Nørrebro should use the four-point moving weighted average, shown in Equation 4. In this equation, “real” is the most recent sensor data, and “real<sub>m<sub>x</sub>h</sub>” is the value of past data where the variable “x” indicates how old the measured data is in hours. The team recommends this equation because it is roughly approximate to the exponential smoothing function (see Equation 5). As shown in Figure 56, it provides a smooth exponential curve approaching a limit of 1.

$$f(avg) = ((real * 0.64) + (real_{m1h} * 0.235) + (real_{m2h} * 0.09) + (real_{m3h} * 0.035))$$

**EQUATION 4: APPENDIX F 4 POINT WEIGHTED MOVING AVERAGE FOR POLLUTION DATA**

$$f(x) = 1 - e^{-x}$$

**EQUATION 5: APPENDIX F EXPONENTIAL SMOOTHING FUNCTION**



**FIGURE 56: APPENDIX F EXPONENTIAL SMOOTHING CURVE FOR EQUATION 5**

Figure 57 displays the difference in the raw and averaged NO<sub>2</sub> pollution data from the H.C. Anderson sensor over a 55-hour period. The graph shows where the equation has smoothed the data into a more realistic format to help account for outliers.

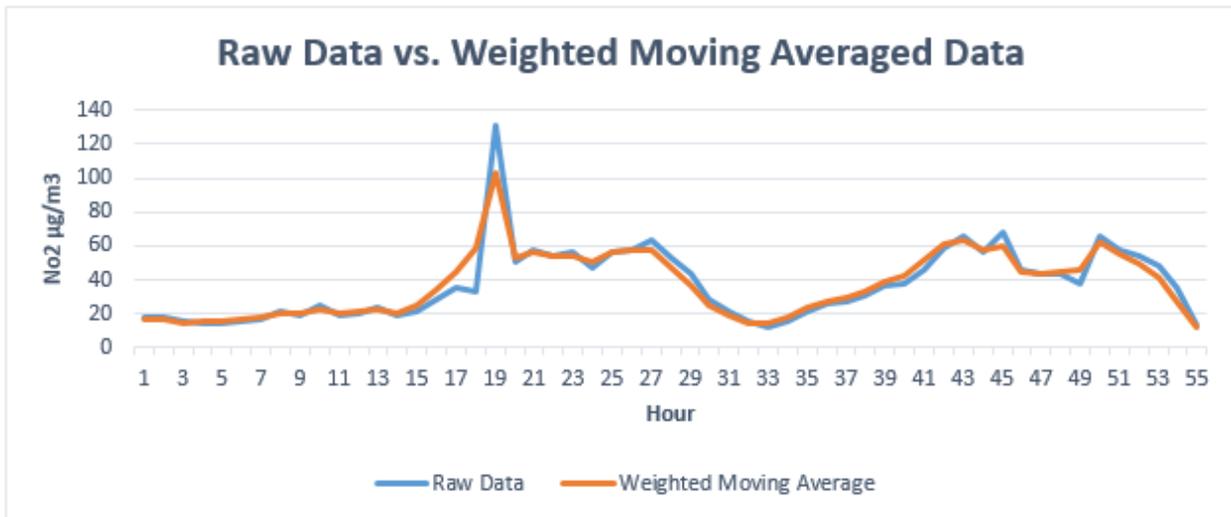


FIGURE 57: APPENDIX F RAW DATA COMPARED TO WEIGHTED MOVING AVERAGED DATA

### Utilizing CAQI

Once they smooth the data, Miljøpunkt Nørrebro should convert the data into the desired air quality index, CAQI. CAQI is the standard air quality index for Europe and it is understood throughout Europe. To do this, Miljøpunkt Nørrebro needs to put the data into an Excel spreadsheet containing the CAQI piecewise function for NO<sub>2</sub> (see Equation 6). NO<sub>2</sub> should be used because its levels consistently rise about EU standards (see Figure 58), which is not the case for other pollution particulates. Table 10 displays the transformation of the raw data, to the weighted moving average data, to the final CAQI levels.

$$f(x) = \begin{cases} .5x & x \leq 100 \\ .25x & 100 < x \leq 200 \\ .125x & 200 < x \end{cases} = \begin{cases} = IF(x < 100, x * 0.5, 0) \\ = IF(x > 200, 0, IF(x \geq 100, 50 + 0.25 * (x - 100), 0)) \\ = IF(x > 200, 75 + 0.125 * (x - 200), 0) \end{cases}$$

EQUATION 6: APPENDIX F PIECEWISE FUNCTION FOR NO<sub>2</sub> CAQI

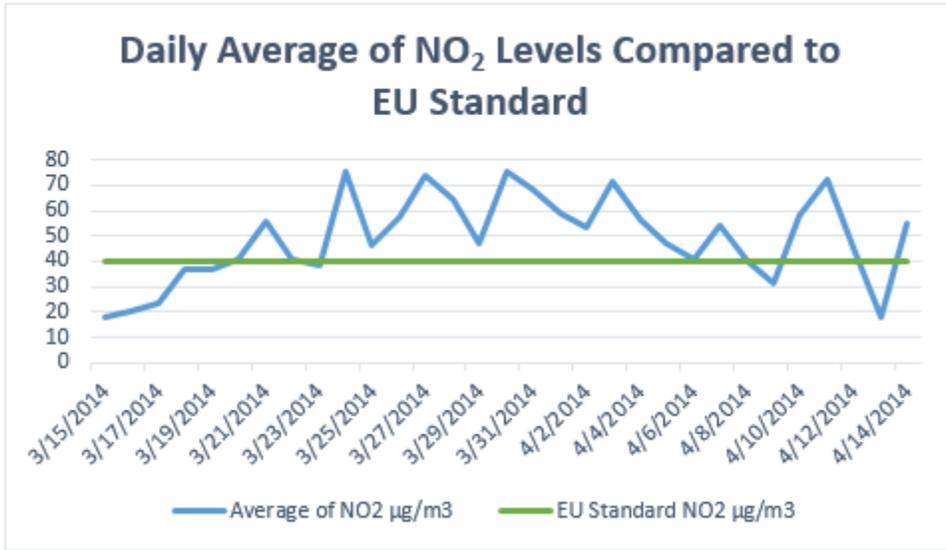


FIGURE 58: APPENDIX F DAILY AVERAGE OF NO<sub>2</sub> PARTICULATE DENSITIES COMPARED TO 2014 EU STANDARD

Date	Time	NO <sub>2</sub> µG/M <sup>3</sup>	NO <sub>2</sub> Moving Average	CAQI	Level on Display
April 14, 2014	15	45.85	49.1468	24.5734	Very Low
April 14, 2014	14	55.98	54.81295	27.40648	Low
April 14, 2014	13	52.55	53.1904	26.5952	Low
April 14, 2014	12	54.8	54.9728	27.4864	Low
April 14, 2014	11	48.7	56.475	28.2375	Low
April 14, 2014	10	65.64	70.9401	35.47005	Low
April 14, 2014	9	72.82	80.90755	40.45378	Low
April 14, 2014	8	95.08	94.34525	47.17263	Low
April 14, 2014	7	93.16	92.1053	46.05265	Low
April 14, 2014	6	102.13	88.5132	44.2566	Low
April 14, 2014	5	68.85	62.709	31.3545	Low

TABLE 10: APPENDIX F POLLUTION DATA TRANSFORMATION TO CAQI

### Final Recommendations

Miljøpunkt Nørrebro needs a communication tool that will make the Nørrebro community aware of the high traffic pollution levels in the neighborhood. The team recommends that Miljøpunkt Nørrebro try to obtain funding to create a dynamic sign in Nørrebro. If they can receive enough funding for this endeavor, they should install the sign either next to the bike counter on the Dronning Louises Bro, or in the Nørrebro Runddel. If Miljøpunkt Nørrebro is not able to get enough funding, the team recommends that they develop a smartphone application instead. The smartphone application could be an intermediate step for a dynamic sign; it could be used to gain support for the endeavor before building a sign. If this were to happen, the app and dynamic sign could both be used together to educate the community of Nørrebro about the pollution levels in the area. Regardless of the communication tool, the team recommends that Miljøpunkt Nørrebro use the Speedometer Display as the design, and that they use the pollution sensor data from H.C. Anderson Boulevard sensor. They should also use the moving weighted average smoothing and CAQI methods described in the report to format the pollution data into a universally understood format. With these recommendations, the team hopes that Miljøpunkt Nørrebro will be able to create an effective communication tool for education the community about the air pollution levels in the neighborhood.