Flood Prevention and Daylighting of Ladegårdsåen

A Project to Create Green Space and to Provide Better Drainage of Rainwater

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Authorship Page

For our report, each team member worked on revising and editing all sections of this paper.

Nésa-Maria Anglin

Nésa-Maria transcribed and organized the previous proposal made by Orbicon which served as a basis for our design features and options for the canal. She focused on designing the green space along the canal, as well as researching water quality in the canal, biodiversity and how to clean the water by using rain gardens. She also developed sketches for the pedestrian walkway. She wrote the following sections of the research paper: Executive Summary with Shane Ruddy and Anders Jensen, the following sections of the Background chapter: History of Nørrebro, History of the Ladegårdsåen, Past Daylighting efforts in Copenhagen with Shane Ruddy, The Ladegårdsåen Today, Environmental Awareness, Flooding and Drainage Issues and the Opening of the Cheonggyecheon River in Seoul, Korea. She also wrote the introduction for the Design Concept and reference sections of the report.

From this project, I learned to rely on my strengths and not to focus on my weaknesses. One of the biggest challenges I faced was using citations, and even though it is still a challenge I have come to understand the deeper meaning to the importance of it. Writing, for me, was a challenge as this report was technically based, and I am more of a creative writer, but as I progressed I felt that I have learned how to become a better writer through revisions, comments from my peers and advisors. Finally, I learned about claims and the importance of using relevant sources and data to argue and defend my positions.

Anthony Hassan

Anthony Hassan was responsible for compiling the information we gathered from experts in the field in order to select and confirm a route. Using a variety of maps, which illustrated the environmental issues affecting the route, he built a persuasive argument to justify the reasons why we should daylight the canal along this particular route. He also created several bridge designs to support soft traffic across the canal. He wrote the following sections of the research paper: Introduction, the following sections for the Background Chapter: Traffic and its Potential Reduction with Shane, Harmful Pollution and Opening the Aarhus River in Denmark, co-wrote the Methodology section with Shane, and the Recommendations and Conclusion Chapters of the report.

Throughout my time working on this project in Copenhagen, I learned a great deal about organizational writing. I learned how to use my writing to clearly explain key facts in detail to use as evidence for claims. I also toned my skills as a group member by reducing my susceptibility to procrastinate, increasing my content of constructive criticism, and enhancing my ability to be patient. Pertaining to the concept of daylighting, I learned that projects related to canal or river openings are very complicated. There are many important factors pertaining to the success of such a project which I overlooked and did not understand before my experiences working abroad.

Shane Ruddy

Shane Ruddy was responsible for creating designs for the canal and the tunnel, as well as determining the dimensions needed for the route and the design features along the route, such as store front areas and bike lanes. He helped determined the water sources and the secondary uses for the water from the canal. He also wrote the following sections of the research paper: Acknowledgement, Abstract, and the following sections for the Background chapter: Benefits of Daylighting, Past Daylighting efforts in Copenhagen with Nesa-Maria, Traffic and its Potential Reduction with Anthony, the Introduction section to the Case Studies and the Daylighting Design Option. He co-wrote the Methodology section with Anthony and the Executive summary with Nésa-Maria and Anders Jensen.

This project taught me how to use data and information to properly argue and justify a decision you have made. The project was very large and complex, and therefore, I learned the importance of organizing gathered material and making sure that it is presented in a logical and structured order. Displaying information using bullets, numbering, and strategic headings and subsections was an approach I learned to follow. Specific to our project, I learned that daylighting plans encompass many different aspects that take time to analyze. The importance of flood protection in urban areas and the different ways of dealing with this issue became much more apparent to me throughout my work on the Ladegårdsåen daylighting.

Abstract

Our team assisted Miljøpunkt Nørrebro, an environmental organization in Copenhagen, in selecting a pathway for reopening the piped Ladegårdsåen canal. We identified design options that meet the city's goals to add green space and alleviate flooding along the chosen route. Using maps and expert interviews, we developed and justified design concepts for a canal, pedestrian areas, rain gardens, bike paths, and a dual-purpose tunnel serving as a motorway and reservoir.

Executive Summary

Copenhagen faces many environmental problems; the most compelling are a lack of green space and recent extreme rainfall causing flooding. This project aimed to address these problems by (1) investigating the possibility of daylighting Ladegårdsåen, a piped canal that is located under the busiest road in Copenhagen, the Ågade-Åboulevard (AA), and (2) developing a feasible design concept that our sponsor, Miljøpunkt Nørrebro, and other stakeholders might pursue further.

Previous plans to daylight Ladegårdsåen failed due to a lack of funds and motor traffic considerations. Prior to our arrival in Copenhagen, a planned congestion ring was scrapped, meaning we could not rely on decreased traffic in the area where we planned the canal and would need to address that obstacle. The more recent need for flood alleviation was, however, a new development that made the need for a canal more urgent and desirable.

Within this context, our objective became to design the daylighting and green space in a way that would alleviate flooding, while still meeting the demands of a major motor traffic corridor.

In order to select a route and create proper designs, we planned out a four phase approach. In Phase 1, we simply gained a better understanding of the problems and motivations surrounding daylighting projects in general and the opening of Ladegårdsåen specifically. Phase 2 focused on confirming a route, which was done with the help of expert interviews and by establishing parameters to evaluate the different routes. Phase 3 involved refining the route and developing possible design options. This required a large amount of data collection, including maps, technical documents, and an inventory of physical features of the site. Maps, such as the heat and noise maps, were used to illustrate the different problems that affect the route more prominently than other surrounding areas. A trip to a previously daylighted river in Aarhus and a study of other daylighting projects was also important, as we wanted to analyze and incorporate relevant elements of those designs. Phase 4 involved mapping out a visual plan and justifying the major features.

Our design solution, to both help with city-wide flooding and to make room for daylighting along the route, is a dual-purpose motorway tunnel design that can handle displaced traffic along the AA, while serving as an emergency reservoir system (inspired by SMART project in Kuala Lumpur). Reservoir capacity is preferable to direct outlets into the harbor because, (1) it is not realistic to divert huge amounts of water to the harbor directly, and (2) reservoir capacity is not affected by high tides coinciding with extreme rain, while bringing water directly to the sea would (because of decreased slope). Reservoir capacity would also not be affected by rising sea levels due to climate change.

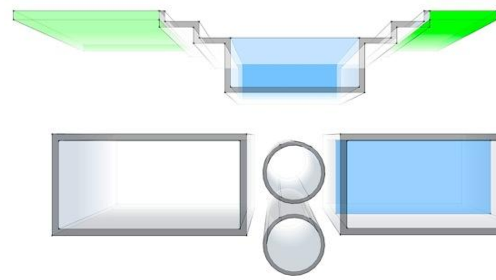

Figure 1: Canal and Dual-purpose Motorway Tunnel Design (Recreated from our designs in Section 4.5.2 using computer software by Eigil Nybo, 2012)

The supply of water is low in the canal itself, so our stepped, double profile design allows for a narrow, but naturally appealing flow of water through its base channel; in times of heavy rain, the water can rise up and flood the canal's ascending steps, increasing the capacity. Other design features - bicycle paths, a pedestrian walkway, and ornamental bridges - were added for practical and aesthetic reasons, and would attract residents and visitors to local businesses and provide community uplift.

We propose a water system, in which the canal would receive water from rooftops, the natural water catchment area, and foundation drains. During dry periods, some water would be recycled back into the canal. When the system contains excess water, we propose that it be used as sekunda (semi-clean) water, for toilet flushing, heating, washing, etc. Some of this water would be cleaned by rain gardens, using a natural filtration system, situated at various flood prone areas along the canal. Collecting and using sekunda-water will decrease stress on sewers and drinking water supplies.

Our designs and choice of route correlate with the City of Copenhagen's policies to integrate water (blue) and green structures. Ladegårdsåen would be the missing thread to create a blue/green grid of connected green corridors and waterways, as well as strengthening Copenhagen's claim to being bicycle capital of the world and a leading green city. Moving traffic underground would obviously remove noise and particle pollution, raising living quality in the area.

We delivered this report, a PowerPoint presentation, and hand-outs visualizing and justifying our design concept to Miljøpunkt Nørrebro and other stakeholders. The designs are fairly basic, but provide a concrete starting point for further pursuing and promoting the daylighting project. Further information will be featured on a website created by Anders Jensen of Miljøpunkt Nørrebro.

We also recommended:

- Further analysis of the amount of water that can be supplied to the canal and how the sekunda-water system can be implemented.
- Gaining community and political involvement

Because of the complexity and scope of this project, a more broad and technical analysis should be conducted, based on the research and design ideas in this project.

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Chapter 1: Introduction

Before the end of the nineteenth century, many highly populated areas around the world experienced a dramatic change now known as "urbanization," which is essentially the industrial and commercial growth and development of cities (United States Environmental Protection Agency, 2010). Such changes are due to the economic and social expansion of urban areas caused by an increase in population (2010). With urbanization and an increase in industry came a rise in dangerous pollution and the decline and abandonment of green areas and waterways (2010). According to a University of Michigan article, *Urbanization and Global Changes* (2006), the effects of urbanization are tied to negative global changes and are responsible for many environmental and social issues. Environmentalists state that urbanization is a threat to the environment and to the well-being of humans because it sets off a chain of environmental problems that manifest over time (2006).

In Denmark, urbanization dates as far back as medieval times (Andersen, 2004). Small cities were established between the 8th and 11th centuries, but large, rapid economic and urban growth in the second half of the 19th century caused a population explosion (2004). This happened especially in the city of Copenhagen, the country's capital (2004). Such effects from the city's urbanization were the destruction of farm lands and other green spaces and the piping and burial of streams and canals. One such canal is known as the Ladegårdsåen, which was placed in pipes in 1897 and currently flows under one of the busiest roads in Copenhagen (Frederiksberg Kommune, 2009). It is located in the borough of the city known as Nørrebro. In the past, Nørrebro was described as a "sparsely populated country side" (Nørrebro Local Historical Society and Archives, 2012) but today is densely populated with both humans and automobiles. According to Miljøpunkt Nørrebro, an environmental, grassroots organization, the people of Nørrebro have expressed a desire to add more green space to the area. Along with this, noise and air pollution caused by the high volumes of traffic in the area are also a concern for the citizens (L. Barfred, Miljøpunkt Nørrebro, personal communication, January 24, 2012).

Such desires and concerns were developed from several environmental factors affecting the area. Due to the large amounts of carbon dioxide emissions, Copenhagen has experienced a phenomenon known as the heating effect (City of Copenhagen, 2011). Local meteorologists believe that this effect has brought upon a climate change which has caused unstable rain patterns (2011). In the summer of 2011, terrible flooding occurred in Copenhagen due to unexpected, extreme rainfall (O. Larsen, Miljøpunkt Nørrebro, personal communication, March 16, 2012). In light of this, the city needs to find ways to control the storm water in order to reduce flooding (March 16, 2012). However, Miljøpunkt Nørrebro sees the increase in rain water as an opportunity to create green space in the area (March 16, 2012). One way they hope to accomplish this is through the opening of the Ladegårdsåen canal, a concept known as "daylighting". This became a realization due to the recent flooding, which acted as motivation for the project. The Ladegårdsåen could potentially provide a means to collect the extreme storm water runoff and transport it out of the city and into larger bodies of water. Another motivating factor for daylighting the canal was a congestion ring of tolls which was proposed to be placed around Copenhagen in order to reduce traffic. Having less traffic to distribute would make it easier for the canal to be opened. Unfortunately, this ring fell through, but the idea and desire of opening the Ladegårdsåen remains (March 16, 2012).

A previous proposal to open the canal was established in 2007 by Orbicon, an engineering firm located in Copenhagen. However, this was only meant to be an "idea project" (Gabriel, 2012) for the Copenhagen municipality with the sole purpose of providing an architectural and natural uplift to the area. At that time, using the canal as a tool to reduce flooding was not considered. In fact, no rainwater runoff was supposed to enter the canal (2012). Therefore, not much research has been performed on how daylighting the canal might provide a system to collect and transport heavy rain water in order to reduce flooding. Moreover, research is needed to explore how opening the canal might also create more green space as an environmental and recreational uplift to the area. One way to gather such information and ideas related to possible designs is through the analysis of other canal daylighting projects. By understanding the benefits, advantages, and designs celebrated by similar daylighting projects, such factors could be applied to the Ladegårdsåen. Challenges and disadvantages would also have to be considered as well.

The goal of this project was to develop and illustrate design options and ideas for daylighting the Ladegårdsåen for Miljøpunkt Nørrebro. Such designs would need to focus on options for collecting and diverting storm water, increasing green space, and providing a recreational, environmental, and economic uplift to the area. They would have to consist of sections views of the canal with dimensions, designs of drains or reservoirs, different types of green space, areas for bicycle lanes, areas for pedestrian walkways in conjunction with café and store fronts, and types and locations of bridges for different purposes. From there, the designs could be technically built upon in the future by professionals in order to further address these issues. Although the different ways to divert traffic on the street above the present canal is an important factor to be considered and discussed, Miljøpunkt Nørrebro advised our team not to focus on this matter. Rather, our team noted broad strategies for doing so, but did not thoroughly investigate these options in great detail. The focus of this project was to investigate daylighting the Ladegårdsåen in order to protect Nørrebro against flooding, provide the area with more green space, give the community a recreational boost, and to instill pride in the citizens. Our final report and design deliverables will be used as recommendations for Miljøpunkt Nørrebro if they wish to pursue this project more in depth with community involvement.

Chapter 2: Background

This chapter provides information on Ladegårdsåen, a buried, piped canal and the issues that our sponsor, Miljøpunkt Nørrebro, hopes the reopening of the canal will address. Problems with pollution, a need for more green space, flooding, and traffic in the Copenhagen district of Nørrebro have led Miljøpunkt Nørrebro to begin pushing for this daylighting project. We begin with a broad definition of daylighting according to Buchholz and Younos' 2007 "Urban Stream Daylighting" report, in which they describe it as the intentional exposure of parts or all of a waterway that was once covered. Daylighting is a new movement that fits in with the focus of striving for greener cities worldwide, and Copenhagen is no exception to this green push. A description of the history of the canal and the Nørrebro district follows, including background information on previous attempts to reopen Ladegårdsåen. The problems and motivations for this daylighting project are overviewed and the use of daylighting as a means of addressing them is discussed. Finally, we review a number of case studies of other daylightings to overview the advantages and disadvantages of daylighting, and to point out design examples that could be considered. The problems encountered in other similar cases can be lessons for future generations, while successful projects can be used as guidance to instruct new daylighting plans.

2.1 Description of Daylighting

Humankind has rapidly altered landscapes around the world by building and expanding cities, roads, and farmlands. Streams and canals that were once the centers of development have been diverted, polluted, and even buried underground. The idea of placing waterways underground can be traced back to the Industrial Revolution. Thousands of miles of creeks and rivers worldwide were placed underground in pipes to try and avoid contamination as urbanization expanded (Buchholz and Younos, 2007). Many towns, during the Industrial Revolution, dumped industrial and human waste into streams polluting the water, and therefore, leaving towns to bury the waterways to keep them clean, which they believed was their best option (Buchholz & Younos, 2007). Buchholz and Younos explain how the piping of waterways was also done to help make it easier for urban areas to grow and expand, and there is a clear connection between the growth of automobile-oriented cities and the increase in the burying of waterways. Once waterways were buried, roads, rather than bridges, could be constructed and more room was available for housing and urban development. All of these efforts to bury water beneath the surface have pushed water off the map and out of many people's everyday lives.

Richard Pinkham, in his 2000 report "Daylighting: New Life for Buried Streams," describes a new movement that has helped to revive many of these lost waterways and address the new interest in green infrastructure. This movement is known as daylighting, and Pinkham (2000) describes it as "projects that deliberately expose some or all of the flow of a previously covered river, creek, or stormwater drainage" (p. 5). It represents a significant change in the way people look at surface water in their neighborhoods and cities. Reasons for this movement include the new understanding of the importance of preserving natural drainage patterns and surface water routes and simply regaining the beauty and greenery that streams and waterways can bring to an area (Pinkham, 2000). Burying waterways can be troublesome, as many of the pipes will eventually rust and need to be dug up and replaced, while some culverts simply can't handle increased amounts of water traveling through them (Buchholz & Younos, 2007). One important aspect of daylighting to remember is that, unlike stream restoration, opening a stream or waterway back to the surface will not necessarily ecologically restore it, or bring it back to its natural state (Buchholz & Younos, 2007). Stream restoration, which can be connected with a daylighting project, is "the return of a riverine ecosystem to a more natural working order that is not only sustainable over the long-term, but aims to recreate rivers that are more productive, aesthetically appealing, and valuable from a conservation perspective" (Miller, 2008).

Daylighting not only opens waterways that were completely buried; rather, it exposes waterways by removing decks, highways, or any obstruction keeping them from view (Pinkham, 2000). Pinkham explains that waterways can be opened in the same channel that they once traveled through freely, or be placed into new channels. Daylighting is a way to regain nature in urban locations and allow water to flow exposed throughout the different settings it encounters.

2.1.1 Benefits of Daylighting

Daylighting has become popular over the past several decades because of its many benefits. Brook Ray Smith of the University of California, Berkeley explains in his 2007 daylighting article that stream daylighting projects have great potential to reduce stormwater flows and, therefore, the potential to play a role in flood reduction. Daylighting can lead to alterations in traffic and pedestrian patterns, which could possibly reduce traffic and congestion by dispersing traffic and encouraging people to find other modes of transportation (Barfred, personal communication, 2012). Social benefits of such projects include connecting people with nature and allowing them to feel good about their community and its role in preserving the environment (Pinkham, 2000). Pinkham explains how daylighting projects can help beautify a neighborhood, often leading to higher property values and business growth. He also states that the addition of green space is yet another outcome that can be achieved through daylighting; by being added along opened waterways, it can improve the aesthetic and environmental value of the area.

2.2 Copenhagen's Push for Green Space through Daylighting

Copenhagen, Denmark, like most modern cities, puts a huge emphasis on green space. The city has been experiencing population growth throughout the 20th century and up to the present, which has led them to focus on controlling urbanization and keeping their city environmentally friendly (Cahasan & Clark, n.d.). Green space literally means "a plot of undeveloped land separating or surrounding areas of intensive residential or industrial use that is maintained for recreational enjoyment" (Dictionary.com, 2012). The Village Neighborhood of Philadelphia explains the many benefits of green space in their 2012 article "Why Protect Urban Green Space." Some of these include:

- Absorbs rainwater and helps to improve drainage
- Absorbs pollutants and reduces noise pollution through vegetation
- Provides recreational areas for citizens
- Provides a connection for residents between urban life and the environment
- Attracts businesses to the area
- Provides habitats for wildlife

Copenhagen has been passionately striving to better green its city over the past decade, with strong efforts being made specifically in recent years. Copenhagen's push for green space is part of a much larger, worldwide effort to protect the environment. The City of Copenhagen's report, Copenhagen Agenda 21 2004-2007 (2004) describes Agenda 21 as a program that was adopted by 181 countries at the UN Conference on Environment and Development, which was held in Rio de Janeiro in 1992. They depict Agenda 21's goals "to eliminate imminent environmental threats, limit excessive resource consumption and with the support of citizens direct developments in a more sustainable direction," (City of Copenhagen, 2004) which are evident in the city's goals today. The Green Structure Plan (described below) illustrates the city's concern over, what they feel, is a lack of green space.

Trying to keep the City of Copenhagen green and environmentally friendly has been a goal of city planning committees for years. Copenhagen's Green Structure Plan is the way the city incorporates green elements into its neighborhoods. According to Cahasan & Clark (n.d.), in their review of the push for green space in Copenhagen, the following are major factors in the city's plan.

Key principals:

- The plan's central idea revolves around the "5 Fingers Concept," a design for the City of Copenhagen that originated in the 1940s. It is simply the idea that urban areas of the city follow linear corridors extended outward which are connected by transit (often railways) and extend just like fingers from the city center. The area between the fingers is protected as green wedges.

- The area between the fingers will be kept as undeveloped green wedges.
- The fingers will follow public transportation as they grow, particularly railways.
- Citizens will live very close to green spaces.

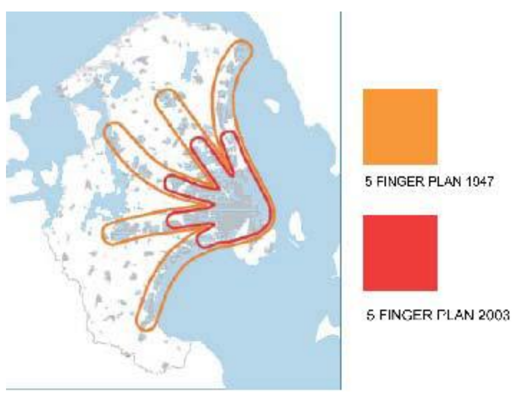

Figure 2: 5 Finger Plan (Cahasan and Clark, n.d.)

Nørrebro has fallen somewhat behind on maintaining a fair balance between urbanization and green space compared to the rest of the city. The district is located in the palm of the hand in Figure 2. It is not that there is no green space in the Nørrebro district, it is simply that there is a very strong urge to add more throughout the entire city. According to Lars Barfred (2012), of Miljøpunkt Nørrebro, additional green space would be tremendoulsy helpful in improving the quality of life in Copenhagen. According to "Copenhagen's Green Accounts 2010", written by the City of Copenhagen (2011), the Copenhagen City Council unanimously decided in 2007 that it was their goal to make Copenhagen carbon neutral by 2025, as well as the Eco-metropolis of the world by 2015. The goal is to make Copenhagen a role model for other cities and a cleaner and greener place for its citizens (City of Copenhagen, 2011). The city wants to improve the quality of parks and green space in Copenhagen and add recreational areas (City of Copenhagen, 2011). Copenhagen's push to improve the quality of life of its citizens by making a greener environment is portrayed by the graph below (Figure 3). It illustrates the drastic push toward green space in the city by the huge jump in the number of trees planted in 2010 compared to those planted in all previous years (City of Copenhagen, 2011).

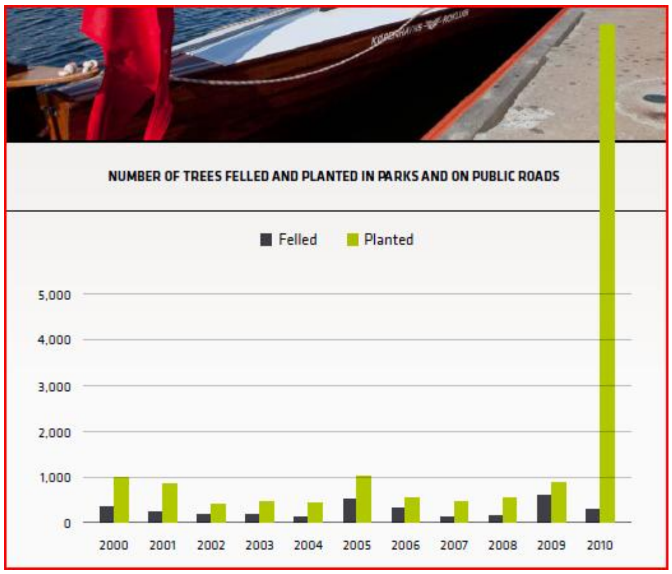

Figure 3: Planting Trees to Increase Green Space (City of Copenhagen, 2011)

Nørrebro has been working to add green space to its highly dense and urbanized neighborhoods. The district already has several major areas of green space, including Assistant Cemetery, Nørrebro Park, and bike and pedestrian paths (Lone, 2009). Many of the, once gloomy, courtyards between buildings have been transformed into green areas for recreation, demonstrating the change the neighborhood is striving for (Lone, 2009). This pressure to add more green space is one of the main reasons as to why the reopening of the Ladegårdsåen should take place. This project could answer this problem by providing a large amount of green space in an area that currently is made up of pavement and automobiles.

2.2.1 History of Nørrebro

In order to understand why this particular project was created, it is important to revisit the history of Nørrebro and the Ladegårdsåen, the previous efforts to daylight this canal, and how the Ladegårdsåen exists today. The history of the Ladegårdsåen canal is shaped by Nørrebro history. According to the city of Copenhagen website (2011), Nørrebro is one of the most populated multi-cultural districts of Copenhagen (Figure 4). With a population of over 70,000 people, it's surprisingly that Nørrebro in the past was described as, according to Nørrebro Local Historical Society and Archives article *"Nørrebro Story"* (2012), "a sparsely populated country side."

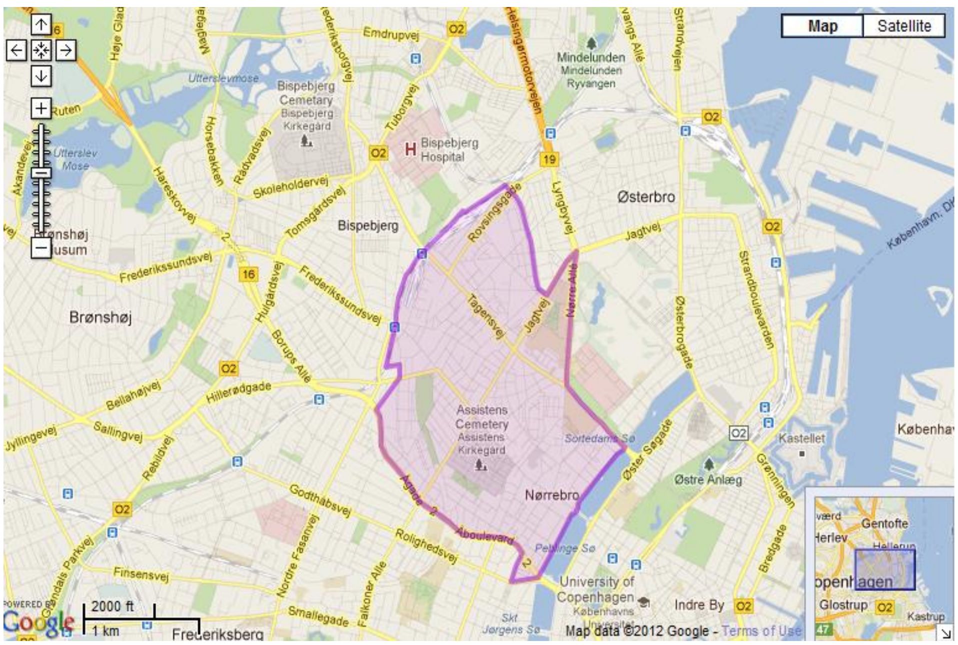

Figure 4: District of Nørrebro (highlighted in purple) in Copenhagen (City of Copenhagen, 2011)

Settlements in 18th century Nørrebro were scattered throughout Blegdamsvej, Fælledvej and a part of Nørrebrogade (*"Nørrebro Story"* (2012)). Most of the inhabitants were craftsmen, workers, millers and gardeners (Figure 5). At the end of the 18th century, people emigrated from borgerskabet and embedsstanden into Nørrebro. In 1852 Nørrebro experienced a significant population shift because the city decided to dissolve the demarcation line (*"Nørrebro Story"* (2012)). The demarcation line was designed to prevent the construction of homes between Falkoner Allé-Jagtvej and the Lakes, thus confining the city into its geographical limits (the City of Frederiksberg, 2010). Population increased from 10,000 in the 1850s to 105,000 in the 1990s (*"Nørrebro Story"* (2012)). The population shift created the desire for modernization and progress. However, with growth comes at a cost to the environment. Hans Andersen, a geography professor at the University of Copenhagen, article *"The end of*

Urbanization? Transformation of the urban concept" stated that Copenhagen and the rest of the nation have entered into a new era; many green space and canals were paved to accommodate the bustling population (Environment Protection Agency, 2012). The atmosphere from the 1800s onwards defines what Nørrebro is today- a diverse working class neighborhood (Figure 6).

Figure 5: 19th Century Nørrebro (Nørrebro Story, 2012)

Figure 6: 21st Century Nørrebro (City of Frederiksberg)

2.2.2 History of Ladegårdsåen

The Ladegårdsåen was an opened stream in Nørrebro that ran from Damhussøen into The Lakes (Figure 7). The Lakes consists of five rectangular water bodies (lakes). There is limited documentation of the canal prior to 1897 (Loldrup, 2009). The canal got its name after a farm that Christian IV built in 1623 (2009). The canal was primarily used for recreational purposes (bathing, cooking) and for watering crops (Figure 8). In 1897, the canal was placed into pipes and paved over due to the expanding population (Figure 9, 2009).

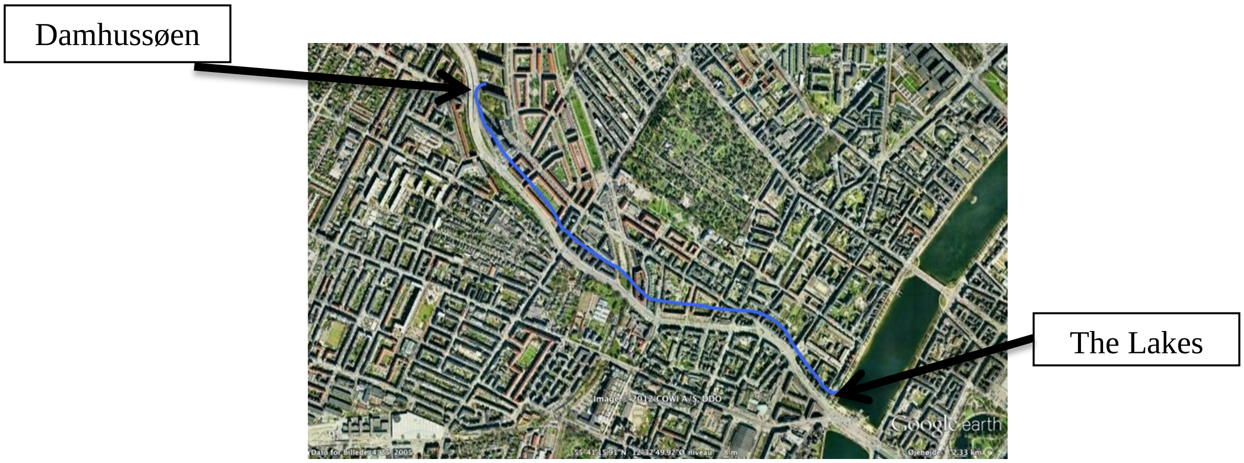

Figure 7: Canal's Path from the Damhussøen to the Lakes (Adapted from Google Maps, 2012)

Figure 8: The Opened Ladegårdsåen during the 1800s (Local History Image Collection, Frederiksberg Library, 2009)

Figure 9: Closing of the Ladegårdsåen Canal in 1897 (Local History Image Collection, Frederiksberg Library, 2009)

2.2.3 Past Daylighting Efforts in Copenhagen

The reopening of the Ladegårdsåen canal is an idea that has been expressed by local Nørrebro citizens and by our sponsor, Miljøpunkt Nørrebro. In 2006, Technical and Environmental Committee of the City of Copenhagen was funded 1.5 million kroner, by the municipality of Copenhagen, to draft a preliminary evaluation regarding the possibilities of opening one or more piped waterways in Copenhagen (Genåbning af Ladegårds Å, 2008). Re-opening one or more piped waterways has been a visionary goal for the Agenda plan (2008). However, since the Ladegårdsåen was more complicated than the other waterways, Å Grøndals Å and Lygte Å, that the Technical and Environmental Administration suggested, more time was needed to prepare a proposal for the Ladegårdsåen project.

In 2007, the Park and Recreation Committee for the city also conducted a feasibility study for daylighting Ladegårdsåen canal (Agenda 21 Grøn Nørrebro, 2010). However, the technical and environment committee conducted a more in depth analyses of the canal, while the Parks and Recreational Committee provided drawings of the Ladegårdsåen (Figure 10 and Figure 11). The different routes were analyzed and the focus of the project was the beautification of the city to improve the quality of life of the citizens (2010). This was a visionary study, with no money being put into the effort (Agenda 21 Grøn Nørrebro 2010). The focus was on coming up with some possible designs of what the outcome of this project could entail. In conjunction with Orbicon, an engineering consultant company, the Parks and Recreational committee designed sketches of how the area would look if the Ladegårdsåen was re-opened at the proposed routes.

Figure 10: Sketch of the Ladegårdsåen at Borups Allé-Rantzausgade (Agenda 21 Grøn Nørrebro, 2010)

Figure 11: Sketch of the Ladegårdsåen at Åboulevard-Ågade (Agenda 21 Grøn Nørrebro, 2010)

The Technical and Environmental Committee, in 2007, developed a plan to analyze the different possibilities of re-opening the Ladegårdsåen canal. The Committee believed that opening the canal would create a recreational lift for Nørrebro (Genåbning af Ladegårds Å, 2008). This is one of the many reasons why Miljøpunkt Nørrebro has been pushing to make this project become a reality. The Committee plans evaluated two routes where the canal could potentially be opened. The **direct route**, which mimics the current flow of the piped canal, could be opened at **Åboulevard and Ågade** (Figure 12) or at the **side route** at **Borups Allé and Rantzausgade** (Figure 13).

Figure 12: Proposed Opening of Ladegårdsåen Canal Via Åboulevard and Ågade (Lars Barfred, 2012)

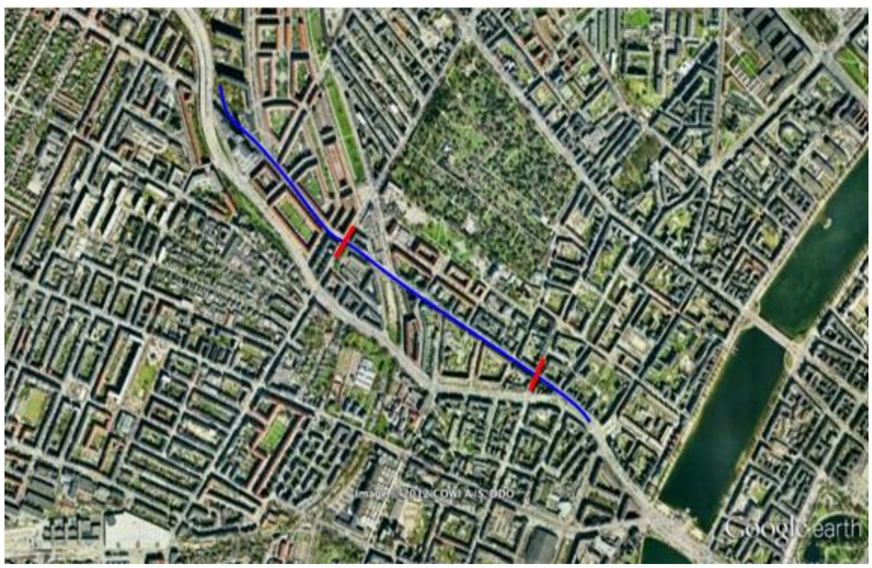

Figure 13: Proposed Opening of Ladegårdsåen Canal Via Borups Avenue and Rantzausgade (Lars Barfred, personal communication, 2012)

Using traffic counts as a guide, the technical and environmental committee decided that opening the canal in Borups Allé-Rantzausgade would be the best option as it promotes the creation of new spaces and establishes a connection between Copenhagen, the Lakes, and the inner city (Genåbning af Ladegårds Å, 2008). Information on the Agade-Åboulevard, in regards to why it was rule out as a possibility, was not disclosed the technical and environment committee's report. After committee had selected the Borups Allé-Rantzausgade, they only evaluated the benefits, problems and solutions of the side route. According to the technical and environmental committee, navigating at the Borups is not an obstacle, as it has a relatively broad path towards the northern side of the road with a wide sidewalk toward the houses and shops in order to create room for café life, stores, and bicycle and traffic lanes (Genåbning af Ladegårds Å, 2008). The project would have given the city a great recreational lift and would also give more access for soft traffic (pedestrians and cyclists).

Rantzausgades, on the other hand, posed to be quite problematic, as the roads between Griffenfeldsgade and Åboulevard are very narrow (Genåbning af Ladegårds Å, 2008). To remedy this, two proposals were prepared: (1) orienting Rantzausgade from Åboulevard against Jagtvej and (2) converting the narrow street to a wider one to accommodate both cars and cyclists. These solutions would have been able to be implemented without compromising safety (2008).

In order for this project to be successful, it had to take into consideration both traffic and construction and thus preparing a proper conceptual design, that encompasses all of the project aspects, was estimated at a cost of 3 million kroner (Genåbning af Ladegårds Å, 2008). The Technical and Environmental Administration estimated that the project expense would cost approximately 250-500 million kroner (2008). In 2009, the Technical and Environmental Committee voted to shelve the project due to lack of funding needed to undertake this expensive project (Genåbning af Ladegårds Å, 2008).

2.2.4 The Ladegårdsåen Today

Today, many environmental groups (such as Miljøpunkt Nørrebro) as well as local citizens have expressed wishes to re-open the Ladegårdsåen. Our sponsor views the canal as a possible solution to the environmental issues affecting district. From our liaison, Lars Barfred, we learnt that Nørrebro is a polluted district and that the Ladegårdsåen is now situated beneath Åboulevard, the busiest road in Nørrebro (Figure 14). He also explained that there is a lot of traffic congestion on that road and this contributes to both air and noise pollution. Nørrebro is a thriving business district, and pollution decreases property values, decrease in city revenue, generated through tourism, decreases health and makes the environment unpleasant and unbearable to live in (Lars Barfred, 2012).

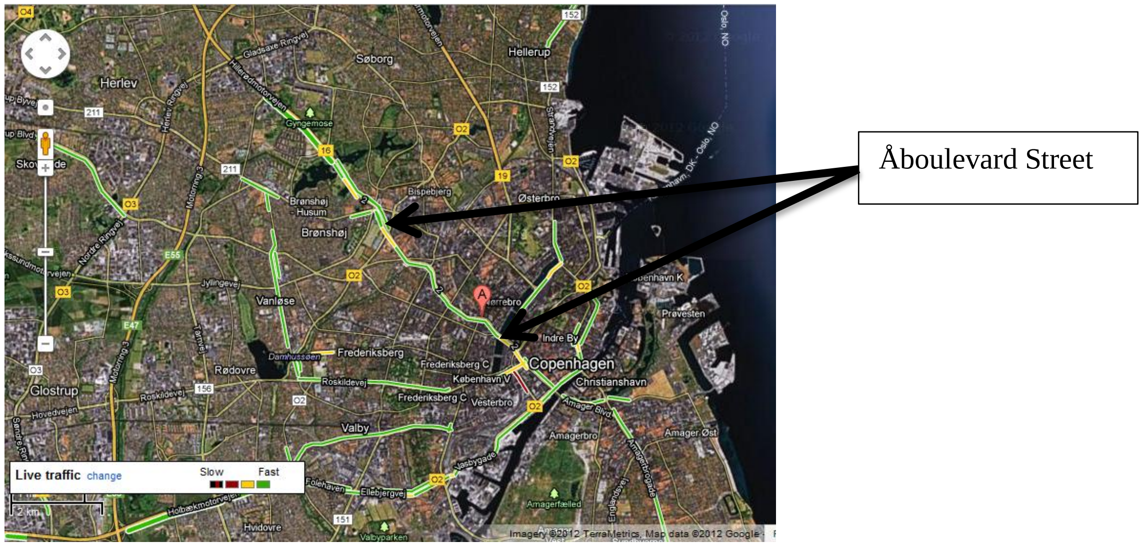

Figure 14: Traffic Congestion of the Åboulevard (Situated Over the Ladegårdsåen) (Google Maps, 2012)

After the first proposal was rejected in 2009 due to financial issues, Miljøpunkt Nørrebro have been fighting for the canal to be re-opened because they believe that the Ladegårdsåen can solve the environmental issues currently the affecting Nørrebro. After the past two summers of heavy thunderstorms (August 14th 2010 and July 2nd 2011), which caused severe property damage in Copenhagen, Miljøpunkt Nørrebro saw this as the most opportune time to re-open the canal and have been pushing for the project. Barfred believes that opening the canal will not only add aesthetic value to the city, but will reduce temperature. Opening the canal will divert traffic patterns to the side routes, which will reduce air and noise pollution. Studies have shown that open canals offer a better protection against flooding than piped canals. Also, with the opening of the canal more people will opt to cycle through Nørrebro.

2.3 Current Reasons for Daylighting Ladegårdsåen

The City of Copenhagen has experienced its own set of environmental problems over the past several years which helped in the advocacy for opening Ladegårdsåen. Such factors can be classified as either an environmental problem or a motivating factor for the canal's opening. The problems disrupting the environment and local citizens include damaging flooding, and traffic and its harmful pollution. Our sponsor, Miljøpunkt Nørrebro, believed that the daylighting of Ladegårdsåen could help in the resolution of these issues by collecting stormwater runoff, reducing traffic pollution, and adding green space. The motivating factors which made the present day the opportune time to open the canal were the environmental awareness in Denmark and the current measures being taken to reduce traffic and its pollution and better manage stormwater runoff. Our sponsor wanted us to show how all these factors helped advocate for the opening of Ladegårdsåen.

2.3.1 Environmental Awareness

Sino-Danish network's article "Life in Denmark" (2011) states that Denmark, has always taken a revolutionary and rigorous standpoint on environmental conservation. The article expanded on this stance by stating that in 1971, Denmark established the Ministry of Environment and "was the first country in the world to implement an environmental law." The modern society reflects the Danish attitude on environmental preservation. The openness of its cities and their short distances redefine Denmark as a bike friendly nation (2011). According to the International Federation of Environment and Health website (n.d.), Denmark signed the following agreements: the Antarctic Treaty, the Climate Change-Kyoto, and the Endangered Species Act to help alleviate global warming and environmental degradation. These agreements were established to reduce carbon dioxide (CO_2) emissions (n.d.).

Figure 15: Fiord and a Small Valley, one of the Very Finest Botanical Locations in the Country (International Federation of Environment and Health)

According to a survey conducted by the Readers Digest in 2007, Denmark was ranked 10th in the world for living green (Figure 15) while Copenhagen (the nation's capital) was recognized as one of the most eco-friendly city in the world; a statement which is supported by the fact that over 60% of the hotels in Copenhagen are green, (Sustainable events in Denmark, 2011). According to the article "Life in Denmark," half of the world's largest solar heating plants are located in Denmark; there are ten in total (2011). Even though Denmark is aware of nature's limitations, it is also aware of its shortcomings in its effort to become greener.

According to the Climate Adaption Plan A2 (2011), since there are more pollutants in the atmosphere, rain fall patterns have become unstable causing long periods of drought, extreme flooding, warmer winters and colder summers. Therefore, local Meteorologists believed that global warming was the root cause for the heavy storms that has occurred over the past two summers (City of Copenhagen, 2011). This statement correlates with the Intergovernmental Panel on Climate Change (IPCC) report, *"Climate Information"*, 2007, which states that due to global warming, rainfall, on average, have increased across the globe (IPCC, 2007). Copenhagen is striving to become a greener city by promoting cycling and establishing green corridors throughout the city (City of Copenhagen, n.d). The Municipality has expressed great interest in establishing a super green corridor along with the re-opened Ladegårdsåen as they believe that the citizens and the community would truly benefit from it and would help them reach their goal to become carbon neutral in 2025 (City of Copenhagen, n.d).

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2.3.2 Flooding and Drainage Issues

Copenhagen was struck by two violent thunderstorms on August 14^{th} 2010 and July 2^{nd} 2011 (City of Copenhagen, 2011) (Figure 16-CNN report, 2011). According to The Guardian UK news article *"Floods damage homes"* (2011), approximately 150mm (6in) of water fell on Copenhagen. Local Meteorologists believed that global warming is responsible for the disastrous storms (the City of Copenhagen, 2011). Karsten Anderson, director for the Institute for sustainable Development, stated that inadequate drainage systems are responsible for the flooding that occurred during the past two summers; a claim which is supported by Cowi, an advisor for the Copenhagen Climate adaptation plan.

Figure 16: Effects of the 2011 summer flooding in downtown Copenhagen (CNN, 2011)

Global warming is defined as an increase in temperature which is caused by greenhouse gases, most notably CO_2, released into the atmosphere (National Geographic, 2012). The National Research Council (1999) states that, surface and subsurface ocean temperatures will continue to rise due to the accumulation of greenhouse gases in the Earth's atmosphere. Two studies, published in Nature scientific journal, have concluded that there is a connection between global warming and flooding, specifically, global warming cause's extreme rainfall. Their research links greenhouse gasses as the main contributor to the unstable rain pattern. Seung-ki Min, research scientist in climate change detection and analysis at Environment Canada, report *"Human contribution to more-intense precipitation extremes"(*2011) states the increases in greenhouse gases have led to the intensification of heavy rainfall particularly over the Northern hemisphere land masses (Min, 2011). Pardeep Pall, professor of Atmospheric, Oceanic and Planetary Physics, at the University of Oxford, report "*Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000"(2011)* states that greenhouse emissions increased the risk of floods occurring in England and wales by more than 20% (Pardeep, 2011).

Figure 17: Flood Projection in the Year 2110 (226cm over sea level will flood inner Copenhagen) (Seas are rising globally, 2011)

According to the Climate Adaptation Plan, created by the City of Copenhagen officials to help the Copenhageners adapt to the changing climate, it is expected that the sea level around Copenhagen will rise up to one meter within the next hundred years (Figure 17). If this happens, the water levels will be higher and more deadly in comparison to the past two summer storms (Seas are rising globally, 2011). It is expected that precipitation during the winter will increase up to 55% and decrease during the summer by 40% (Copenhagen Climate Adaption Plan, 2011). The Climate Adaption Plan proposed three method plans to help Copenhagener adapt with the increasing heavier rainfall.

The first method of this plan involves adding larger sewers (Copenhagen Climate Adaption Plan, 2011). Presently, the drainage system is at its capacity. Hence new drains needs to be installed throughout city in order to reduce the strain on the existing ones (2011). Sørensen et al., members of the Copenhagen Energy Sewerage Department, report "*Historical overview of the Copenhagen sewerage system"* stated that "the sewer system covers approximately 6,800 hectares in Copenhagen (which covers approximately 9,000 hectares)". With the addition of more underground basin, it would cost an estimated DKK 10-15 billion in addition to another DKK 3-5 billion to separate rain and waste water. This method is not cost effective, because it requires excavation with affects the residents, business owners and overall would be a nuisance to the community (Copenhagen Climate Adaption Plan, 2011).

Method two involves managing the rainwater locally (Copenhagen Climate adaption plan, 2011). Water is a source that is something that we can't live without but it's something that we try to get rid of (2011). Instead of guiding the rain water into the sewers and adding more stress to the system, we use green space to absorb rain water (Figure 18). Since this method can be achieved by investing DKK 5 billion, it is preferred over the first as it is cheaper; (2011).

Figure 18: Green Space Areas in Copenhagen

The third method focuses on directing flooding to areas which would be the least damaging (Copenhagen Climate adaption plan, 2011). Though not the most effective method, as it only useful when the area starts to flood, it guides rainwater to areas which will cause the least damage for example car parks or playing field (Figure 19, 2011).

Figure 19: Flood Prone Areas that would Cost the Least Damage

Karsten Anderson, director for the Institute for sustainable Development, stated that "Copenhagen on July 2nd with rainfall of 160mm in 1 ½ hours in the future will be repeated with increased frequency and strength…the city's original old waterways should be reopened and the width of the streams…for instance, Ladegårds Å…" , (Joint Association of homeowners in

Copenhagen, 2011). Karsten Anderson is stating that piped streams, for example the Ladegårdsåen should be re-opened in order to help alleviate flooding by acting as a reservoir to hold the excess water in times of extreme rainfall (2011).

2.3.3 Traffic and Its Potential Reduction

Reducing traffic is a main priority for many city municipalities and Copenhagen is no exception. Renovations are being done to the city's metro and bicycling systems, which will hopefully decrease automobile use. With fewer automobiles on the road, the people of Copenhagen will likely be safer while traveling within the city. When the new Social Democrat-led government took control of Denmark in 2011, their answer to the congestion problem was a payment ring (betalingsring) around the city. This would make it so that those driving into the center of Copenhagen would be charged to pass through the payment ring (danemarca.com 2011). Changes in political power led to the payment ring being dismissed. The payment ring, according to Lars Barfred of Miljøpunkt Nørrebro (2012), could have reduced traffic in the city by about 30 percent. The reason this was such a strong motivation for the opening of the canal was that with less traffic traveling over the buried waterway, the feasibility of getting rid of some or the entire road to make way for the open canal was much more practicable. With fewer cars on the roads, fewer people would be affected by any changes made to the area around Ladegårdsåen. The payment ring, even though it fell through, did help stir up the desire to reopen the canal. The dropping of the payment ring does show, however, that car owners and small businesses are skeptical about green solutions encroaching on their privileges, and could have an impact on what canal path is a realistic option. It illustrates the importance of developing a project that meets the necessary goals without disrupting any particular group of people too drastically.

Other than directly trying to reduce the numbers of cars, Copenhagen is attemptting to completely remove drivers altogether. One way the city is trying to do so is by improving the metro system. Running on electric power, the metro is an clean way to travel. The current metro system that exists in Copenhagen today was finished in 2007, consisting of twenty-two stations (Kristensen, H.D., n.d.). Being driverless, operating twenty four hours a day, and having a punctuality record of 98.2%, it is extremely popular, receiving more customers every year (Kristensen, H.D., n.d.), including 52 million passengers in 2010 and 13,000 departures every day (Kristensen, H.D., n.d.). These facts are outstanding; however, the city still wants to improve the use of the metro. In 2018, a new line will be completed. This line will be known as Cityringen and will consist of a loop around Copenhagen (Kristensen, H.D., n.d.). The estimated number of passengers of this new line will be 72 million a year, 20 million more than that of the current metro lines (Kristensen, H.D., n.d.). This increase in metro passengers may reduce the number of citizens using automobile transportation. The City of Copenhagen (2012) claims that Copenhagen wants to make sure that this "public transport is the preferred alternative to cycling" rather than automobiles (paragraph 2). Therefore, traffic may be less of an obstruction for daylighting the Ladegårdsåen in the future.

Another way Copenhagen is trying to reduce the amount of automobile traffic on its streets is by promoting bicycling. By creating a city of cyclers, not only will the citizens be much healthier, but there will hopefully be a reduction of citizens using cars. The City of Copenhagen (2012) states that "There is a close connection between pleasant cycling conditions and clean, healthy and livable urban environments where people feel at home" (paragraph 1). As previously stated, according to Niels Tørsløv, "Copenhagen has almost 40% of all their overall trips by bike" (Toderian, B., 2009, paragraph 3), meaning that 40% of the trips in Copenhagen are performed on bicycle. While this amount is very high, the city is trying to further increase its cycling percentage. They intend to reach the goal of having 50% of all transportation done on bicycle in the near future (Toderian, B., 2009). Several measures are being taken to do so, including the recent installment of over 5,000 new bicycle racks (Toderian, B., 2009). Snow is removed off of the cycling paths even before automobile roads, resulting in 60% of cyclers continuing to ride throughout the winter (Toderian, B., 2009). Curbs separate bike paths from streets and dangerous intersections are marked with blue paint, creating a safe environment for cyclers (Toderian, B., 2009). Giving bike routes street names provides cyclers with a sense of place and excluding traffic lights allows for quicker travelling (Toderian, B., 2009). With all these efforts taking place to increase bicycle transportation, motor traffic might be less of an obstacle for the canal. However, the route of the canal will need to incorporate large quantities of bicycle traffic.

Due to the fact that Ladegårdsåen runs under one of the busiest roads in Nørrebro, all the aforementioned efforts trying to reduce the amount of automobile traffic in Copenhagen make its daylighting more realistic. If the traffic on that street and those surrounding it decreases, hopefully more space will be created to allow for Ladegårdsåen to flow.

Opening the canal also has potential to reduce traffic on its own. A traffic study performed in Copenhagen (May 11th, 2009) by Jenna Beatty, Tom Coletta, and Ryan Rogan provides insight into the effects of the closure of part of a busy street parallel to the one Ladegårdsåen runs under. They studied how the traffic in the area would be diverted once the street was closed. They first stated that most people initially think "the solution to heavy traffic is to simply widen the road" (Beatty, J., Coletta, T., & Rogan, R. (2009)). However, doing so "will allow for more car traffic which will turn into a larger problem later on." (Beatty, J. et. al., 2009). After performing a variety of traffic counts in the area, they came to the conclusion that there was "a 7.3% decrease in the overall personal vehicle traffic in the area" due to the closure of part of the busy, main road (Beatty, J. et. al., 2009). This was due to the fact that most of the traffic was either diverted to surrounding streets which were very capable of taking on the increase of cars, or citizens stopped driving cars altogether. What this study suggests, is that the opening of Ladegårdsåen might reduce the traffic in the area in the same way as the street closure in this study did, but it might just displace the motor vehicles which presently use it to other side streets. However, if roadways still remain along the canal, this "diversions" effect will be slightly diminished. This study, accompanying the potential reduction in traffic currently taking place, will hopefully aid in promoting the daylighting of Ladegårdsåen.

2.3.4 Harmful Pollution

Our sponsor has made it known to us that the opening of Ladegårdsåen could play a role in reducing traffic, which could lead to helping address the larger issue of pollution in Copenhagen. Although not apparent to most, noise pollution is very real. According to a documentary on Reportage-enviro.com (November 15, 2011), a website controlled by the University of Technology in Sydney, Australia, consistent noise heard by humans during sleep causes an increased level of stress hormones. This increased stress affects people during the day, making them more irritable, therefore, decreasing their quality of life. In fact, "Mothers exposed to [extreme] noise after the fifth month of pregnancy are even regarded to have a tendency to give birth to smaller babies" (University of Technology, November 15, 2011, minute 1:17). The elderly are also affected to a great extent. The University of Technology (November 15, 2011) stated that the elderly have an increased risk of cardiovascular diseases, heart attacks, and strokes when exposed to noise above 60 decibels and that "for every extra 10 dB of noise, the risk of heart attack increases 14% in people over 65" (University of Technology, November 15, 2011, minute 2:12).

Traffic in Copenhagen (2010) provides a useful table in understanding the extensiveness of the city's situation, as seen in **Error! Reference source not found.**. The publication's author, Niels Tørsløv, the head of the Copenhagen Traffic Department states that "58 dB…is characterized as a low noise level at which a maximum of between 10 and 15% of all individuals perceive the noise as a severe nuisance" (Tørsløv, N., May 2010, Page 9, Paragraph 2). Therefore, the remaining 60% of homes is classified as being negatively impacted by noise. Niels even states that "In the case of 17% of homes, the noise level is so high that they are characterized as severely impacted by noise (68 dB or higher)" (Tørsløv, N., May 2010, Page 9, Paragraph 2). Therefore, noise pollution affects a significant amount of Copenhagen's population. In fact, the University of Technology (November 15, 2011) states that nearly 70% of people living in Copenhagen are affected by noise pollution. This pollution is caused mainly by traffic congesting the tight streets in the area. In fact, buildings in Copenhagen have trembled as a result (University of Technology, November 15, 2011). Due to all the aforementioned issues resulting from noise pollution in Copenhagen, "Denmark is one of the most affected European countries [from noise]" (University of Technology, November 15, 2011, minute 0:01). Figure 20 shows a map of the noise levels in the city. Nørrebro is located northeast of the blank are in the center of the map.

Table 1: Noise Levels & Percentages of Homes Experiencing Each Type

Weighted daily average for traffic noise in Copenhagen near all homes

	< 58 dB	58-63 dB	63-68 dB	68-73 dB	> 73 dB
Number of homes	112,827	79,432	44,713	42,435	6,673
Proportion of all homes	39 %	28 %	16 %	15 %	2 %

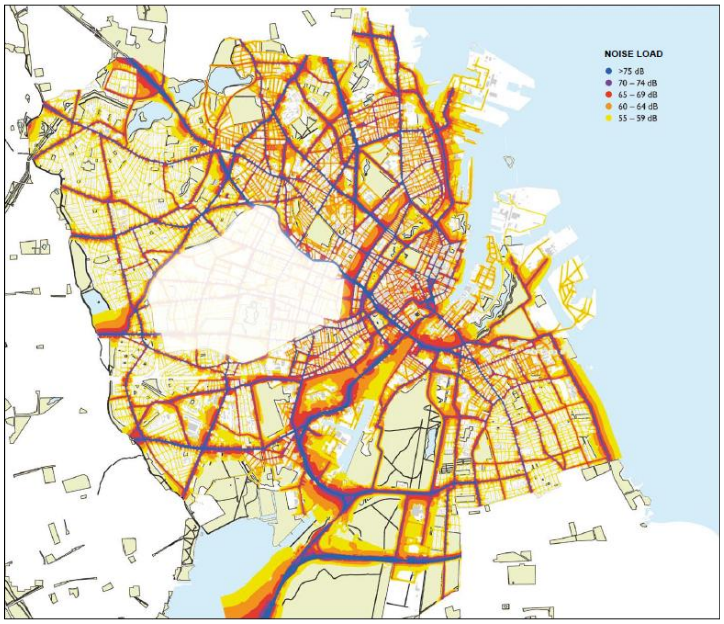


Figure 20: Noise Levels in Copenhagen, (Traffic in Copenhagen, 2010, p. 8)

Reducing noise pollution is a rather difficult task. Other than reducing traffic, there are not many ways to attack this problem. One that has had some effect is the implementation of noise reducing asphalt, which muffles the sounds of automobiles slightly(University of Technology, November 15, 2011).Other measures consist of building new roads away from the congested areas in the city as well as implanting noise barriers on loud streets (University of Technology, November 15, 2011). The problem with building such barriers is the difficulty with blending them in with the urban environment (University of Technology, November 15, 2011).

Advocating for the opening of Ladegårdsåen could possibly be made easier by showing how its daylighting will potentially result in less automobile traffic which is the main source of noise pollution. Also, with an increase in green space, noise has the potential to be muffled or absorbed, rather than echoing off hard surfaces such as buildings and asphalt.

Being much more dangerous to humans than noise, air pollution is regarded as the main problem caused by automobiles that needs to be controlled and fixed.*Traffic in Copenhagen* (2010) by Niels Tørsløv stated that 90% of the air pollution Copenhagen faces is due to car and truck traffic. Many scientists believe such pollution is the main factor responsible for global warming, a phenomena which could negatively change the world. More importantly, such poor air quality increases the risks of developing deadly diseases. Those mainly affected are ”children, the elderly and persons with respiratory problems” (City of Copenhagen, 2012, paragraph 1).

Such diseases caused by air pollution include cancer, respiratory diseases, and allergies (City of Copenhagen 2012). Therefore, rather than having minor consequences, such as those created by noise pollution, air pollution severely affects people's health and well-being.

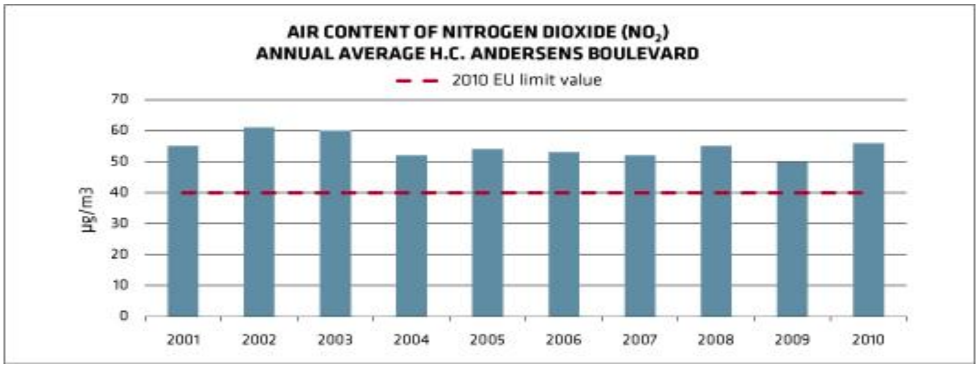


Figure 21: NO2 Levels in Copenhagen: H.C. Andersens Boulevard, (Clean air – still a challenge, 2012)

In Copenhagen, the main pollutant in need of being controlled is nitrogen dioxide (NO2), as seen in Figure 21 (City of Copenhagen, 2012). This chemical has potentially deadly affects in children with respiratory illnesses (Keiding, LM; Rindel, AK; Kronborg, D.). In fact, according to the University of Technology (November 3, 2011), pollution caused by traffic "is responsible for 15% of asthma among children and 25% of cardiovascular diseases among the elderly" in Copenhagen (minute 4:55). This staggering factor shows the shear effects of poor air quality caused by automobile transportation. Furthermore, almost half of the total pollution is solely due to private automobiles (University of Technology, November 3, 2011).

Assessing Sensitiveness to Transport (*Untitled*, n.d.) has stated that "The European Union (EU) has established health based air quality limit values or target values for a number of pollutants" (paragraph 3). Beyond this, the Danish Environmental Protection Agency has established a plan to go above and beyond these requirements of the EU, making them even stricter in Denmark, and Copenhagen (City of Copenhagen, 2012). Assessing Sensitiveness to Transport (*Untitled*, n.d.) has also exclaimed that the city has created environmental zones within certain areas in which only cars which fulfill several requirements such as emissions standards can enter. Electric powered automobiles are also being promoted by the city. For two examples, Copenhagen has an electric bus line which cleanly transports passengers around the city, and also allows free parking and no taxes to private electric vehicles (University of Technology, November 3, 2011).

Similar to the efforts to directly reduce noise, these efforts to directly reduce air pollution show that the city of Copenhagen and the European Union are aware of air pollution's harmful effects on their citizens and environment and are trying to resolve the problem. Therefore, advocating for the opening of Ladegårdsåen could possibly be made easier by showing how its daylighting will potentially result in a reduction of air pollution by a creating more green space and reducing automobile traffic. In order to gain even more support for the project, determining benefits that similar projects have encountered is crucial.

2.4 Case Studies

As previously mentioned, the daylighting movement is fairly new. Some projects took place in the 1970s opening up creeks, but Pinkham states that the 1984 Strawberry Creek daylighting in Berkeley, California is considered the model for this movement (2000). Since the Strawberry Creek project, daylighting has increased worldwide, especially in parts of Europe (Pinkham 2000). Zürich, Switzerland, for example, has already had over nine miles of storm drains and brooks daylighted since 1988 (Pinkham 2000).

In Pinkham's report, eighteen different projects are examined to gain a better understanding of daylighting. Table 2 below illustrates the main benefits and challenges of daylighting. The highlighted notes are aspects that will be crucial to our specific project in Nørrebro.

Table 2: Benefits and Challenges of Daylighting (Pinkham 2000, Buchholz & Younos 2007 and other case studies)

Benefits	Challenges
Flooding and Runoff -Choke points and flooding problems associated with culverts that are too small to handle the capacity of water can be relieved. - Hydraulic capacity is increased because a floodplain is recreated. -Runoff velocities are reduced, which helps reduce erosion, by the coarseness of the bank and bottom of the waterway. -In some cases, it allows for urban runoff to avoid being combined with the sewer systems, therefore, decreasing the amount of sewage making it to the treatment plants and preventing combined sewer overflows.	**Construction/Cost** -Often a large amount of earthmoving is involved in daylighting projects because the culvert must be removed and the new channel formed. Extra soil may need to be removed from the area and this whole process can be expensive. -The best place to recreate the waterway is in the old channel, which can be hard to locate. This process often requires searching the history of the waterway, studying the soils, and analyzing the waterway characteristics upstream and downstream. -Daylighting projects often have little available space,
Cost and Maintenance -Open drainage systems and waterways are much easier	

to maintain and repair than buried pipes and culverts. -In many cases, it is more cost efficient to daylight a waterway than to replace the culvert.	meaning it is not always possible to produce a natural channel geometry and incorporate the appropriate forms of vegetation. -These projects must be engineered to fit in with the stormwater management system of urban areas. Hydraulic issues sometimes become a problem. For example, when daylighted sections have to be placed back into pipes.
Pollution -Pollutants can be neutralized or transformed, therefore improving water quality by allowing the water to be exposed to air, sunlight, vegetation, and soil. -Reduction in green house gases due to the addition of green space. -Reduction in the heat in urban areas (coming from the urban heat island effect).	
Habitat -An aquatic habitat can be recreated, helping to improve fish life. -The banks of the waterway can be recreated to add habitat areas for wildlife.	
New Uses -Provide new recreational areas, whether it be for a golf course, a park, etc. -Can be used to connect urban greenways and create paths for recreation. - Can be used as an outdoor laboratory-type setting for schools.	**Public Education/Awareness** -With daylighting projects, the public is not always aware that there is a historic waterway buried underground, and they often don't understand the problems with keeping the waterway buried (such as bad water quality and less area for wildlife). -These plans often necessitate extra public education to help people visualize what is going to take place. With no physical features to be seen, the community needs to be taught about the waterway and the future project. -Creating an open waterway can scare communities as they fear the risk of people drowning, diseases spreading, flooding, and additional environmental regulations. Therefore, these issues must be addressed in the planning process.
Neighborhood Improvements -Can enhance the attractiveness of a neighborhood. - Property values will increase. - Will draw people to businesses in the area by providing a new attraction. -The building and maintenance of the new waterway will create job opportunities.	
Social and Physiological -The project will build relationships and boost morale as citizens and businesses come together for a similar cause. -Help reconnect people with nature. -People will feel good about fixing what can be considered a bad decision of burying the waterway in the	

first place.	

Canal and stream restoration or daylighting projects are completed in a variety of different ways for many reasons. Specific case studies will follow in the next sections and display some of these advantages and disadvantages and several other positive outcomes. As seen by the table above, the psychological benefits of daylighting are very important. Bringing nature back into society is a huge benefit for people because it gives them a sense of purpose in helping their town or city and the entire world. Projects range from small creeks and culverts to true rivers and take place in rural countryside and downtown urban areas (Pinkham 2000). Land uses at daylighting sites vary tremendously from former rail yards to golf courses to commercial downtown areas (Pinkham 2000).

Daylighting projects also vary greatly in cost and often involve many potentially expensive actions and materials. Pricing includes cost for "technical studies and design work, acquisition of properties or easements, excavation and rough grading, hauling of fill, materials for the streambed and in-channel structures, landscaping materials, hand labor for final grading and revegetation, and more" (Pinkham 2000, pg. 10). Gary Mason, who is a designer and coordinator of several daylighting projects, has stated that for these projects, it can be expected that it will cost $1,000 per linear foot (Pinkham 2000). This report was published in 2000, so this doesn't take into account any inflation over the past twelve years, and this is just a rough estimation to go by, because every project will be different. By looking at another source written by Pinkham in 2002, titled "Stream Restoration and Daylighting," you can again see the variation in daylighting costs. Because of the huge discrepancies between different projects, it is impossible to determine an accurate average price for daylighting projects. It is known, however, that projects completed in urban, business districts often cost the most money (Pinkham 2002). When performing daylighting projects, it is crucial to brainstorm potential sources of monetary support. Pinkham explains how businesses might get involved in such a project to gain publicity, rather than a huge monetary gain, while other businesses may lower prices in order to be part of a novel project (2000). It is, therefore, important to evaluate all possible options before you rule out a project as being too expensive. These projects can gain funding from many areas, including city park budgets, public works budgets, local businesses, donations from individuals, etc. (Pinkham 2000).

2.4.1 Daylighting Design Options

Case studies provide valuable information on the different design options of daylighting projects. According to Buchholz and Younos (2007) there are five major design focuses found amongst daylighting projects.

1. “Creation of a park amenity
2. Economic development / flood reduction
3. Ecological restoration
4. Creation of an outdoor classroom / campus amenity
5. Residential daylighting” (Buchholz and Younos, 2007, p. 13) (daylighting occurring on private property)

These types of designs can overlap, meaning one project can address several of these purposes. Stream daylighting initiatives that are part of a larger park design project are often more accepted by the public because the benefits of adding a new public park often outweigh the technical challenges or proposed dangers of daylighting (Buchholz and Younos 2007). Daylighting projects can focus on economic development and flood reduction, which is very relevant to the project in Nørrebro. Daylighting projects “have been undertaken to reduce urban flooding and promote subsequent urban revitalization and redevelopment efforts” (Buchholz and Younos 2007). One important case study is from Kalamazoo, Michigan; it is regarded as one of the most urbanized areas to encounter a successful daylighting project (Buchholz and Younos 2007). Their design required the demolition of parking lots and was successful in that it protected the downtown businesses from a 500-year storm event, got rid of the need for flood insurance, and drastically altered the city’s floodplain map. These types of designs often consist of concrete-lined basins because of the urbanized locations they are built in (Buchholz and Younos 2007). The final products usually do not resemble streams, because rather than focusing on addressing green space issues or the biodiversity of an area, they focus on simply adding a canal-like waterway (Buchholz and Younos 2007).

Other design focuses that aren’t as important for our cases include ecological restoration projects. This type of daylighting focuses on recreating a waterway to its natural form with an emphasis on “restoring fish passage, improving aquatic habitat, and improving water quality” (Buchholz and Younos 2007). Outdoor classrooms can be the focus of daylighting projects, which simply means the design plans focus on aquatic ecology. The final idea design described by Buchholz and Younos is residential daylighting. They explain that this is when projects take place on private residential property, but they had very few case studies to help clarify this type of daylighting.

It is fairly easy to find literature on stream restoration and stream ecology; daylighting, however, has little information written about its purpose and use (Buchholz & Younos 2007). Therefore, the best way to learn and understand the science of daylighting is by carefully studying different case studies. The next sections will analyze some specific case studies in more detail. This will demonstrate some of the general steps followed in a daylighting project.

2.4.2 Opening of the Aarhus River, Denmark

One important case study being considered is in Denmark. The Aarhus River travels from the Solbjerg Lake through Aarhus, Denmark, and into the Barbrand Lake (Fode, H., 2009). In the 1930s, Aarhus was vastly expanding. In time, the decision was made to cover this river in order to create a road which became known as the Åboulevarden, or the River Boulevard (Visit Aarhus, n.d.). In doing so, the beauty given by the river was taken from the city (Long, F., 2010).

In the early 1990s, the city of Aarhus wished to make the center of the city car-free, and therefore established a debate around the opening of the river and its possible advantages (Visit Aarhus, n.d.). After creating much public awareness, "two parts of the river were indeed re-opened in 1996 and 1998 respectively" (Visit Aarhus, n.d., Paragraph 2).

Figure 22: Bridges Crossing the Aarhus River (*Aarhus Å*)

The city of Aarhus experienced a major uplift. According to Dansk Arkitektur Guide "Land[s] by the river are designed with decorative seating and bridges, and they have become a central point of the city's population and cafés" (as seen in Figure 22) (Dansk Arkitektur Guide, n.d., Paragraph 1). Also along the river are many new restaurants, cafés, and bars, providing citizens with a place to relax and enjoy themselves (Long, F., 2010). Lone Jørgensen exclaims that "A spring day by the Aarhus River with a cold draught beer and a bite of "smørrebrød" (open face sandwich) can easily turn into a lifelong love affair" thus suggesting the atmosphere created by the opened river is very appealing (Jørgensen, L., 2011, Paragraph 5). Figure 23 and Figure 24 show two images of the Aarhus River during the day and night respectively.

The banks of the Aarhus River, which was once paved over with city streets, are nowadays dotted with restaurants, bars and live music venues.

Figure 23: Aarhus River Daytime (Long, F., 2010)

Figure 24: Aarhus River Nighttime (The Aarhus River)

Although not much has been uncovered surrounding the events leading up to the re-opening of the river, as well as the community involvement, it is hopeful that the people of Denmark understand the positive outcomes of daylighting rivers and canals. Therefore, the opening of Ladegårdsåen and its advantages might be apparent to the citizens of Nørrebro. If not, this case study will hopefully provide some sufficient persuasion. We later decided to visit this river to find out more about this project and to draw from its design options.

2.4.3 Opening the Cheonggyecheon River in Seoul, Korea

Cheonggyecheon is an 8.4 m long river located in downtown Seoul Korea. Andrew Revkin, a New York Times writer, in his article "*Peeling Back Pavement to Expose Watery Havens"* stated that the Cheonggyecheon has been in existence since the Joseon Dynasty 600 years ago, but for the past forty years its beauty has been paved over in the name of industrialization and progress (2010). By the year 2000, Cheonggyecheon was no longer the pride of Seoul, but a heavily polluted, noisy, and congested waste land born from the desire to become modernized (Cheonggye Freeway, 2007). Justice for this eyesore came on July 2003, when, then Mayor, Lee Myung-bak commenced a restoration project which cost an estimated 386 billion won (US $281 million) (Cheonggyecheon River, 2010). Despite the cost, the project was deemed important to the government, as well as to the people, because it would: (1) regain pride in the people, (2) aid in government revenue, through tourism, and (3) create an eco-friendly environment by reducing pollution and traffic congestion (Cheonggyecheon River, 2010).

The results from the re-opening of the Cheonggyecheon have been overwhelmingly positive. This project has been dubbed by the Preservation Institute as "A model for Asia and the World" (Cheonggye Freeway, 2007). Since it's re-opening in 2005, air and noise pollution have been reduced, while property values have increased (Revkin, 2010). Myung-Rae Cho, a professor at the Dankook University in Korea, in his report *"The politics of urban nature restoration"* states that the stream helps to cool the areas that are overheated by the heat absorbing asphalt. He expanded on the fact that temperatures in the summer have become 2.3 degrees cooler, and that open streams help to nourish green space that promotes the enrichment of the ecosystem (p. 159). Lee In- Keun, Seoul's assistant mayor for infrastructure, stated that there is a dramatic shift in orientation, "we've basically gone from a car-oriented city to a human-oriented city" (Revkin, 2010). Revkin admires the initiative and the high standards set by

Korea and challenges the rest of the world to “peel back pavement that was built to bolster commerce and serve automobile traffic decades ago," (2010).

The situation of daylighting the Cheonggyecheon is very similar to the Ladegårdsåen in Nørrebro, Denmark. Like the Ladegårdsåen, the Cheonggyecheon was buried under the busiest road in downtown Seoul, Korea (Myung-Rae Cho, p. 150). Therefore, both regions experience problems with traffic congestion which causes air and noise pollution. The City of Copenhagen officials, as well as Miljøpunkt Nørrebro, have proposed the idea of re-opening sections of the Ladegårdsåen in order to reduce air and noise pollution, offer better protection against flooding and to make the area more aesthetic. Myung-Rae Cho states that a majority of Seoul’s citizens supported the restoration as they believed that restoration of the river would revive downtown’s economy (p. 151). He did not go into full details as to how the government promoted the project or how they conducted surveys; however, the survey claimed that 86% of Seoul’s residents gave their full support for the restoration project. A report by the Graduate School of Design at Harvard University, titled “*Deconstruction/Construction: Cheonggyecheon River Project”* explains that the success of the restoration of the Cheonggyecheon would not be possible without proper communication between all stakeholders, the mayor (and current president Lee Myung-bak), the urban design committee, engineers, the Seoul Metropolitan government, and the public (n.d.). The Commission for Architecture and the Built Environment’s article (2011) “Design Process,” on the Cheonggyecheon project expanded on the roles of each stakeholder. The Cheonggyecheon restoration center, created by the Seoul Metropolitan government, acted as the focal point for research and development plans (2011). The Cheonggyecheon Restoration Citizens Committee of professional and citizen groups were tasked to respond to the concerns and opinions of the public by organizing public information sessions and consultations (2011). The main objective

Figure 25: Re-opening of the Cheonggyecheon in 2005 (Cheonggye Freeway, 2007)

of the Cheonggyecheon project was to develop a feasible route to direct, the now displaced, heavy volume of traffic and to gain public support (2011). The objectives of the Cheonggyecheon project are very similar to ours, as we have to evaluate feasible routes to open the canal that will not impede safety and will not negatively impact people's daily lives, while also creating green space. We will further elaborate on our objectives in our Methodology Chapter below.

Chapter 3: Methodology

The goal of this project is to aid Miljøpunkt Nørrebro in choosing a pathway and a design concept for daylighting the Ladegårdsåen, a canal which is currently piped under Åboulevard, one of the busiest roads in Nørrebro, a section of the city of Copenhagen, Denmark. Our design ideas will need to align with Miljøpunkt Nørrebro's goal to create green space and address the recent increase of extreme rainwater runoff. It must be a feasible design that Miljøpunkt Nørrebro can develop further, and one generally supported by the community. Therefore, we will not only choose a pathway and a design concept, but also will write a report justifying our decisions. This report will be based on interviews with engineers and municipalities and on information pertaining to flooding, noise pollution, urban heat, elevation, and other physical characteristics and constraints located on the pathway we choose. We will also review other projects, notably the daylighting of the Aarhus River in Aarhus, the second largest city in Denmark. Table 3 depicts the overall structure of our project and the way we approached it.

Table 3: Project Goals and Timeline

1	Analyze the problems and motivations surrounding the opening of Ladegårdsåen	Research daylighting and why it should be done in Nørrebro	■							
		Conduct interviews: liaison and other experts	■							
2	Select a route	Clarify and evaluate research with sponsor		■						
		Conduct interviews with Municipality and Orbicon		■	■					
		Create decision matrix			■					
3	Refine the route and develop design options	Collect data on physical site features, including maps			■	■	■	■		
		Travel to Aarhus, Denmark to analyze a similar case study					■			
		Research pictures and possible designs for daylighting and green projects				■	■	■		
		Create and revise possible design ideas					■	■	■	
		Interview a Professor of Forests and Landscaping							■	
4	Complete Deliverables on the Ladegårdsåen Project	Create sketches illustrating the different designs we created for the many aspects of the canal						■	■	■
		Deliver final PowerPoint presentation: important stakeholders will be invited								■

3.1 Phase 1: Research the Problems and Motivations Surrounding the Opening of Ladegårdsåen

In Phase 1, prior to arriving in Copenhagen, Denmark, we gathered necessary background information. This was used to develop our plans and objectives once on-site. We learned that the previous Ladegårdsåen proposal done by Orbicon, which was started in 2007, was never pursued further because of cost factors. Miljøpunkt Nørrebro was now revisiting the project however, due to recent developments, including the recent flooding caused by unstable rain patterns and the greater push for green space. These factors might make such a project more feasible and fundable. Our Background Chapter reports on other research in this phase, including:

1. Problems in Nørrebro: flooding, lack of green space, traffic, noise and air pollution.

2. Recent motivating factors for opening Ladegårdsåen: flooding and stronger emphasis for green space
3. Benefits and uses of daylighting, based on other case studies: help with flood reduction, help lowering pollution and temperature, add green space to the region, add a recreational boost

What follows is a detailed description of the methods used on-site (Phases 2-4) to accomplish our goals and reach a final outcome. This included, but was not limited to, various interviews with engineering experts and municipality members in an effort to select the best and most feasible route and design ideas for an opened canal. Other objectives that were achieved involved using information we had gathered and written about in the project's website and gathering information on the different design ideas, physical features, and the parameters needed to evaluate the different routes and synthesizing it into an understandable document. The Methodology Chapter is an overview of the entire process that this Interdisciplinary Qualifying Project for Miljøpunkt Nørrebro entailed.

3.2 Phase 2: Confirm a Canal Route

The second phase of our research began once we arrived in Copenhagen. Our first task was to evaluate two possible paths of the canal; a **side route**—Borups Allé and Rantzausgade (BR)-- and a **direct path**-- Ågade and Åboulevard (AA). Originally, our liaison was leaning more towards the AA route; however, we kept the BR route in mind in case any obstructions on the AA route arose. To choose which route was more feasible, we needed to gain expert advice. We wanted to understand the kind of parameters one would need to consider for a design, and we wanted to evaluate both routes in terms of those parameters, using a decision matrix. This would provide information on the most practical route.

3.2.1 Develop Criteria for Expert Interviews

From our previous research, we developed an initial list of parameters to consider when evaluating routes for daylighting. These included: available space, obstructing obstacles, flooding risk, roads and traffic, canal/piping location, elevation and slopes, noise and heat pollutions, and bike routes. In order to refine these parameters and choose which ones were essential, we discussed recent flooding issues with a member of Miljøpunkt Nørrebro. Our sponsor was also helpful in providing us with useful documents and information he had to help in refining our parameters, including:

- Articles on past and present green projects in the area.
- Information on climate change and waterways
- Economic issues for the municipality of Copenhagen
- Current efforts related to our project being done by the municipality of Copenhagen

From there, we also conducted interviews with experts to further narrow the parameters and seek out possible design options. First, we met with Søren Gabriel, an engineer from Orbicon, who was involved in the 2007 proposal that looked at daylighting along Ågade-Åboulevard and Borups Allé-Rantzausgade. Secondly, we met with Stefan Werner, a member of the Parks and Water Division of the Municipality of Copenhagen, the division which had been involved with the initial push to open buried waterways in the city. Table 4 below shows the early list of daylighting parameters we developed, mentioned above, along with the locations and/or sources where information can be located on them. The notes column explains the specific aspects of each factor that must be explored and better understood. These different factors were addressed in the interviews to gain a better understanding of their roles in daylighting and their effects on the different routes.

Table 4: Original Daylighting Parameters

Daylighting Parameters					
Parameter	How to Locate Information?				Notes
	Reports/Maps	Interviews	Websites	Field Testing	
Available Space/Obstacles	***	***	***	***	Take pictures and measure areas, such as the road width and sidewalk widths Anaylze effects on pedestrian and car traffic, such as where bridges would be needed, and look for any structures that may affect the possible routes
Flooding	***	***	***		Determine the severity of flooding along the route and how it compares to other areas of the city
Roads and Traffic	***	***		***	Obtain traffic counts on the selected route, and determine if bus routes will be affected
Canal/Piping	***	***		***	Determine how much water is currently flowing through the pipe and a better understanding of where the water comes from. Determine if pipes will be a factor in construction.
Elevation	***	***		***	Analyze the changes of elevation for the selected route to prove that it would be feasible for a daylighted canal
Noise and Heat	***		***		Analyze the effects of noise and heat along the selected route compared to othe rareas of the city to argue and advocate its opening along the selected route
Bike Routes	***	***		***	Determine the current bike route patterns along the path and if this area is popular for cyclers

Available space was an important parameter because the area available for a daylighting project was a huge factor in determining what route would be more feasible and more beneficial. Wider routes would allow for more green space to be added and would provide more room for a canal, which is why it was important to learn about the space required for daylighting designs through our interviews. Space was determined by analyzing factors such as the width of the road, bike paths, and sidewalks. **Obstacles** were taken into account, such as any railways, major intersections, and/or buildings. The distance between buildings varies along the routes, making it important to examine the widest and narrowest sections of the routes.

In terms of **flooding**, we wanted to gain a better understanding of how this factor varied among the routes. Was one route more prone to flooding than another? We also wanted to see how the flooding in the area of the two routes compared to the flooding the whole city experienced. This parameter played a huge role in helping the project gain support, because the canal needed to be a source of relief for the increased amounts of rain. Therefore, we also needed to gain a brief understanding of how this flooding issue came about and any plans that have already been created to address this issue.

Traffic was a third parameter we knew we needed to consider because a daylighting project would result in the need to reroute or alter the traffic patterns. Bus routes were another factor that could potentially be affected and, therefore, the bus patterns around the two daylighting routes needed to be looked into as well. Traffic was a huge stumbling block, especially for the AA route. The falling through of the payment ring illustrates the importance of cars to Copenhagen and how hard it is to affect the flow of traffic throughout the city in any way. Our liaison had suggested that a tunnel could be an option for the traffic, so these interviews were a good way to gauge if a project as complex as a tunnel would even be feasible. The interviews were also used to see what other options could be done to deal with traffic.

A fourth parameter was the actual location of the **piped canal** under the streets and the flow of water in it, including where the water comes from and how much is actually flowing through it. We needed to gather information on where other pipes were located along these routes or if there was a map we could look at for this information in order to determine if a daylighting project would affect the pipes already in the ground. We expected we would need to look at this because a daylighting project involves a large amount of excavation, and with Copenhagen being such an old city, there are many pipes buried underground that need to be avoided or moved. This topic on the canal's water also led us to focus several questions on how clean the water in the Ladegårdsåen is and the effects that allowing storm water to run into it could have once it was opened. From our previous research, we knew that storm water runoff could pollute the water and that water contamination is something that must be considered in daylighting projects. We planned to get knowledge on this topic through our expert interviews.

Elevation was another important parameter that we wanted to focus on in our interviews. In order for the canal to be practical, the slope of the land would have to run in a negative direction (downhill) for the different routes. It is obvious that water will flow naturally from a higher elevation to a lower elevation, but it had to be proven that the two routes followed this pattern. Elevation changes, when looking at a topographical map, would also allow us to determine the natural path water would follow in times of flooding. Specific ways to find out this information and where to gather it needed to be determined, as well as a natural understanding of the water flow throughout the area.

Noise and heat pollution was a factor that could be used to determine which routes were facing more pollution. We didn't plan to address these in our interview, even though they were relevant to the project, because Miljøpunkt Nørrebro already had access to maps with this information. Our previous research had shown that daylighting projects (especially those involving the addition of green space) can help reduce the temperature of the area, and with the potential decrease of traffic along the route, they can help reduce noise pollution. These parameters could be used to help justify a daylighting project; by showing that the selected area for daylighting experienced very high amounts of noise pollution and heat compared to the rest of the city, it would illustrate the importance of creating an opened canal along that route.

The last parameter shown in the above table is **bicycle routes**. These routes were important to look into because biking is a huge part of life for citizens in Copenhagen and we needed to see how a daylighting project could improve or worsen biking along the different routes. We wanted to look into the location of bike routes along the two possible canal paths and how popular each route was for bikers. All of these criteria were issues we wanted to discuss in our interviews to help us come up with a more complete understanding of the parameters related to daylighting and ideas on how to select the best route for the project. These were the parameters that we had developed prior to coming to Denmark, but we planned on revising and refining them through the knowledge gained in the interviews.

In addition to asking the experts to comment on these parameters so we could assess and refine them, and to lead us to documents that might provide more info, we also used the expert interviews to gather ideas on possible designs for the shape of the canal. Not the path it will follow, but instead a cross sectional view with dimensions of it was the design we were interested in. Different shapes for the area where the water will flow all the time and during times of flooding were the specific design features we wanted to gain information on. This also included the design of the embankments of the canal enclosure. These interviews were the first major step in our creation of possible design options for the canal, and if the experts had any ideas on the depth and width that would be required for the canal, it would be a great starting point for us. We also wanted to find out more information on Orbicon's previous efforts to daylight the Ladegårdsåen.

For each interview, it was important to have an interview plan established with a list of the questions we planned to ask. The introduction was critical; we started off each interview explaining who we were and where we were from. We then stated why we were in Denmark and gave a brief summary of the project we were working on.

Our interview plans for the Orbicon and Municipality interviews are shown below (Figure 26 and Figure 27).

Interview Questions for Orbicon

<u>Introduction and Overview:</u>

- *Introduce ourselves and explain why we are in Copenhagen*
- *Introduce the project and the ideas we have developed*

3 parts of the interview: (preview these parts so that they know what the interview will entail)

1. *We first want to find out what your role was in analyzing previous daylighting projects in this area, including what you found, what you recommended, and what happened. If you have any reports on this, we would appreciate access to them if that is possible. Since a lot has changed in the past six years, we also want your opinions on whether your past recommendations/findings would still be applicable today.*
2. *We would like input on the Ågade-Åboulevard route and the possibility of exposing the canal along this entire path down to the harbor (following H.C. Andersens Blvd.) or part of it, combining it with a tunnel in the area to alleviate traffic and maximize green space. It could flow into the lakes and/or harbor as well. Based on what you know of this area, we want to know if there are engineering factors that you believe would not make these plans feasible.*
3. *We need to gather as much information as possible on topography, building structures, roadways, and the underground and surface waterways in this area to determine what the constraints and possibilities are. We would appreciate any advice on locating this information or some discussion of what you already know about these engineering parameters in the area.*

<u>Interview:</u>

- Explain what we know about the past daylighting efforts in Copenhagen
    - 2006: First push to open buried waterways by the City of Copenhagen?
    - 2007: You became involved in the project in 2007 when the Ladegårdsåen proposal was first initiated and began analyzing the different routes for the canal?

1. Who initiated the proposal that you were working for (the Technical and Environmental Committee of the City of Copenhagen)?
2. What did you hope the canal would solve or accomplish?
3. What was your role? What kinds of analyses did you do of the different sites? What types of factors

did you examine? What were your conclusions/recommendations and what became of them (was cost the reason the project didn't proceed)?

4. Do you have the full report on this? We would like a copy if that is possible. Do you have access to maps and records for the Ågade-Åboulevard and the Borups Allé-Rantzausgade sites that we could look at?
5. Did you incorporate residents' or businesses' input on these plans?
   a. What was their response?
6. Why was the route of Borups Allé-Rantzausgade chosen for the previous proposal in comparison to the route of Ågade-Åboulevard?
7. Based on your analysis, do you see any potential problems in daylighting these areas (show on map) along Ågade-Åboulevard? From an engineering perspective, are there features of this area that make daylighting prohibitive? What about a tunnel? **Did you ever consider a tunnel for either route in your analysis?**
   a. Did traffic have an impact on that decision? Did you have a plan for rerouting traffic? Did you foresee construction of bridges across the canal, and if so, what factors determined the locations of them?
8. Where does the water (in the pipes) flow into currently? Does some of the water flow into the harbor? Into the lakes? What feeds the canal?
   a. If the canal was to be opened, how would it connect to the lakes and/or harbor? What would be the impact on the amount of water carried by the canal? Would this help with flooding problems in the area?
   b. We were told that the lakes cannot handle the amount of water that the opened canal will be draining into them. We were also told that the lakes flow into the harbor. If this is true, we are confused on why this is an issue?
   c. Is the water flow in the pipes regulated? Is the water level in the lakes regulated?
9. What are the pipes made from? Is this material toxic?
10. If the canal was opened, do we need to worry about contaminants getting into the water, and if so, what treatment options could be used?
11. We understand that Copenhagen has maps showing the different severities of flooding throughout the city called "Blue Spot maps"? Have you seen these maps? Do you have access to them?
12. Do you know if there are any current efforts the city has made to daylight waterways since 2009?
    a. Have the municipalities made any efforts to continue or alter your previous project since 2009?
13. We know that today:
    - The payment ring has fallen through
    - Flooding has been very bad in recent years
    - There is more push for green space

How would these factors affect your decision in selecting a route today? What changes would your proposals require in order to adapt them to act as collections of rainwater runoff?

14. What engineering solutions (roads, tunnels, and bridges) could be used to reroute or alleviate traffic issues that might result from daylighting along Ågade-Åboulevard today?
15. What engineering factors would determine the feasibility of a tunnel?
16. Did you consider taking the canal all the way to the harbor in your previous efforts? Do you believe there are any engineering factors that could make this impractical?

We are interested in analyzing your previous proposal in more detail, so if you have any documentation or resources you could provide us, we would really appreciate it.

Figure 26: Interview Questions for Orbicon Engineer

Interview Questions for Municipality – Water and Parks

- *Introduce ourselves and explain why we are in Copenhagen*
- *Introduce the project and the ideas we have developed*
- Explain what we know about the past daylighting efforts in Copenhagen
  - 2005-2006: First push to open buried waterways by the City of Copenhagen?
  - What are the current efforts being put forth to green the city? Is there a possibility of any major green corridors being constructed in the near future?
- Is a tunnel a feasible option?
  - If not, without the introduction of a payment ring, do you have any ideas of what could be done to handle the large amounts of traffic or where it could be rerouted?
- How do you feel a daylighting project would fit in with the current goals of the municipality?
  - Do you see any potential problems in daylighting these routes (show on map): Ågade-Åboulevard? Borups Allé-Rantzausgade?
- What environmental impact do you think this project would have on the area?
- We understand that Copenhagen has maps showing the different severities of flooding throughout the city called "Blue Spot maps"? Have you seen these maps? Do you have access to them?
- If the canal was opened, do we need to worry about contaminants getting into the water, and if so, what treatment options could be used?
  - How will canal water interact with the water in the harbor?
- We know that today:
  - The payment ring has fallen through
  - Flooding has been very bad in recent years

- There is more push for green space
- Is any funding going to be released for projects addressing these issues?

Figure 27: Interview Questions for the Parks and Water Division of the Municipality

We used a tape recorder during all of our interviews because this allowed us to give our full, undivided attention to the respondent. Permission had to first be granted by the respondent, which it was for every interview. We had at least one team member taking interview notes; the note taker recorded the most important facts so that they could be used before the interview summary was written up (using the tape recording). When analyzing our interviews, we had to be aware that some answers were biased, and we took into account the context of the interview, such as the person and their stance on the project. For each interview, an interview summary was written up to organize all of the information obtained.

3.2.2Decision Matrix

After both expert interviews were conducted, and further discussions were held with members of Miljøpunkt Nørrebro, options for this project became clear and our parameters became more refined. It was determined that this daylighting project must be looked at as a two-stage process. Stage 1 included creating a path and design concept for the area consisting of either the AA or BR route, up to the lakes. It can be seen in Figure 28 below, where AA is represented by the red path, while BR is represented by the green path.

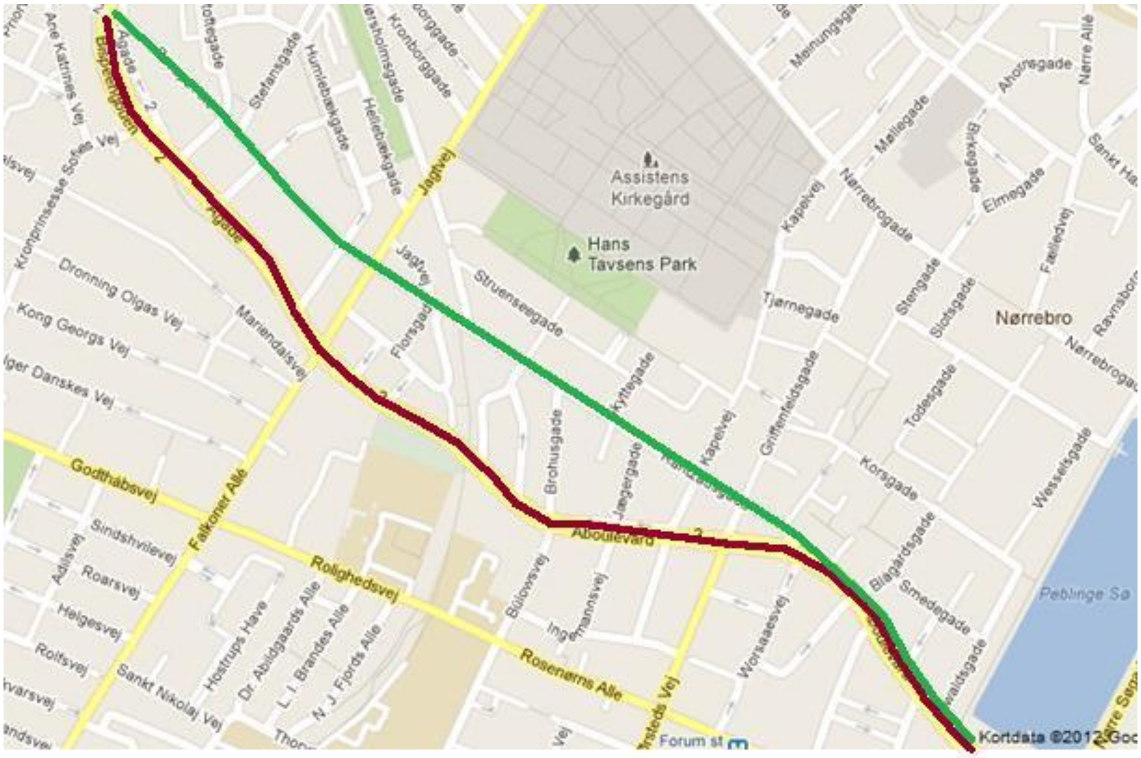


Figure 28: Possible Canal Paths for Stage 1

Stage 2 included identifying options for carrying the water from the point right before the lakes to the harbor. Both stages are very complex. Stage 2, however, encompasses areas outside of Nørrebro, and is therefore outside the jurisdiction of Miljøpunkt Nørrebro. This led us to decide that, with only six weeks remaining, we would focus on Stage 1 of the project in order to develop a more complete and precise analysis, but we would touch on broad options possible for Stage 2.

Table 5 shows the options that were developed through the interviews and the work with Miljøpunkt Nørrebro. We came to the conclusion that Stage 1includedthree choices: 1.) The AA route could be developed with an underground tunnel to handle displaced auto traffic from the busy road or 2.) The AA could be developed without this option, although we recognized traffic diversion would be an issue, and 3.) The BR route could be developed. We also outlined broad options for Stage 2 in each case.

Table 5: Different Canal Route Options for both Stages

	Stage 1	Stage 2
1.	Ågade-Åboulevard (with a tunnel)	Southern Route (in a pipe)
2.	Ågade-Åboulevard (without a tunnel)	Southern Route (on the surface)
3.	Borups Allé-Rantzausgade	H.C. Andersens Blvd (with a tunnel) (canal is piped)

In order to choose among the routes, we created a decision matrix (see Table 6) comparing the three options for Stage 1 against the parameters on the right.

Table 6: Canal Route Decision Matrix for Stage 1

Stage 1			Scale *1 to 5*	***Decision Matrix***
Ågade-Åboulevard (with tunnel)	Ågade-Åboulevard (without tunnel)	Borups Allé-Rantzausgade	*1= Very little or very difficult* *5= A large amount or little difficulty*	
			Green	*How much it will create*
			Flooding	*How much it will alleviate*
			Neighborhood Lift	*Reacreational improvements*
			Bicycle Corridors	*The amount that can be created*
			Motor Traffic	*How little it will be affected*
			Construction	*How difficult it would be*
			Total	

The parameters used in the decision matrix were refined and reinforced from the previous parameters by using the features that the experts stressed needed to be looked at for a daylighting project. The most important six were selected to be used for our decision matrix to determine an outcome. The first parameter we had already noted (not in Table 4), green space, was important because Miljøpunkt Nørrebro is an environmental, grassroots organization which focuses on greening the city. Our project needed to concentrate on adding green space to the route that we chose, and this parameter was a measure of how much green space could be added to the particular path we were evaluating. Flooding was the second parameter on the decision matrix, one we had noted before the interviews in Table 4. Due to the extreme rains that the city experienced the previous two summers, this factor focused on the routes' potentials to alleviate the flooding issue. The decision matrix focused on which route would have more potential to help with flood reduction based on size and the knowledge gathered from the expert interviews. Neighborhood lift was the next parameter, another factor that had been determined previously in the Background Chapter, and addressed the affect daylighting a specific route could have on the businesses and life of the people along the path. Aspects considered in the uplift of an area included:

- Enough space to create areas for recreation, such as sports facilities or playgrounds
- Potential for business improvement
- Inviting, park-like setting to attract tourists and shoppers

The fourth parameter that was added to the decision matrix was bicycle corridors. This factor involved looking at the space available for bike paths and if the route was already a popular biking route. This was a parameter that we had already established in Table 4 and was simply reinforced through our interviews as an important factor to look at.

Motor traffic is the fifth parameter, which looks at which route would have the least impact on the traffic on the road(s). From the beginning of our study, it was evident that traffic would be a huge constraint, and like some of the other parameters, this was reinforced through our interviews. With so many people dependent on cars and with the recent rejection of the payment ring, it would be impractical to not take into consideration how traffic will be affected. Although it was important to our sponsor to reduce automobile use in the city, as previously stated, we were not focusing on specifics of how to reroute or divert the traffic, although option 2's tunnel would obviously be one way to address this. The sixth, and final, parameter was construction. This parameter was selected after interviewing experts and learning about the issues that can be faced with such a complex project. Each of the different options presented its own construction difficulties. A tunnel, for example, might involve a very difficult construction process. The options were evaluated to see which would be the hardest to construct.

Each of the routes was scored against the six parameters, with 1 being lowest score and 5 being the highest. A score of 1 meant very little or very difficult, such as very little green space could be created. A score of 5 meant a large amount or little difficulty, such as a large amount of green space could be created. We assigned scores based on estimations, the information gathered through the previous interviews, and our own on-site observations. The top right of the table displays the grading scale used for each category. We then totaled scores on the parameters for each route to choose the one with the highest score.

3.3 Phase 3: Refine the Route and Develop Design Options

Once we used the decision matrix to choose a route, we then began to refine the route and develop design options. The information we had collected throughout the project, as well as the interviews with the professional experts, facilitated our design process, but we had to gather more factual information on:

- The physical conditions of the selected route.
- Design ideas from other projects (specifically a previously daylighted river in Aarhus).

By executing these steps, we gained the necessary knowledge required to successfully develop our design plans.

3.3.1 Data Collection on the Physical Conditions of the Site: Documents/Maps

In order to better understand the route we were working on, a thorough analysis of its existing conditions was necessary. According to Daquan Zhou, in his 2004 report *"Restoring Our Urban Streams: A Study Plan for Restoring/Rehabilitating Stroubles Creek in Blacksburg, Virginia,"* there are three types of data that should be collected.

1. **Baseline data:** physical conditions data, chemical conditions data, biological conditions data, and possible information on the entire watershed
2. **Historical data:** mainly done in preparation off-site
3. **Social, cultural, and economic data**

Some of the three types of data were gathered, but with the limited amount of time available, our main focus in Phase 3 was on the physical conditions in the area. The more we analyzed the confirmed route, the more accurate and precise our design sketches could be.

Table 7 below displays the various documents relating to the physical conditions of the canal's route that needed to be obtained in order to further refine and justify the pathway of the daylighting and to begin considering design options. As well as collecting these documents, it was also necessary to translate the Orbicon proposal created for the previous Ladegårdsåen project in order to gather any relevant information that was already accumulated, both physical and social.

Table 7: Documents on Physical Conditions of the Site

Daylighting Documents	
Documents	**Where They Were Attained**
Blue Spot Maps (Flooding Areas)	Municipality
Elevation Maps (Topographical Maps)	Municipality, ScanMaps (map store)
Noise Maps	Sponsor, Municipality Websites
Heat Maps	Sponsor, Municipality Websites
Traffic Counts	Municipality
City Maps (Road Maps, depicting the different structures)	Sponsor, Municipality Websites, ScanMaps (map store)
Waterway Maps of Copenhagen Area	Municipality, Sponsor

The documents needed to be gathered early on so that we could begin refining and developing our argument for a specific pathway and design. The list of what was needed was developed with the help of our sponsor and the information acquired from the expert interviews. The different documents were used as supporting information for our argument and as material used in our final presentation.

With our route confirmed and documents on physical conditions collected, we began to analyze many of the different parameters previously mentioned in Table 4 and Table 6. Both sets of parameters were pieced together and used to describe the site. The first major step was analyzing the basic physical features of the route, focusing mainly on elevation, slope, and dimensions. We had many questions that needed to be answered in order to begin developing design plans, which are shown in Table 8.

Table 8: Physical Features and Design Questions

Physical Features	What We Need to Find?
Dimensions	How wide is the road at various points along the route?
	What structures and obstacles exist along the route and where?
Space's Effect on Design	How wide can the canal cross section be?
	How wide do bike paths and pedestrian walkways need to be?
	How much room will be allocated for green space?
	How much space do emergency vehicles require?
Intersections' Effect on Design	Where are major intersections?
	Where do motorway bridges need to be constructed?
	How will these be incorporated with the different design features?
Elevation's Effect on Design	What is the elevation and slope at various points along the selected route?
	How much water can the canal handle based on the different design dimensions and the different slopes along the route?
Green Space and Water Quality	Where and how would rain gardens be incorporated?
	What variety of green space (plants) can we use?
	What soil would be needed to filter the water?
Water Channel	What would be the best design for the canal?
Flooding	How would we transport flood water out of the city?
	Could a reservoir be an option to hold the water during times of flooding?
Traffic	How would a tunnel be implemented along the route?
	How could we make the canal and tunnel a unified system?
Water Sources	How will we get enough water to supply the canal?

Street length, width, **elevation**, slope, etc. is all information that was gathered from interviews with experts, maps (such as topographical), and the previous Orbicon study. Some of the basic information, such as **obstacles** along the route, was gained by simply walking along the route, while some of the dimensions (**available space**) were found using measuring tools on the City of Copenhagen's website, where very detailed maps were available. Ove Larsen, of Miljøpunkt Nørrebro, taught us how to zoom in on a specific street and see the different buildings and how to use measuring tools that were more accurate than using Google Maps. We determined how much space the **bike routes** currently took up and how much room would be available for green space based on the possible waterway designs and dimensions.

For **flooding**, we acquired the blue spot maps which showed the areas most prone to flooding. We used these maps to confirm that the selected route was in an area that needed relief during times of flooding more urgently than neighboring areas. We also got an idea of how much flooding occurred at different locations along the confirmed route.

Traffic was a parameter that we didn't look into in great detail; however, the effects on traffic for the confirmed route were looked into in the aforementioned decision matrix. Using information from interviews and our sponsor, we evaluated which route would have the least impact on traffic. We needed to determine a basic understanding of several options that could be done to deal with traffic. **Construction** was another parameter that we used in the decision matrix, but we didn't focus on it in our design plans, due to time constraints.

At this point, as the above questions illustrate, we needed to determine the constraints related to underground **piping** along the route and the effects this would have on our designs. We evaluated the amount of water that would be flowing through the **canal** by talking with experts and estimating the amount of runoff and rainfall that would enter the canal and how this water would transition from Stage 1 to Stage 2. We, therefore, began trying to answer the question:

How can we create an overflow zone before the lakes that allows the water to smoothly transition from Stage 1 to Stage 2 in normal rain conditions and overflow into the lakes in extreme rain conditions?

We used the gathered documents on **heating and noise** to further validate why the selected route was chosen due to its high amounts of pollution. The heat and noise maps provide great visuals of this information and allow the topic to easily be seen and understood. By performing all of these measures, we were able to test and provide a rationale for the selected route

3.3.2 Aarhus River Trip

Visiting the Aarhus River was necessary in order to gather information on its landscape, its daylighting, and how the project came about, which allowed us to better visualize what the opening of Ladegårdsåen would entail and any issues we might have overlooked. In Aarhus, we were able to visually see possible design features such:

- dimensions of the channel (length, width, and shape)
- how much water runs through it and the capacity it was built to handle
- how it is built into the cityscape
- how popular its landscape is
- how much and what kind of green space exists

- other amenities (paths, benches etc.)
- storm drains, culverts, etc.

By getting a basic visual understanding of a daylighted waterway, amenities like benches, bridges, vegetation, bike paths, sidewalks, a section view of the canal (design features), etc were able to be used to further develop the design ideas we had accumulated through interviews and different case studies. We also got in contact with the Municipality of Aarhus' Department Architect, Thorkild Green, in order to ask about the details involved in the previous daylighting. A huge aspect of the visit was centered on how green space was incorporated into the project and how the businesses in the area were affected. In Aarhus, our approach was similar to that used in Copenhagen, just in a much smaller time frame. Our interview focused on determining:

- the constraints the project faced
- how and why their route was selected
- design options they considered (cross section view of the canal)
- advice on our design ideas
- lessons learned
- how the project was funded
- how the community was incorporated into the design process

This new information allowed us to narrow down the possible design features of the Ladegårdsåen. We came up with the dimensions of the canal (the dimensions had to take into account extreme rain), how much green space could be incorporated, how we thought it should look, etc. Later on, we began to make several sketches of feasible design options addressing the different aforementioned parameters. The drawings were simple, but incorporated the information we determined on how much space was available, the goals of the municipality, and what was most feasible. The designs also encompassed ideas from the Aarhus project and the advice we obtained from the experts. While creating the designs, we focused on developing the best possible outcome to help beautify, with the addition of more green space, and to protect the city against increased flooding. We organized this info to justify our designs.

3.4 Phase 4: Deliver Concept Designs

3.4.1 Sketches of Possible Designs

After acquiring all the aforementioned information and visualizations, we were able to formulate possible designs of the Ladegårdsåen. The collection of information gathered needed to be sorted through in order to determine what designs were the most feasible and which ones we wanted to use. After doing so, we developed sketches of different designs and possible options. We looked at pictures online of daylighting and urban greenery projects to gain a better understanding of what our final sketches could look like. They showed:

- the path the canal could take through the selected route
- the schematic of how to attain water and what it can be used for
- the design of the section view of the canal, including dimensions
- the design of the underground motorway tunnel
- types and locations of green spaces
- type and location of bike paths and pedestrian areas
- types and locations of different bridges
- materials used along the embankment of the canal
- locations of different bench setups

Many aspects of the designs came down to using our own creativity, while still considering the various constraints we determined for such a project. There were no set instructions on how to design and construct urban daylighting projects; therefore, we were bold, yet practical in developing solutions. The purpose of these sketches was to provide visualizations, so it was necessary for them to be very realistic and understandable.

3.4.2 Final PowerPoint and Presentation

Our final deliverable consisted of a PowerPoint presentation containing all of our knowledge gained from professionals, our decision matrix and selected route, the important maps illustrating the severity of the environmental issues on the route, relevant slope of the route and available space images, and our different designs and sketches of the various aspects of the Ladegårdsåen. Several hand-outs were given out during our final presentation as well. They were used to display the most important aspects of the project, including:

- The section view of the canal and motorway tunnel

- The aerial view of the route
- Important maps depicted the issues the route faces
- The sketches of different designs

For our final presentation, we invited several important stakeholders of the project in order to leave an impression on the city, in the hopes that our start to this project could be built upon and further developed in the future. The presentation depicted our final recommendations for Miljøpunkt Nørrebro and the City of Copenhagen.

3.4.3 Website

During our time with Miljøpunkt Nørrebro, a website was created for this project by Anders with the help of the graphic designer. We decided to include our report on the site, which can be split into different sections, as well as our design sketches. This website served and will continue to serve as an introduction to the project for the local citizens, allowing them to learn about what is taking place and to see our different designs. If time allowed, we would have liked to create a survey so that Miljøpunkt Nørrebro could have gathered feedback on our different designs. This is something that we recommend Miljøpunkt Nørrebro do in the future as the project develops.

3.5 Project Flowchart

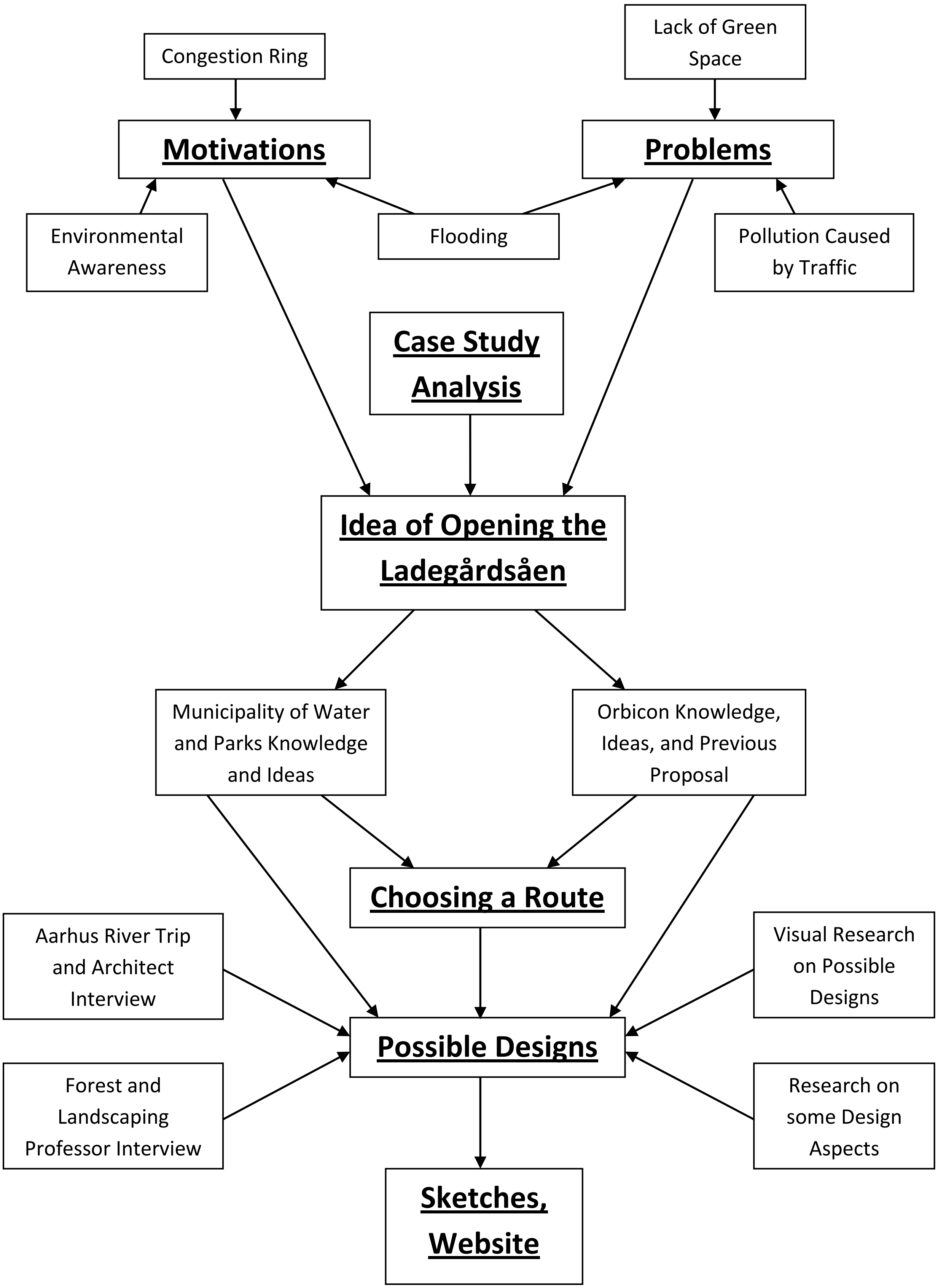


Figure 29: Project Overview

Chapter 4: Results

4.1 Information Gathering and Decision Matrix to Confirm a Route

On arrival in Copenhagen, we first clarified Miljøpunkt Nørrebro's desires for our project in order to make sure we were heading in the right direction. Upon doing so, we were told that the renewed interest for the project was due to extreme storms which occurred in the summer of 2011 in Copenhagen. We also learned that Miljøpunkt Nørrebro focuses heavily on sustainability. In other words, they promote using environmental factors to benefit the community, neither depleting natural resources nor being harmful to the environment. This was compatible with our project in the sense that the opening of the Ladegårdsåen has potential to sustainably create green space and collect rain water, therefore benefiting the citizens of Nørrebro. Our sponsor also believed that with the increase in greenery and with the reduction or diversion of traffic produced by the opened canal that pollution in the area would also diminish, further benefiting the community. This clarification gave us our main focal point for the project: the creation of green space and the collection and transport of rain water to reduce flooding in Nørrebro.

From this point, we realized we needed to decide on the route for the canal. Originally, our parameters for such a decision were:

Table 9: Original Parameters

Available Space	Wider routes are better.
Obstacles	Which route has larger obstructions?
Flooding	Which route experiences more?
Roads and Traffic	Which route has more traffic?
Canal/Piping	Where are pipes located on each route?
Elevation	Which route is lower and has good slope?
Noise and Heat	Which route experiences them more?
Bike Routes	Location and popularity on each route.

Each of these parameters was explained in detail in the previous chapter. From here, we needed to find out information on each of them. We also needed to decide which parameters were the most important and which ones were less so. We decided that the room and need for **green space** in each area was a factor to be added because the main desire of Miljøpunkt Nørrebro was to create more greenery.

During our second day at the office, we had a debriefing with Ove Larsen (a Miljøpunkt Nørrebro employee) about the recent summer's flooding, the sewer systems in Copenhagen, and about the two possible routes (AA and BR). Below are two maps of the routes, the AA highlighted in red and the BR in blue. The green sections are the areas before and after each route that would have to be included regardless of which route is chosen.

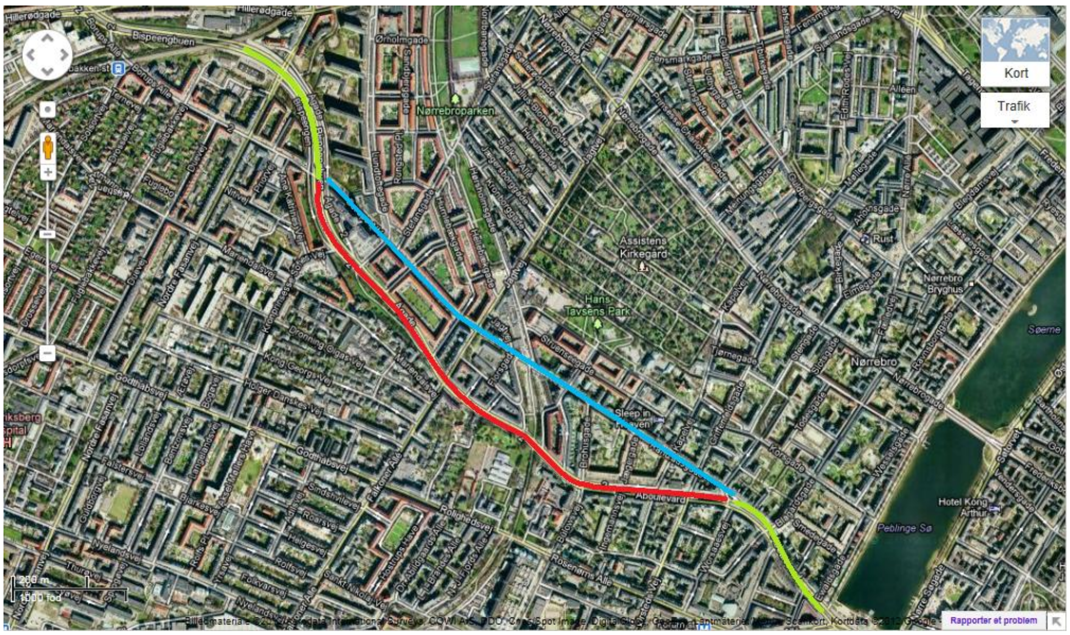


Figure 30: Satellite Map of the Two Routes (adapted from Google Maps)

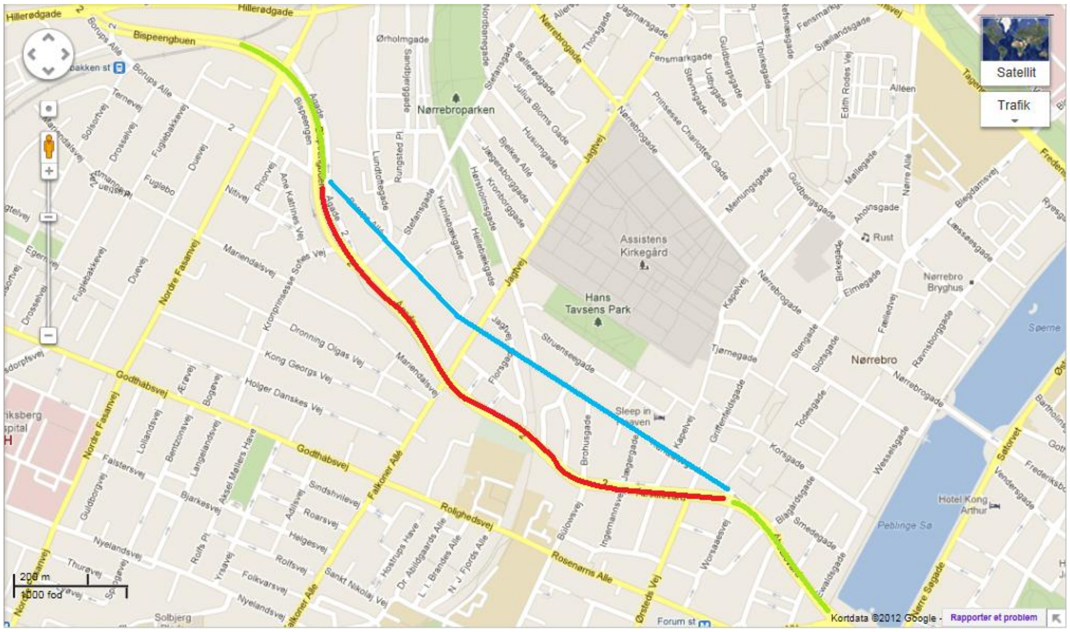


Figure 31: Aerial Map of the Two Routes (adapted from Google Maps)

The main facts and ideas which we took away from the debriefing are illustrated in Table 10:

Table 10: Debriefing with Ove Larsen

Rainwater and Climate Change	Miljøpunkt sees the rainwater as a resource, not as a problem. They need to show this to the people	The total amount of rainfall in Copenhagen is 750 mm per year	According to Climate Scenario A2, 30% more rainwater needs to be accounted for per year, thus the climate is changing	There is more rainfall per year in Copenhagen than surrounding areas. This might be due to the urban heat effect
Possible Solutions for Flooding	There are already many existing uses for rainwater and many potential ideas as well, such as storing it in roof basins to be used in buildings	there is no possibility of acquiring 15-35 billion kroner to upgrade the system to accommodate the increase in rainfall	The people of Nørrebro want more green space, specifically "green corridors" which connect green sections	The canal will need bike lanes and many trees, which is what the people want

The Two Possible Routes	Åboulevard is the lowest area where flood water flows to	The bureaucrats believe the canal on Åboulevard would be too expensive to construct in this bad economy?	Rantzausgade could easily be closed to traffic. It has no need for cars, which are simply parked there all day	Rantzausgade has seen recent drug crime and could be beautified and uplifted into an awesome shopping center

Through the debriefing, we learned what the people of Nørrebro would potentially desire out of the Ladegårdsåen, how much we need to emphasize the management of rainwater, and important biases for and against each of the possible routes. After this debriefing, our team was leaning more towards the BR route. This seemed more realistic at the time, especially after discovering that the payment ring of tolls around the city center which could have reduced traffic on the AA route had fallen through. The AA route exists as a regional transport corridor, therefore, eliminating traffic on this road by the canal would be extremely problematic.

We came to the conclusion that **flooding** was one of the most important factors to be considered. We removed the parameter of **available space** because obviously large amounts of space would be needed for a greater increase in **green space** and for a more beneficial canal system to reduce **flooding**. Therefore, the amount of space on each route would affect those two parameters.

Even though we were leaning more towards the BR route at this time, after speaking with our liaison, Anders Jensen, we learned that the Municipality of Water and Parks of Copenhagen was favoring the daylighting of Ladegårdsåen on the AA route. He explained that a recent architectural project which took place in Copenhagen established the idea of opening the canal past the lakes on H.C. Andersens Boulevard (H.C.A.), connecting it all the way to the harbor, as shown in the map below:

Figure 32: Map of Second Stage Option (adapted from Google Maps)

This connection to H.C.A. could be a second stage of the route, as seen in yellow. Furthering this idea, he suggested the idea of building a tunnel for car traffic underneath the canal along the AA route through H.C.A. in order to provide sufficient space for the canal and green space, as well as to address disrupted traffic. This created the parameter of **construction**. However, we were not going to focus on how the canal was to be constructed, but how difficult, expensive, and disruptive the construction would be. This took into consideration residents living in the area as well as those who pass through the route on their daily commute to work.

In light of these new ideas, we needed to gather information on the feasibility of a tunnel and route. Therefore, we refined some of the interview questions we developed for the Orbicon engineer and the member of the Municipality of Water and Parks of Copenhagen.

We interviewed Søren Gabriel, an engineer from Orbicon who worked on the previous proposal of the project. From this interview we learned the details of problems they faced, possible designs they considered, etc. As previously stated, their proposal was only meant to be an idea project with the purpose of uplifting and beautifying the area. The main facts which we took away from this interview about the current situation and problems involved with such a canal are illustrated in Table 11:

Table 11: Orbicon Interview

How the Situation has Changed	The climate has changed, resulting in an increase in rainfall per year, last summer causing expensive, damaging flooding	The sewer systems were designed for regular heavy rainfall, but could not handle the storm water from the recent summer	Regular heavy rainfall can go into pipes, but extreme rains need to be dealt with on the surface	Solutions involve reservoirs for retaining the water and streams to lead the water away	The lakes can be used as the reservoir capacity in times of extreme rain, therefore the Ladegårdsåen would act as the stream
Problems Encountered	Rainwater is very polluted, especially flowing off of streets. Therefore, a way to clean the runoff before it enters the canal is needed	If the water in the opened canal flowed into the lakes, it would destroy the lakes' water quality, causing extreme algae outbreaks	Currently, the Ladegårdsåen pipes are only open for 3 months in the winter to raise the level of water in the lakes. The water in the pipes is cleaned beforehand	Such a canal will never be able to be constructed with the sole purpose of reducing traffic because it is not a wise economic decision	Last summer's flooding has changed the funding, so such a project might not be feasible at this time unless it has true potential to reduce flooding

From these facts, we acquired expert information regarding why having a canal is important in aiding the reduction of intense flooding. These facts could therefore be used as evidence as to why the canal should be daylighted. We also learned that the canal would have to support 5000 liters per second in times of extreme rainfall conditions.

More importantly, we learned that the water in the canal cannot flow into the lakes, but can only overflow into them occasionally in times of rare, extreme rain. Previously, we believed the water would flow directly into the lakes and then leave them on the other side, flowing into H.C. Andersens Boulevard. Now, we were considering either piping the water under the lakes or carrying it over the bridge somehow. We also needed to gather more information on filtration strategies, such as rain gardens, as a possible means of cleaning the normal rainfall runoff water before it flows into the canal. However, flood water could by no means be cleaned before entering the canal because of its sheer volume and the immediate need to transport it as fast as possible.

The main problem we had at this point was how to get water into the canal because the pipes are currently only open for three months every year due to the fact that there is not enough water from the source to leave them open year round. Therefore, we refined some of our questions for the member of the Municipality of Water and Parks. We also needed to ask about different ways of transporting the water in the canal over the lakes on the surface or underneath them in pipes.

Apart from the above, Søren also provided us with his insight and opinions on the three potential routes, illustrated by Table 12:

Table 12: Orbicon Route Facts/Ideas

AA route (with tunnel)	The tunnel is possible, but probably not for another 20 years due to the poor economy	It would be the municipality's responsibility to pay for it, but their funding has changed due to the recent flooding. Therefore, they will not want to pay for a tunnel unless it can be used for flooding purposes	The sewer company could end up paying for it if it is a storm water project
AA route (no tunnel)	AA is the best option because of its space and and its feasibility	Could use one lane for the canal and green space and the other five lanes for traffic	In the morning, three lanes could travel into the city and two lanes could come out. This would switch in the afternoon: two lanes in and three lanes out
BR route	Does not seem feasible due to its small size	BR was only chosen in the previous proposal because the area needed an uplift and it was easier to implement in regards to traffic	

After taking these professional facts and opinions into consideration, the team started leaning towards the route of AA with no tunnel because it seemed the most feasible with the greatest amount of space. However, we still needed more information on the feasibility of the tunnel to make a decision.

The team decided to take into consideration **neighborhood lift**, a parameter pertaining to how much the area of the chosen route will benefit from the opened canal. This was developed in light of the previous proposal, which had the sole purpose to uplift Rantzausgade both aesthetically and economically. However, we would also take into consideration how each route would experience an environmental uplift, benefitting from the reductions of the problems of flooding, heat, noise, and air pollution, and a recreational uplift, by creating places for socializing and relaxing. Therefore, the team also decided that the parameter of **noise and heat** would be included in the **neighborhood lift** parameter. We also altered the parameter of **roads and traffic** into **motor traffic**. This parameter only considered how little the traffic on the routes would be affected, not how to divert the traffic.

One of the most important pieces of information given to us by Søren was a possible design of the section view of the canal, as seen in Figure 33.

Figure 33: Orbicon Design Section View

This design, which we nicknamed the "reverse pyramid" design, incorporates handling different volumes of water in respect to different rain conditions. On normal days, the water in the canal will just flow through the small channel in the bottom on the design. The steps leading up from that channel will be used as seating for citizens, possibly with benches. However, during days of storm fall, the steps will fill up and be used as a greater capacity to hold the increase in water and transport it away (as shown by the dotted lines in the above figure). On the sides of the canal could be green space, consisting of flowers, bushes, trees, etc. Rain gardens could be placed along the sides as well and, as previously stated, could be used to clean polluted runoff water before it enters the canal. Beyond this greenery would be space for bike lanes and potentially roadways for car traffic, if needed. This design provided us with our first visualization of the canal and its potential design options. We planned on presenting this design to the Municipality of Water and Parks in order to obtain their opinions on it.

We met with Stefan Werner, an expert member of the Municipality of Water and Parks of Copenhagen. From this interview, we learned of the Copenhagen waterway, facts pertaining to the different routes of the canal, and his professional opinions and ideas on the canal design. The main facts we took away from this interview are illustrated in Table 13.

Table 13: Municipality Interview

Why the Canal Cannot Flow into the Lakes	The water in the lakes is controlled and has been cleaned for the past 10-20 years to get to the state the lakes are in now	Rainfall runoff on roads contains heavy metal so it cannot flow into the lakes because they will be destroyed	However, in times of extreme rain, this water can be sent to the harbor and can overflow into the lakes, if it is kept separate from the sewage water	Also, the lakes cannot take on all the water flowing from an open canal because the lakes' outlet is too small to handle the extra water
Climate Change	There will be more rainfall in the winter than in the summer	More rainwater will come all at once in the summer, however	When it is warmer with more moisture, rain becomes more violent	
Topography and Slope	Copenhagen is an extremely flat city	There is roughly a 6 meter drop from the area above Ågade to the harbor area beyond the last lake	The slope along the AA route is about a 1 meter drop per 1 kilometer	
Lack of Water and Possible Solutions	Clean water is sent all around the city in the summer, therefore it is scarce this time of year	Roofs make up 30% of the topographical area in the city, therefore water can be collected from them in roof storage bins	Water from roofs is acceptable to use, fairly clean, and can be transported very far with a strategic design	Reservoirs can be created on the ground in order provide water to the canal in times of draught
Possible Plans and the Routes	Blue and green structures can be incorporated throughout the city in order to connect green areas and waterways	He preferred the AA route over the BR route in order to collect rainwater and help in reducing flooding	In order to get the canal water to the harbor, it will always encounter a railway, therefore it will have to be piped at these points	

One of the main things we learned from Stefan is that we should be thinking big, open, wild, and free. We should not let physical obstructions hinder our creativity, such as buildings for example, although we need to be realistic. Therefore, we were able to remove the parameter of **obstacles**. We were also introduced to a new route the canal could travel once it reaches the lake. Instead of crossing over the lakes and following H.C. Andersens Boulevard, the canal could turn south and continue along the lakes without crossing them until it reached the harbor, as illustrated by the map below:

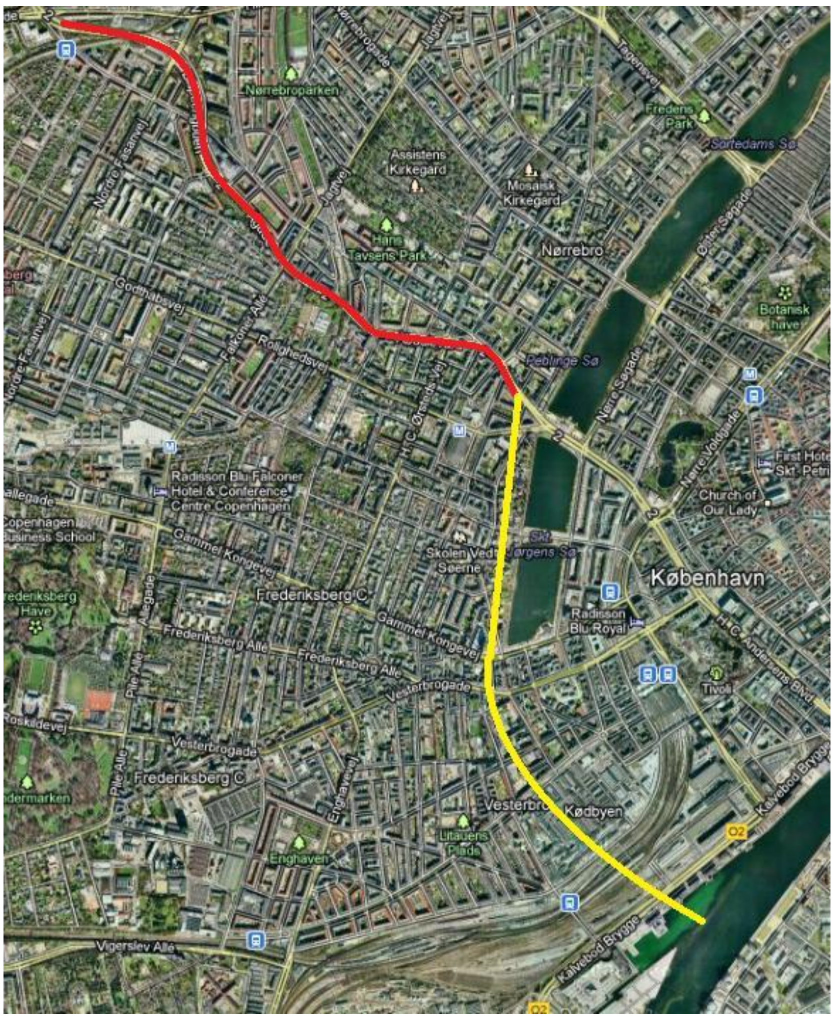


Figure 34: Map of Second Stage Option 2 (adapted from Google Maps)

The red indicates the AA route and the yellow indicates the general direction of the new second stage option.

More importantly, however, we acquired ideas of how to feed water into the canal, such as water from roofs, reservoirs, drains, and natural rainfall as described in the table above. This was our main problem at the time, and having answers was extremely beneficial to the purpose of our project. We also received confirmation that the water in the canal cannot flow into the lakes, but can overflow into them in times of flooding. Along with this, we also confirmed that the water can flow into the harbor.

He also gave us a design concept which he came up with, as shown in Figure 35.

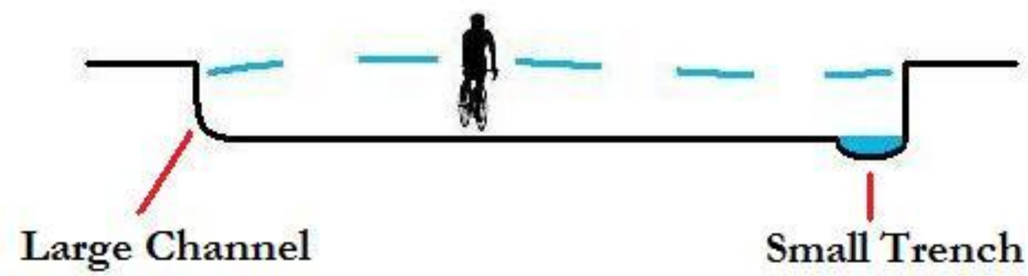


Figure 35: Municipality Design Section View

This design, similar to the "reverse pyramid" design given to us by Søren Gabriel of Orbicon, can handle different volumes of water. Stefan explained the dimensions of the large channel are 5 meters wide and 1 meter high. Normally, the large channel could be used as bike lanes and the actual canal would only consist of the small trench on one side of the large channel. In times of extreme rainfall, the large channel will be able to fill up, as illustrated by the dotted line in the above figure. He explained this capacity will be able to transport 15 cubic meters of water per second, equaling 15,000 liters per second. Similarly to Søren's design, on the sides of the canal could be green space followed by even more bike lanes and potentially roadways. This design provided us with a second visualization of the canal.

However, Stefan mentioned to us that there would need to be at least 100 of these canals throughout the city to actually solve the flooding problem completely. Although we were only focusing on Nørrebro, we realized that the Ladegårdsåen would only have minimal effect on reducing flooding in the area. In light of this, Anders developed the idea of using the tunnel as a reservoir in times of extreme rainfall. We then discovered that this concept is already in use and celebrated in different parts of the world, making us favor the AA route with the tunnel (International Tunneling and Underground Space Association, July 2011).

In terms of our parameters, we decided to drop the parameter of **canal/piping** because there is little knowledge of the locations of old pipes running through Copenhagen, referring to pipes other than the Ladegårdsåen pipes. Therefore, any area that is dug up will have a high chance of disrupting pipes. Stefan advised that digging one meter into the ground would be a safe level to avoid pipes, although implementing a canal and tunnel would definitely disrupt them.

We also decided to include the parameter of **elevation** under the aforementioned important parameter of **flooding** due to the fact that the lowest places experience the most damaging flooding. Stefan had explained that he had cycled the AA route with a GPS system and discovered that the slope was ideal for a flowing canal, in the sense that its elevation decreased along the entire route towards the direction of the lakes. This corresponded to his rough estimate of the slope being a 1 meter drop per 1 kilometer. He also mentioned that the elevations of the areas surrounding the AA route are beneficial for bringing down runoff to the canal.

The remaining parameter was **bike routes**, which was altered into **bicycle corridors**. This parameter was not discussed in great detail in any interview, but was mentioned as being important. As previously discussed, **available space** was not included as a parameter because it influences many of the other, very important parameters our team chose. Those parameters, such as **green space**, **flooding**, and **bicycle corridors**, are extremely important because they exist as the final outcomes which we and our sponsor desired more than anything else. The greatness of these parameters relies on a large amount of space, some more than others. Therefore, the final parameters we used to influence our decision were:

Table 14: Decision Matrix Parameters

Green Space	How much space is available? How much can be created?
Flooding	What areas are more prone? How much space is available for a canal?
Neighborhood Lift	Economically, environmentally, and recreationally.
Bicycle Corridors	How much space is available? How wide can they be?
Motor Traffic	How little will it be affected? The less the better.
Construction	How easy/inexpensive will it be? How little will it affect the citizens?

We created a decision matrix and, using the knowledge we attained from each interview and debriefing, we scored each route according to the parameters from 0 (worst) to 5 (best).

Table 15: Decision Matrix

AA (tunnel)	AA	BR	
5	2	1	**Green**
5	4	1	**Flooding**
5	1.5	1	**Neighborhood Lift**
5	2	3.5	**Bicycle Corridors**
4.5	3.5	5	**Motor Traffic**
0	3	1	**Construction**
24.5	**16**	**12.5**	**Total**

As the matrix shows, the AA route with a tunnel scored highest. The biggest factor attributing to this ranking was the space provided by both the width of the route and by placing the traffic underground. This amount of space will allow for a more green space, a greater ability to collect flood water (especially if the tunnel could be used as a reservoir), and larger bicycle corridors. The fact that the AA is low topographically and that its slope decreases along its route will allow for great drainage. All these improvements will greatly improve the neighborhood environmentally, recreationally, as well as economically. Most of the traffic on the route continues straight through it, traveling further into the city. Placing the road underground will continue to allow those drivers to pass through the route, minimally affecting the traffic. This tunnel will also provide an enormous reservoir capacity in times of flooding. Although the construction of the canal and tunnel will be the biggest negative factor because it will be expensive, difficult, and possibly obstructing and interfering, there are significant positives associated with the route that correspond to the city's and neighborhood's future objectives.

Without the creation of the tunnel on the AA route, a roadway consisting of five lanes will be needed on the surface to handle the traffic with little hindrance. However, reducing the number of lanes will most likely cause more congestion. Therefore, there will be much less space for an increase in greenery, a larger canal to reduce flooding, and wide bicycle routes. This would decrease the environment and recreational aspects of the neighborhood lift. However, the construction of the canal would not be as large of a large hindrance compared to that of the tunnel, but would still be very obstructing.

The BR route simply does not have enough space. This would limit the amount of green space, the size of the canal (and the ability to transport water), and the widths of the bicycle lanes. Therefore, the area would not experience a great environmental and recreational uplift, compared to that of the AA route, but could potentially experience a large economic uplift as predicted by the previous Orbicon proposal (2007). Positively, traffic on the BR route is already minimal. Therefore, if no traffic was allowed on this route, it would not cause much disruption. Lastly, it would be very difficult to build a canal in such a small area. Our final decision remains as the AA route with a tunnel.

4.2 Affirming the Route's Potential to Address Environmental Problems

After filling in our decision matrix and deciding on the AA route with the tunnel, we used a variety of maps to investigate the seriousness and extensiveness of the environmental problems we identified earlier along sections of the AA route in particular:

- Flooding
- Urban Heat
- Noise Pollution
- Air Pollution
- Lack of Green Space

Figure 36 is a flooding map, provided to us by Stefan Werner of the Municipality of Water and Parks in Copenhagen, which shows the severity of flooding throughout the city of Copenhagen. The dark blue areas designate areas most prone to flooding, usually pertaining to streets, which experience the major flow of water. The light blue areas experience lesser flooding, but are still affected to an extent. As seen in this map, Åboulevard

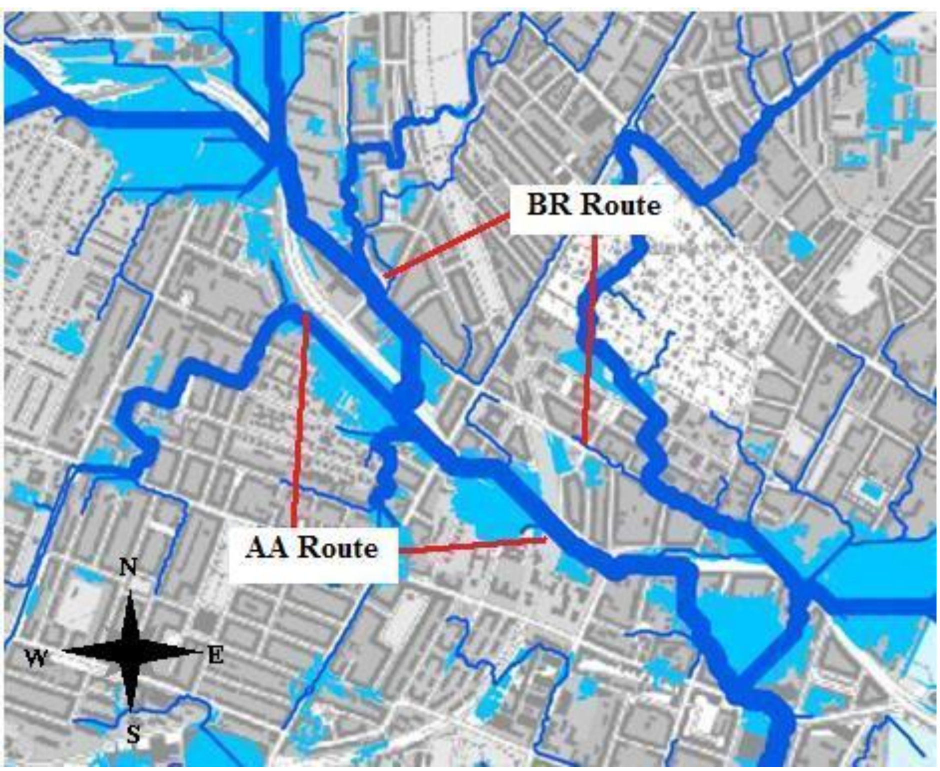


Figure 36: Flooding Map (Københavns Kommune, October 21st, 2008)

experiences an extreme amount of flooding, especially compared to Rantzausgade. Borups Allé is also prone to flooding, specifically from water flowing from the north. The opening of the Ladegårdsåen will be further north of this area, therefore diverting water that could flood Borups Allé into the canal on Ågade. Along with this map, Stefan also provided us with a "blue spot map," as seen in Figure 37, which shows the levels of flooding from the storms in 2010, including the heights of water.

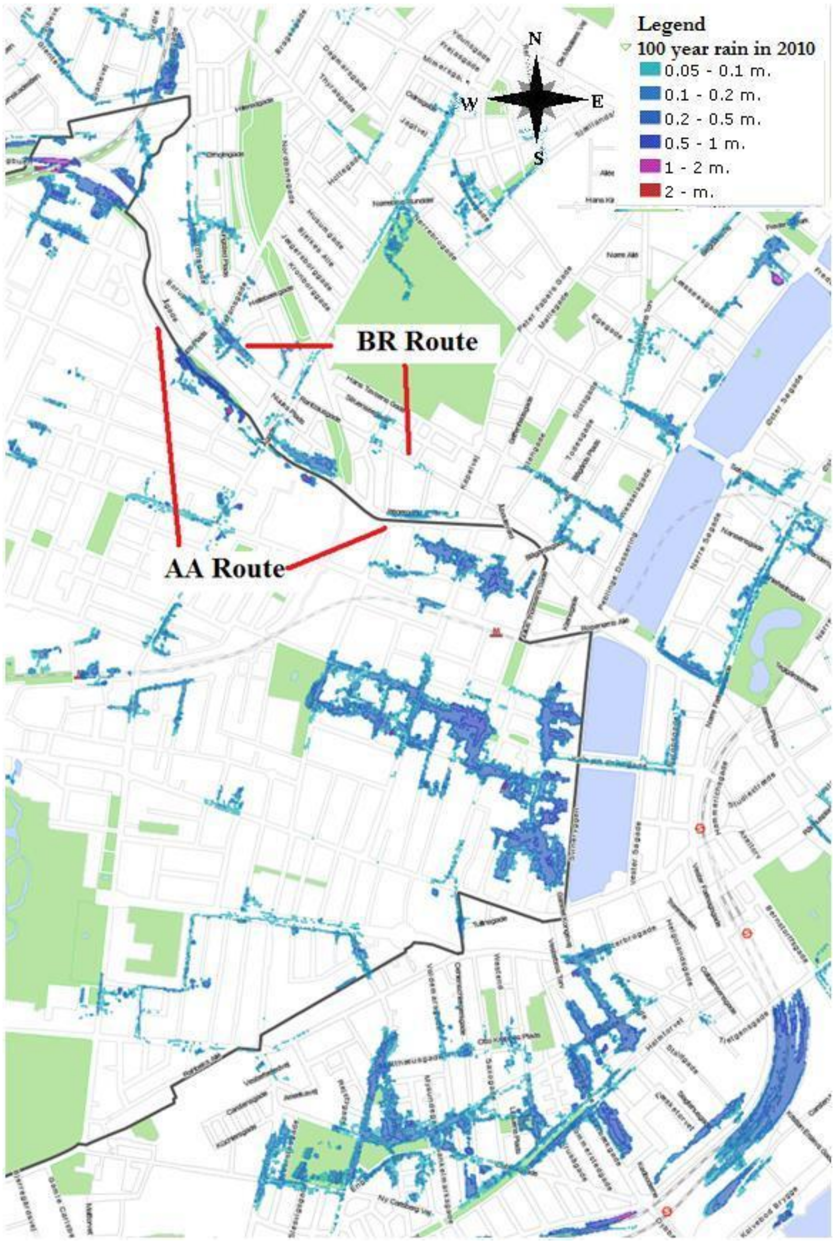


Figure 37: Blue Spot Map of Copenhagen (Københavns Kommune, 2010)

As the legend shows, the flood levels ranged from 0.05 meters to 2 meters. There appears to be much flooding by the western area of the most southern lake and in the area more southern near the harbor. This explains why Stefan mentioned that the path of the canal could flow this way. Figure 38 is a zoomed-in version of the above map which shows the AA route.

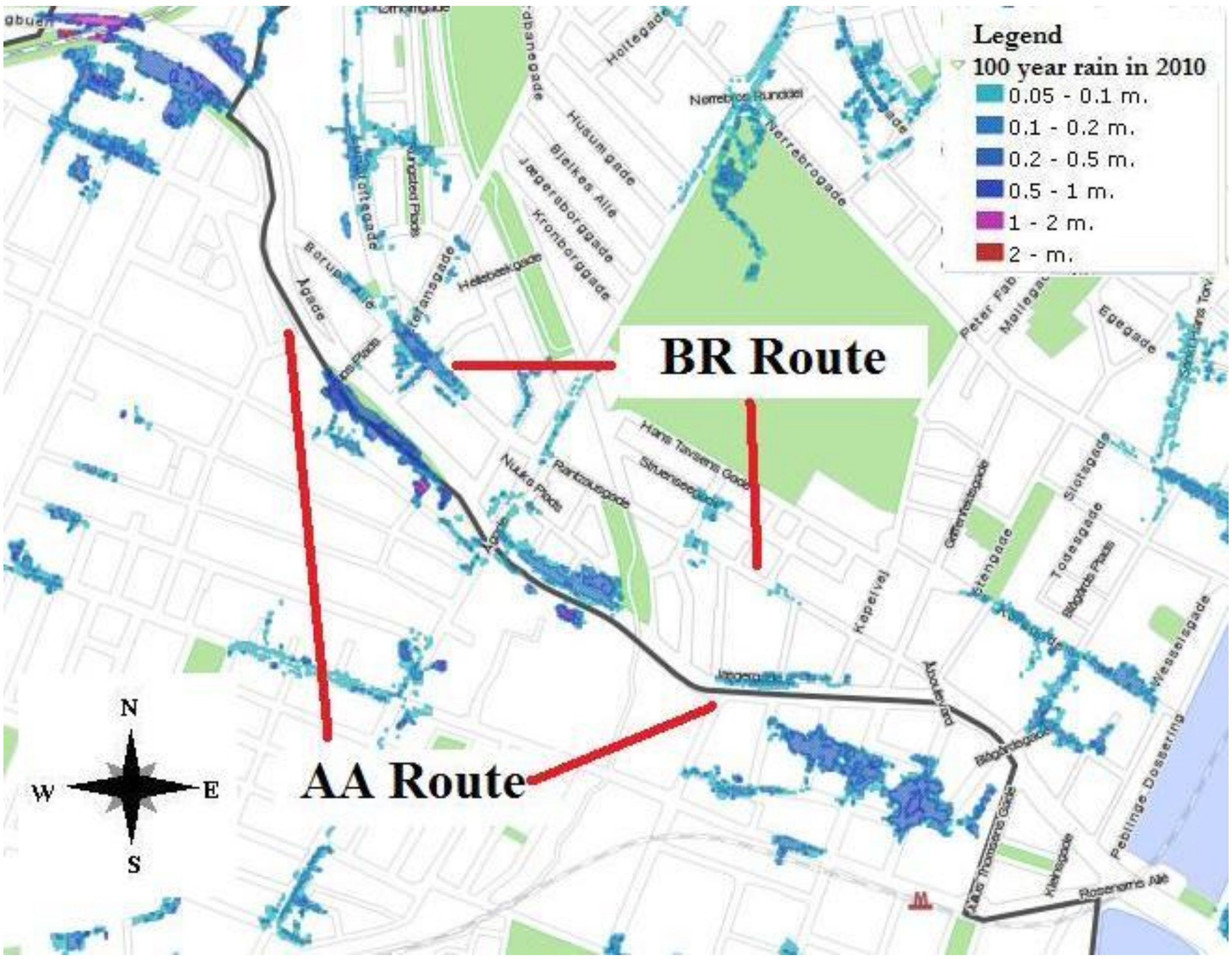


Figure 38: Blue Spot Map of Nørrebro (adapted from Figure 37)

As seen on the AA route above, there are certain sections of this route which are extremely flooded, up to one meter of water and even more at some points. The curved area in the north-western area of the above map represents the area under the high-rise roadway. If this roadway and the rest of the AA are placed underground in the tunnel, the Ladegårdsåen could collect this water and divert it out of the area. The tunnel itself will be able to collect the flood water as well.

In addition, the topography of the area to either side of the AA corridor is conducive for bringing water down to the canal, as seen in Figure 39 below:

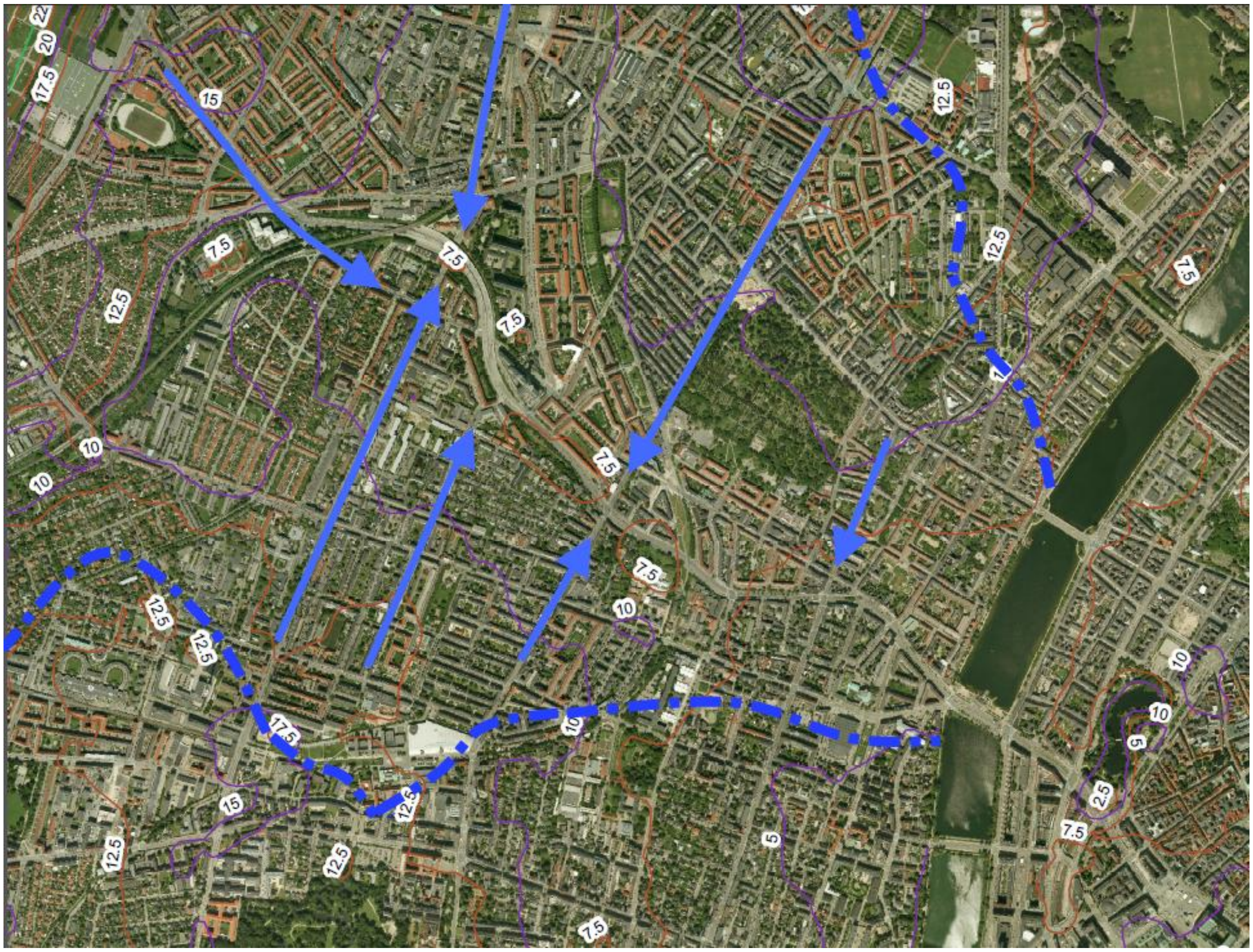


Figure 39: Topography and Watershed Surrounding Ladegårdsåen (Digital Terrain Model [DTM], Denmark)

Although the purple and orange lines indicating the different height levels may be difficult to distinguish, the numbers (representing meters above sea level) on either side of the canal route indicate much higher levels of altitude in those areas. In other words, the areas surrounding the sides of the canal slope down into it. Therefore, water flowing off of these high areas has much potential of flowing into the AA route, which could provide an extremely great collection of rainwater in the Ladegårdsåen. This refers to what is called a natural watershed, which defines the high topographical areas where water flows from into the lower valleys they create. The dotted blue lines represent the highest points where runoff water flows from. Directing runoff could be made more feasible by using the streets that run perpendicular to the AA route as drains which transport water to the canal, an idea made known to us by Marina Jensen, a professor of forests and landscaping at the University of Copenhagen. The blue arrows represent the direction of the water towards the AA route (in the center) running along certain main roads which could be used as drains.

Apart from this slope, the slope of the AA route needed to be a gradual downhill from the start of the canal to the finish at the lakes in order to allow the water to flow through it naturally without the use of pumps. Orbicon (2007) analyzed the slope of the AA route in their study and determined the gradient of the route from the Long Park to the lakes was acceptable in keeping a constant flow of water. Figure 40 shows that from Jagtvej to the area just before the lakes, a decline in the slop is present.

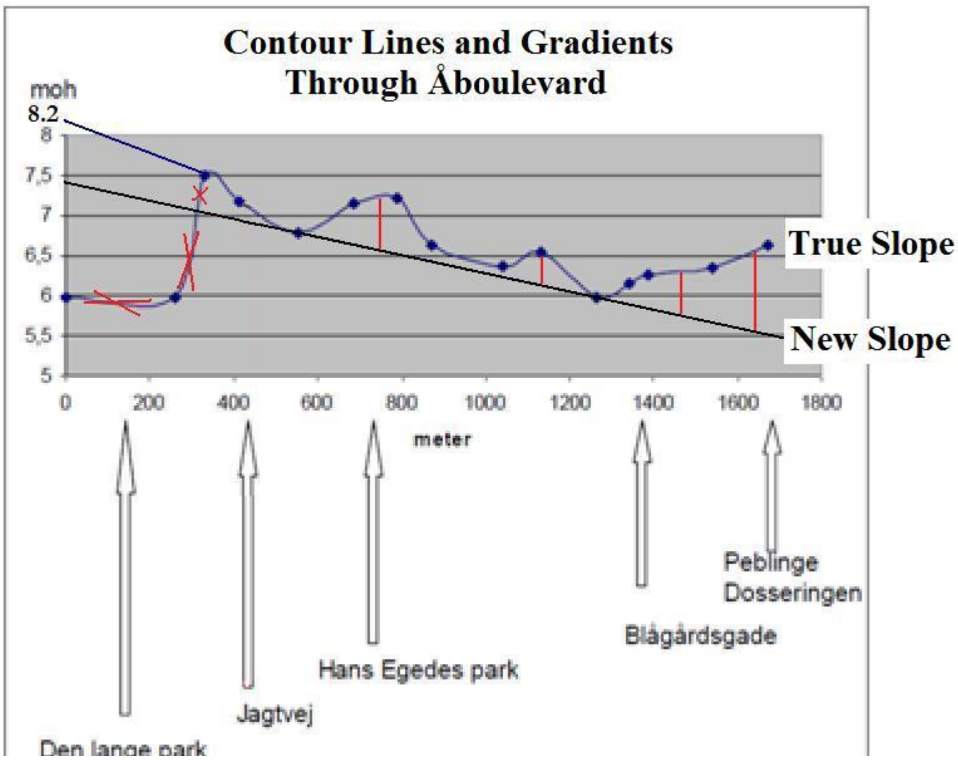


Figure 40: Slope of the AA Route (Orbicon, 2007)

This implies that less construction would need to be performed to adjust the level of the canal. The first area on the graph (the Long Park or Den Lange Park) is the starting point which Orbicon considered. It is different than the starting point our team is using, therefore, it can be ignored and is crossed out in the above figure. However, we learned from Stefan Werner and his GPS system coordinates that the altitude of our starting point, near where Ågade meets Borups Allé, is roughly 8.2 meters above sea level, as seen in the above figure. This suggests that the slope of our chosen route is ideal throughout its entire length. After consulting with Søren

Gabriel of Orbicon one last time, he told our team that the slope of the entire route can be altered into one continuous, new slope provided by digging at different depths. This is made possible because digging will have to be done anyhow for the tunnel underneath. The new slope is represented by the straight black line in Figure 40 above. The new slope needs to connect to the lowest points of the true slope in order for water to flow into the canal. The differences in the true slope and the new slope (as illustrated by the vertical red lines in the above figure) will be eliminated by the reconstruction of the land. In other words, in areas where the slopes are different (the true slope is higher than the new slope), the green spaces will have to slope downwards towards the lowered height of the new slope. The average difference of a little over 0.5 meters combined with the widths of the green spaces averaging 3 to 4 meters on each side (which will be discussed in further detail) will not create drastic slopes of green space to the top of the canal. In places where the slopes are the same, the green space will be able to remain flat. Schematics of these can be viewed in Figure 41 below:

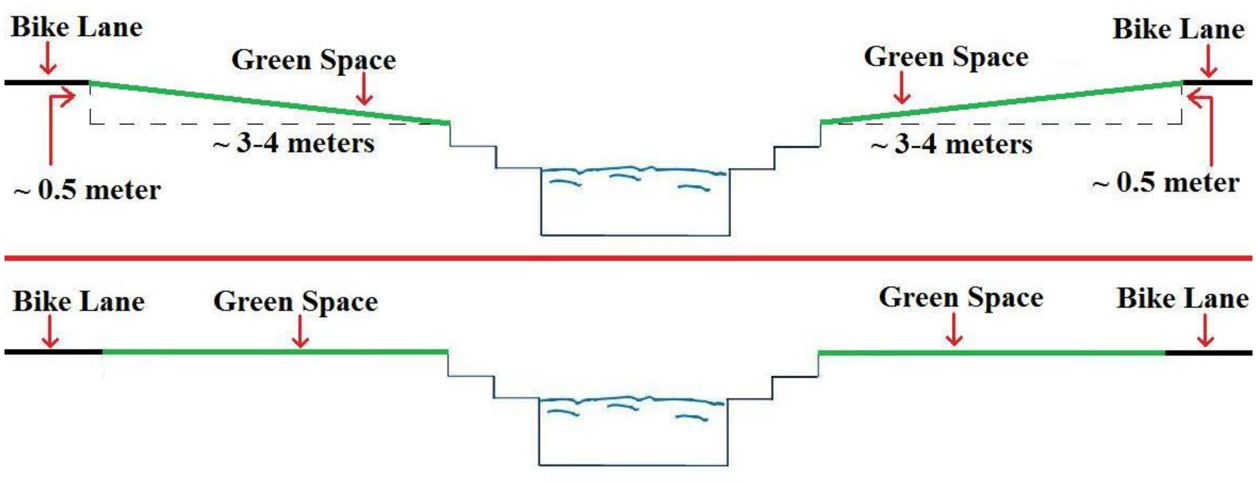


Figure 41: Sloping of Green Space

Although the green space will slant at these certain points, they will be able to be altered so that rain gardens with depressed ground can be implemented to absorb and clean the slow flowing normal rainwater runoff before flowing into the canal (which will be discussed in further detail).

Along with flooding, we further investigated on the heat and pollution problems affecting the area. Figure 42 is a map of the heat levels in the city, specifically in our area of focus. According to the color scale, warmer areas correspond to the red side of the spectrum labeled “high.” Cooler areas correspond to the blue side labeled “low.”

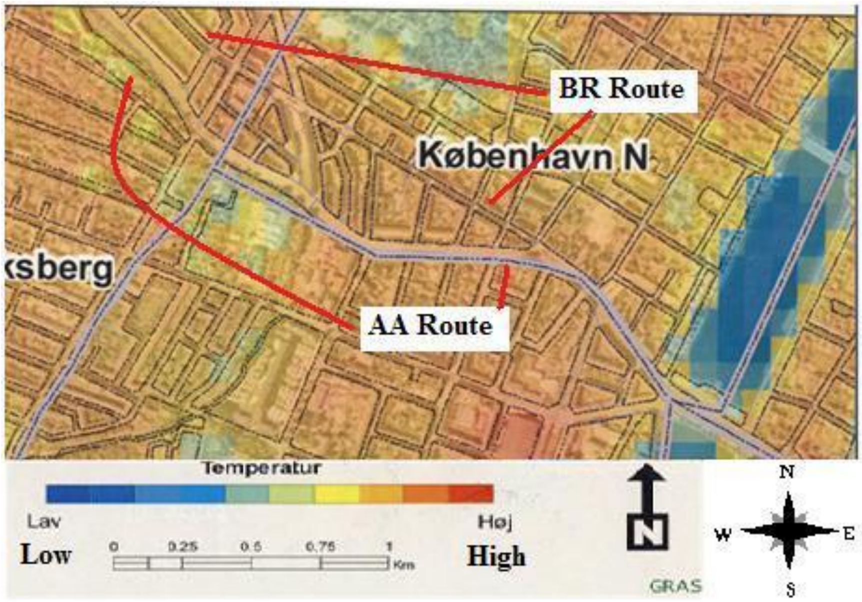


Figure 42: Heat Map (Københavns Klimatilpasnings- Plan, p. 42, 2011)

The AA route is highlighted in blue. This map shows that the AA and surrounding blocks on either side are hot areas. The cooler area to the north represents a cemetery which exists as a significant green space within Nørrebro. Green areas are much cooler than urban areas which contain streets and cars. Therefore, daylighting the Ladegårdsåen on the AA route and creating green space would potentially help cool the area. Reducing this heat by opening the canal falls in line with Copenhagen's plan to reduce heat throughout the city and to create a green infrastructure, acting as more motivation to daylight the Ladegårdsåen (City of Copenhagen, 2011). Also, we learned from Thorkild Green, an architect who worked on the Aarhus River project, the heat levels around the area where the river was daylighted decreased significantly, providing actual evidence of this benefit.

In regards to pollution, Figure 43 is a map which shows the noise levels in Copenhagen. These measurements were taken at 4 meters above ground level, therefore representing the noise levels experienced by residents living in the higher floors of buildings.

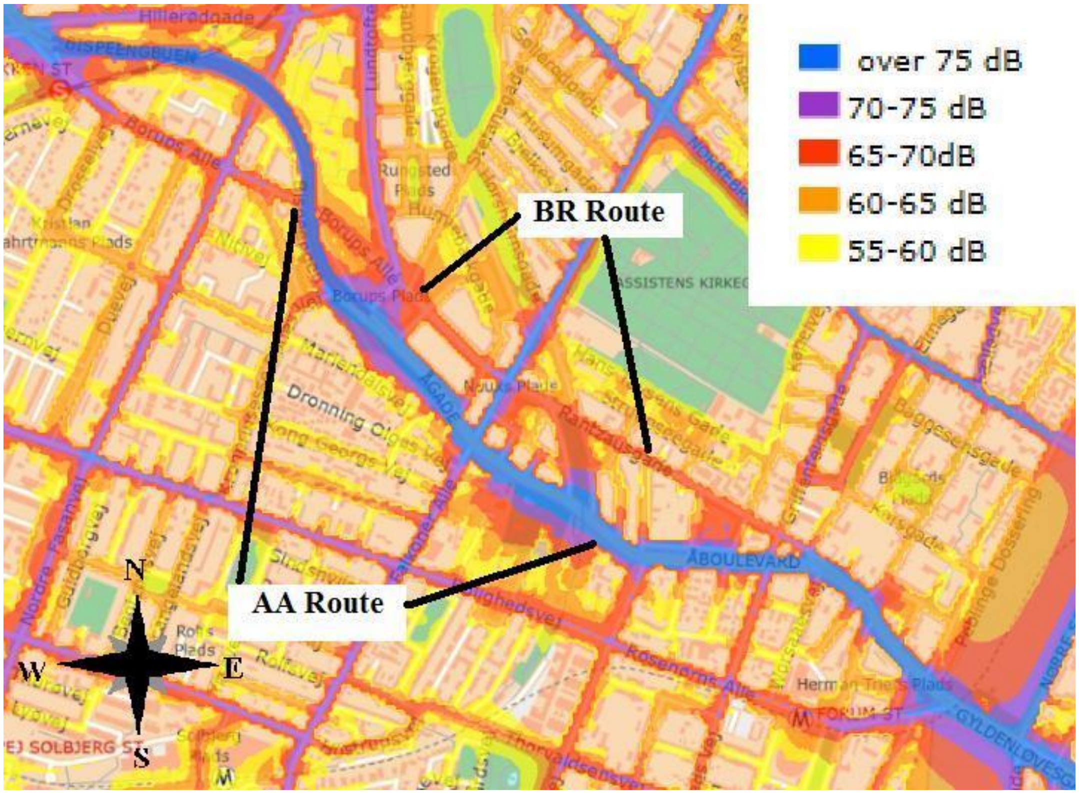


Figure 43: Noise Map (Miljøministeriet Miljøstyrelsen, n.d.)

As illustrated by the scale, the noisiest areas correspond with the color blue and the least noisy areas correspond with yellow. From this map, it is evident that the AA route experiences an extreme amount of noise pollution from traffic, compared to a lesser amount on the BR route. Therefore, the AA route, if daylighted, will potentially reduce the noise pollution in the area, benefitting the residents living along this route and making it more attractive and inviting to visitors.

Along with this noise caused by traffic is air pollution. Figure 44 shows a map of the levels of nitrogen dioxide gas (NO_2) throughout Copenhagen. The green circles signify good levels of this particulate, which are under the European Union's limit of 40 micrograms per cubic meter of air. The red circles signify bad areas which are above this limit.

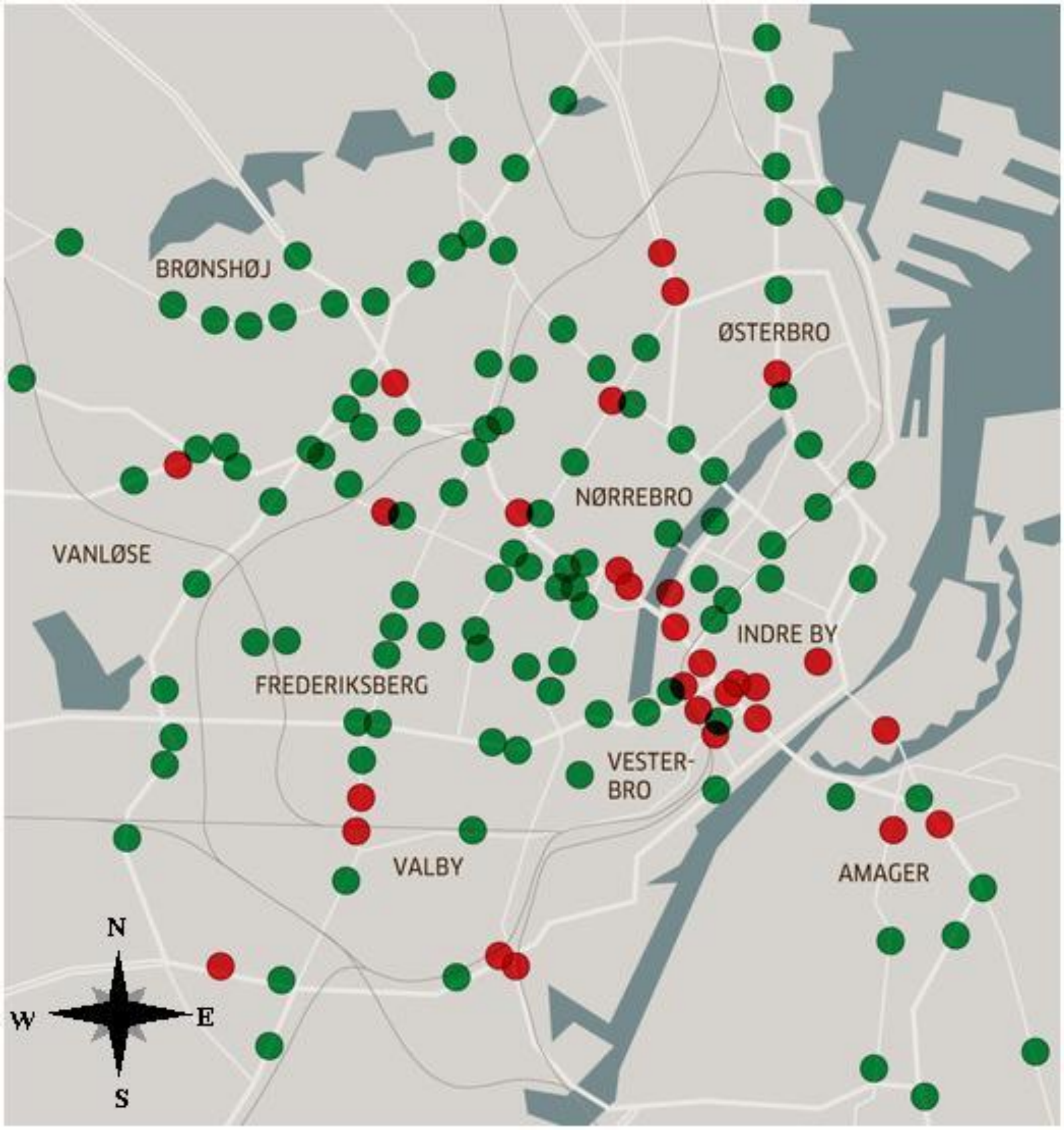


Figure 44: Air Pollution Map of Copenhagen (Nationalt Center for Miljø og Energi, April 12th, 2012)

Figure 45 is a zoomed-in version of the above which shows the AA route.

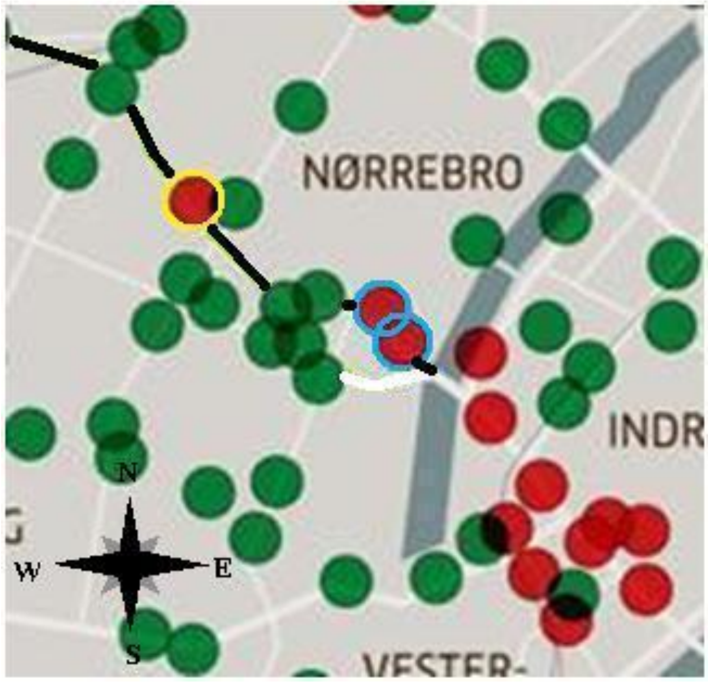


Figure 45: Air Pollution Map of the AA Route (adapted from Figure 44)

The large cluster of red dots in the bottom-right corner corresponds to the areas around town hall square. This area is by far the most affected spot, overshadowing the AA route which is highlighted in black. However, there are some important spots along the AA route which are above the EU limits. The two red dots circled blue correspond to the area where Åboulevard converges with Rantzausgade. Traffic is very congested in this area, causing the high levels of pollution. The red dot circled in yellow corresponds to the area of Åboulevard which is intersected by Jagtvej, a perpendicular street. This intersection is the largest and most trafficked along this route. Opening the Ladegårdsåen would potentially decrease these high levels of pollution along the AA route's surface by diverting the car traffic underground. We learned from Thorkild Green, the Aarhus River architect, that the levels of air particulates around the area where the river was daylighted decreased significantly, providing actual evidence of this benefit. However, the air in the tunnel will have to be cleaned in order to be breathable while underground and to capture the air particulates before reaching the surface. One such tunnel which incorporates a ventilation system that cleans its air is the Lærdal Tunnel in Norway, which is the longest rock tunnel in the world, stretching 24.5 kilometers underground (Road Traffic Technology, 2011). Similar ventilation technology which is used in this tunnel could also be applied to the Ladegårdsåen tunnel in order to reduce the pollution inside of it before it reaches the surface. In doing so, the residents living in the area could benefit from the better air quality.

Finally, because our goal was to create more green space, we needed to show just how scarce the green space was along the AA route. Figure 46 is a map which shows the levels of the different kinds of green space in Copenhagen. The dark green areas represent parks, natural areas, etc. The jade-green areas represent recreational areas, the lime-green areas represent cemeteries, and the orange areas represent allotments which are garden spaces for citizens. The section of the map labeled "Frederiksberg" represents the Municipality of Frederiksberg, which is not associated with Copenhagen. Therefore, its green space levels were not included on this map.

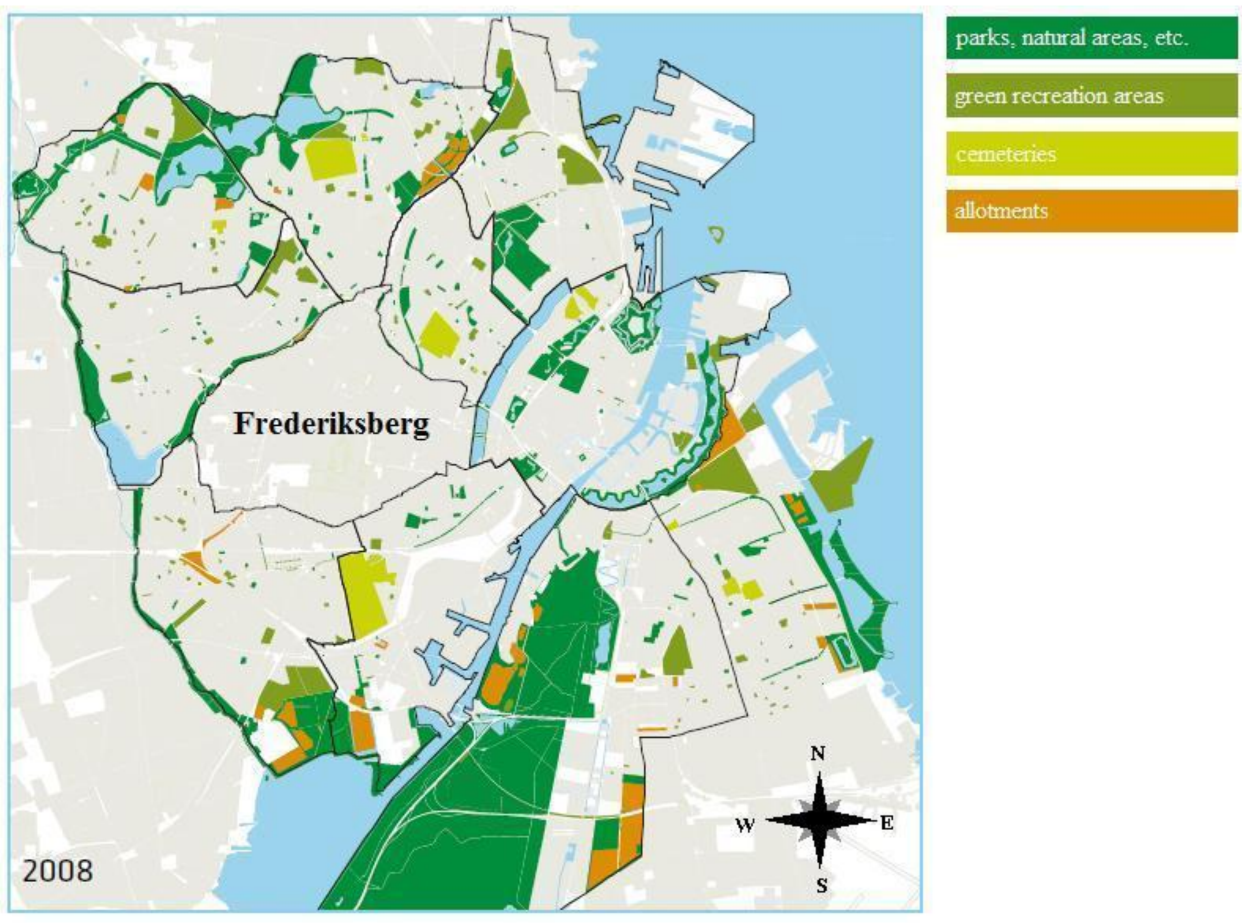


Figure 46: Green Space in Copenhagen (Københavns Kommune, p. 10, 2008)

As illustrated above, there is not a great amount of green space in the entire city. The largest section is the area in the south, located across the harbor. Nørrebro, however, is an area that has a serious lack of public greenery, as seen in Figure 47 below:

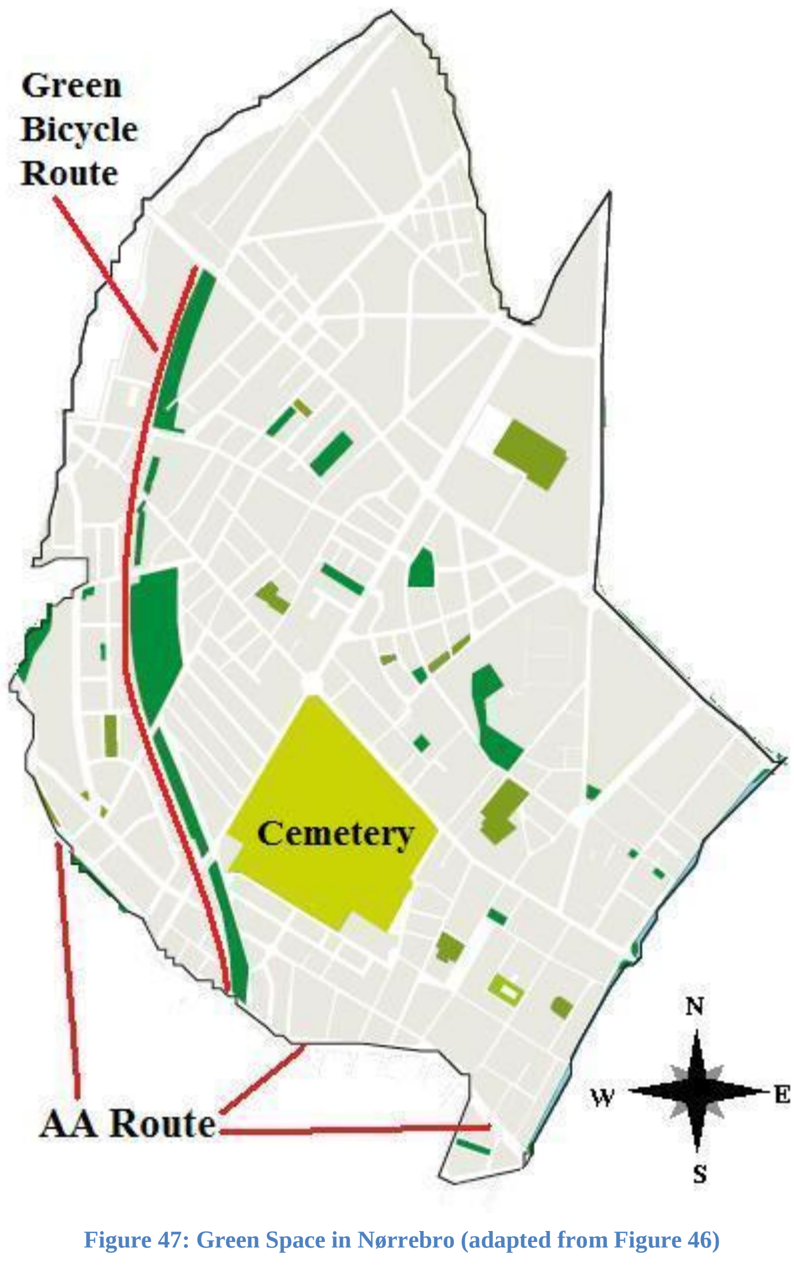


Figure 47: Green Space in Nørrebro (adapted from Figure 46)

The AA route is located along the southern edge of this map. It exists as the border between Nørrebro and Frederiksberg. The largest green area in Nørrebro is a cemetery (illustrated in lime-green), which is very close to the green bicycle route that runs vertically near the left border of Nørrebro. This bicycle route continues very far into Frederiksberg and through an agricultural school. However, these are the only two major green landmarks in Nørrebro. Therefore, an increase in green space created by the Ladegårdsåen would be very beneficial to the community.

Not only did we find that green space is scarce, we discovered that the city already wishes to create more greenery in the form of green corridors, as illustrated by Figure 48:

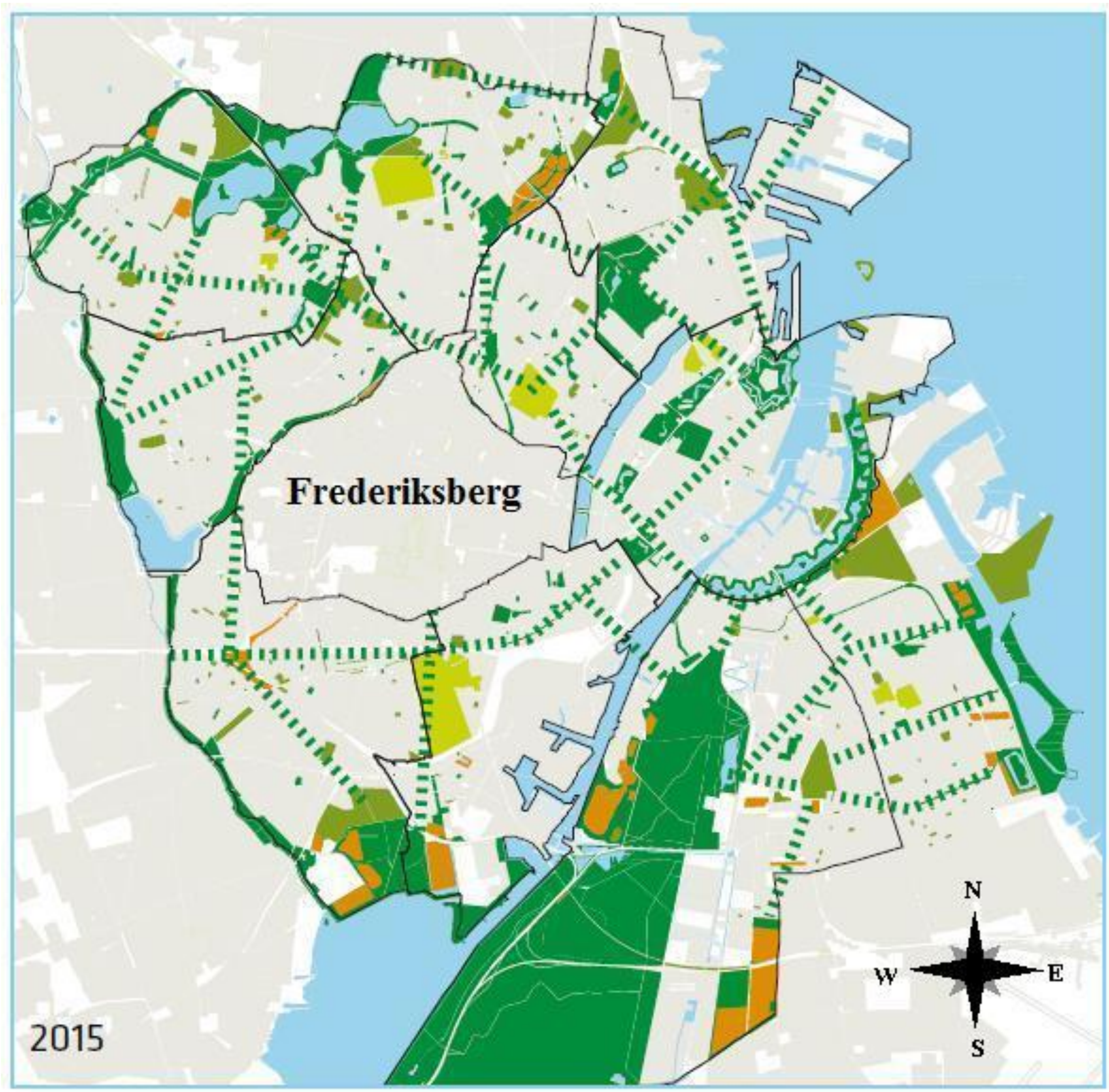


Figure 48: Potential Green Corridors in Copenhagen (Københavns Kommune, p. 11, 2008)

The dashed lines in the map refer to the general direction of each corridor, but the actual paths will have to be changed according to the geographical landscapes. Most of these corridors will be streets with an increase in trees and plants. The city hopes to create these corridors in order to connect green sections together in somewhat of a “criss-cross” pattern. This will allow citizens to travel around the city in such a way as to be connected to greenery at all times. Below is Figure 49, a zoomed-in version of Figure 48, showing Nørrebro.

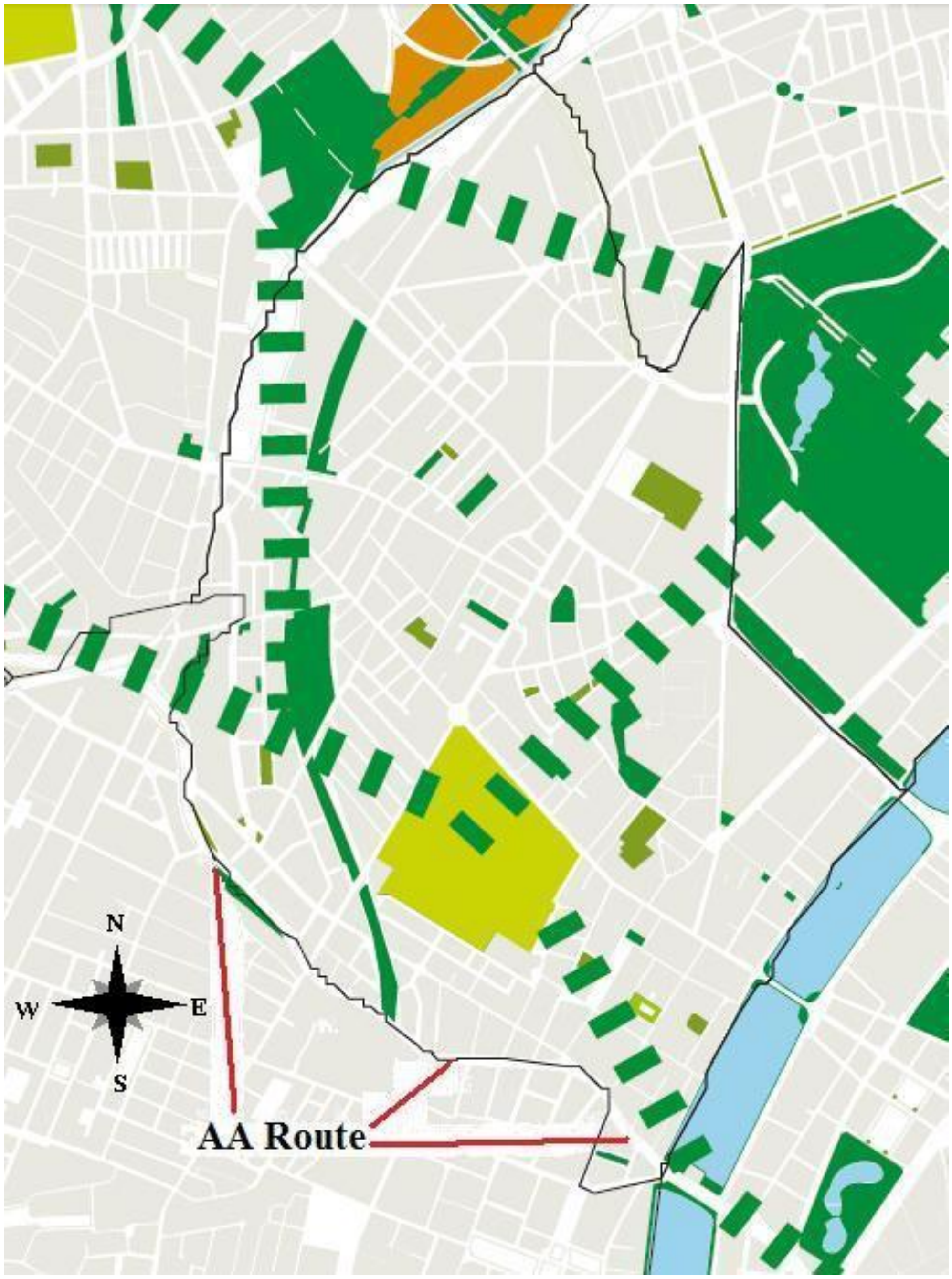


Figure 49: Green Corridors in Nørrebro (adapted from Figure 48)

If the Ladegårdsåen were opened on the AA route, it would connect to the green corridors seen in the bottom right corner and on the left hand side of the above map. It would also connect to the green bicycle route which continues into Frederiksberg and passes through its various green spaces. As previously stated, Frederiksberg is not included on this map, however, the green corridors will also continue throughout it. Therefore, Frederiksberg will play a big part in the daylighting of the Ladegårdsåen because they will also benefit from it.

Although the reduction of the aforementioned issues will provide an environmental and somewhat recreational uplift to the area, we wanted to further consider the potential to uplift the recreation and businesses along the AA route. The Aarhus River is a perfect example of how daylighting a river or canal can bring a recreational and economical uplift to the surrounding area. After consulting with Thorkild Green, an Aarhus Municipality architect, we learned that before the river there was daylighted, its route held a trafficked main road which led automobiles further into the city. The buildings on that street consisted mainly of small businesses but the area was by no means a significant part of the city. In fact, the backs of the buildings were facing the street. However, since the river was opened, the buildings along the route have been transformed into busy cafés, restaurants, bars, shops, etc, creating a vast new place for locals and visitors to socialize as well as new opportunities for business expansion. In a sense, the backs of the buildings have become the fronts. The area of the river experienced a major economic uplift due to these new establishments. Such benefits could be possible on the AA route as well. The area consists mainly of small businesses on the ground floors of each building. The upper floors are used as residential housing. Therefore, the Ladegårdsåen could potentially create more lively businesses and areas for socializing such as those in Aarhus, uplifting the area into an exciting place for people to come relax and spend leisure time.

4.3 Space for Necessary Features

In order to propose a daylighting design that could accomplish all of the necessary goals that Nørrebro and Miljøpunkt Nørrebro hoped to achieve, we had to look at the physical space constraints. The AA route is very wide, but we needed to determine the specific dimensions of the route, including widths, length, and any obstacles we might have to build around. We first needed to determine the widths of the route from building to building at different critical locations. Figure 50 (the northern most part of the route) and Figure 51 (the southern half of the route) display the route with the buildings included. The 7 red lines represent the areas where width measurements were taken. These widths appear in the yellow boxes. The different measurements illustrate the variety of widths along the route, from the narrowest areas of 27 meters and 33 meters to other sections that are over 40 meters. We also measured the current bike path widths, which appear in the green boxes. With these dimensions we evaluated how much space would be needed for each design feature to ensure that there would be room for this project. Our designs would have to focus on and analyze several different areas along the route, because depending on the width, the dimensions and features of the layout will change. Therefore, three different areas were given a number on the maps below (in light blue) and those areas were analyzed further and designs were developed for each.

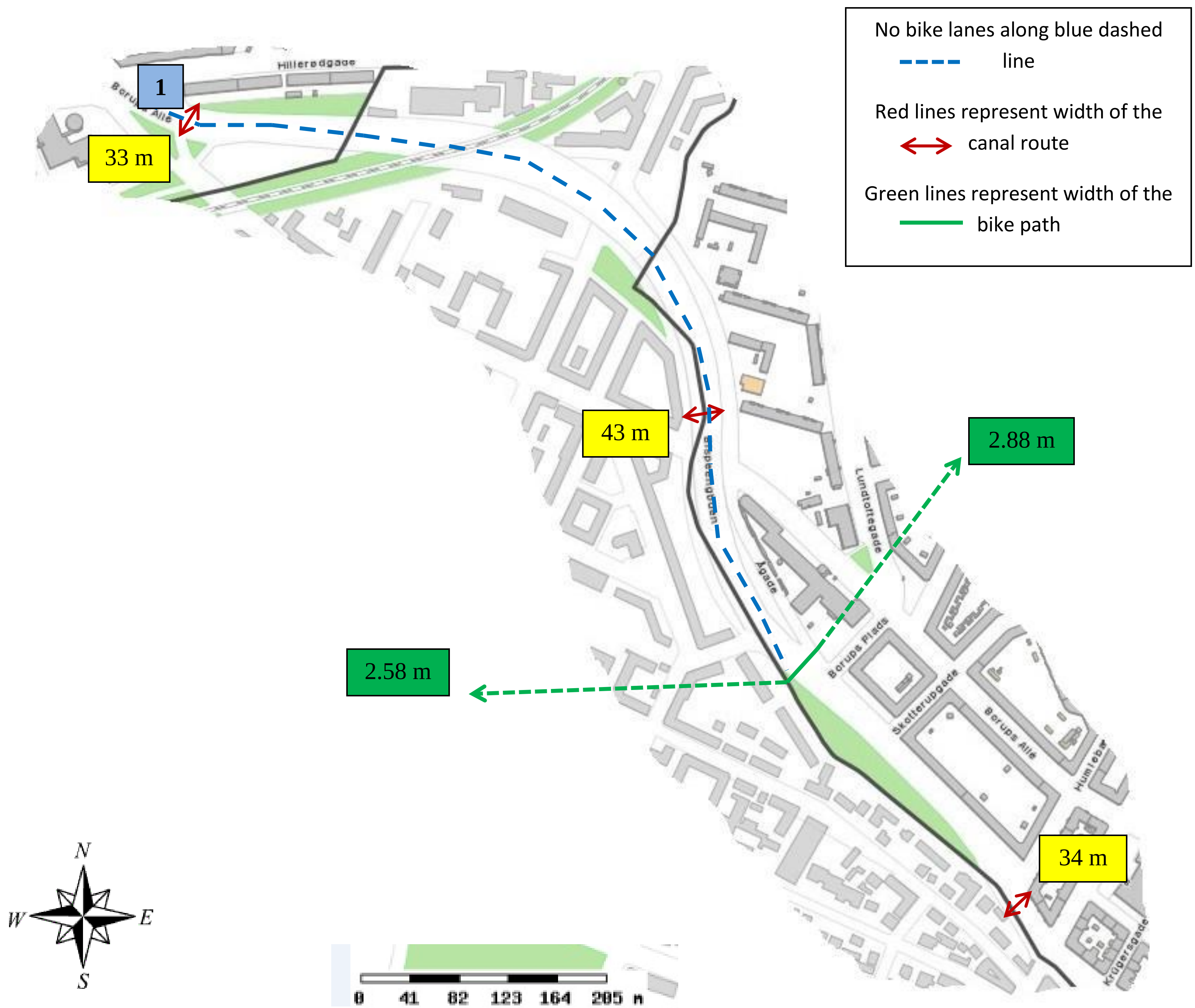


Figure 50: Widths of the Route and Bike Paths in the Northern Section of the AA

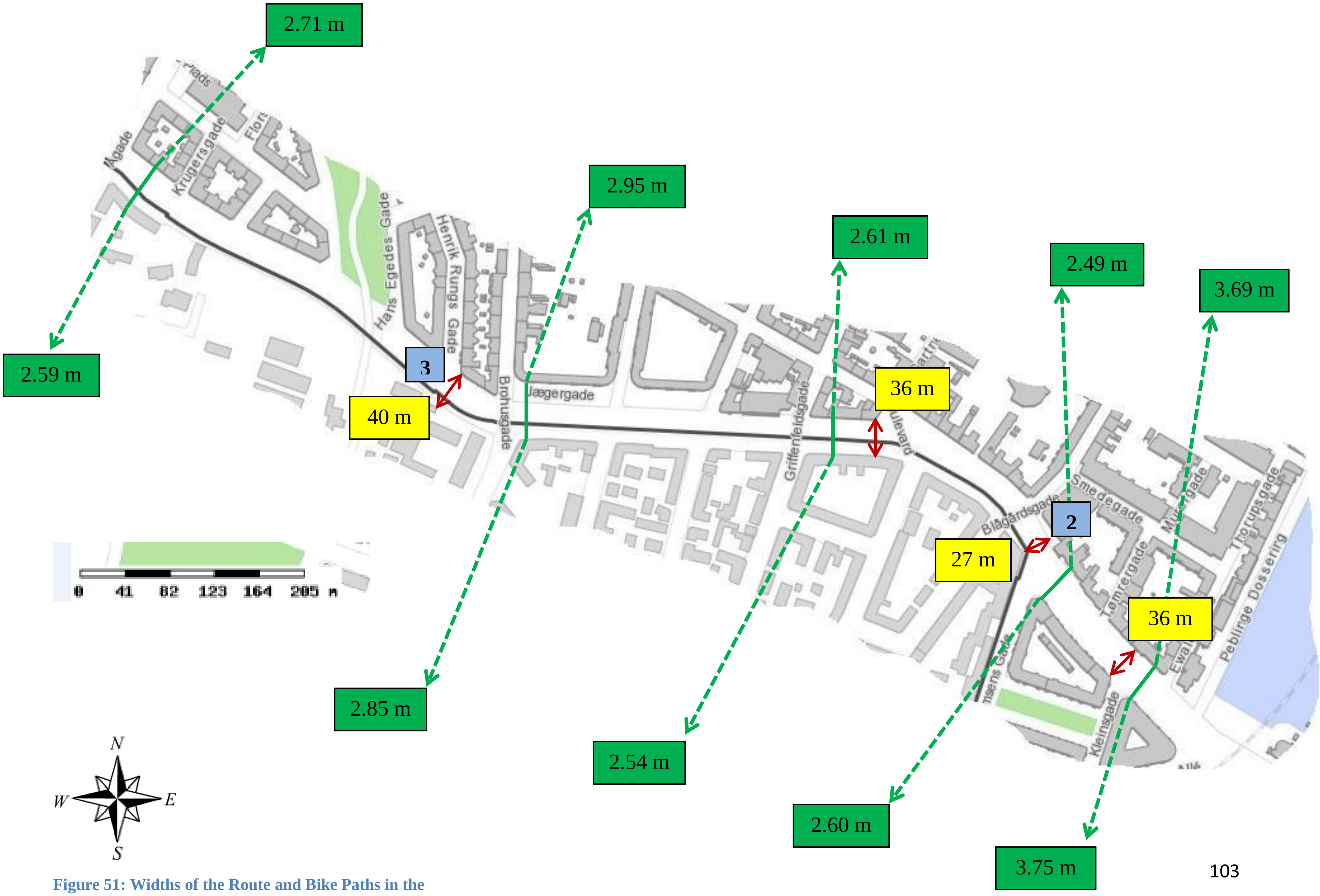


Figure 51: Widths of the Route and Bike Paths in the Southern Section of the AA

A successful outcome for this daylighting project needed to include:

1. Bike paths
2. Storefront area including frontage of at least 2 feet for display and entrances
3. Pedestrian walking and gathering area, which can serve as an emergency vehicle lane if necessary
4. Canal
5. Green Space

The amount of space that each of these features would require had to be determined so that a total could be calculated to see if the different elements could all be incorporated.

4.3.1 Bike Paths

Bike paths were a necessity along the AA route. The route already consisted of paths going in both directions and our designs needed to include them as well. In order to use proper dimensions in our design plans and to double check that this path did have enough space, six different widths were taken of the current bike paths along the AA route for each direction (giving a total of 12 measurements). The measurements were taken at similar locations on opposite sides of the road. The green lines in Figures 50 and 51 depict the areas where the measurements were taken, while the green boxes contain the measurements. Once the route meets Bispeengbuen, the bike routes are diverted to different side routes because the road becomes a high rise expressway. Therefore, in Figure 50 a dotted blue line is used to represent the area where there are no bike paths. Using our measurements, we created Table 16 to determine the average width of the current bike paths along the route, which was 2.85 meters. We are going to make our bike paths 4 meters wide, but these will contain bike traffic going in

Table 16: Bike Path Widths Along the Current AA Route

	Bike Route Widths Along the AA Route at Random Locations
	Bike Route Widths (meters)
	3.75
	3.69
	2.60
	2.49
	2.54
	2.61
	2.85
	2.95
	2.59
	2.71
	2.58
	2.88
Bike Route Width Average (meters)	2.85

both directions. These two-way bike lanes would be needed on each side of the canal, meaning that 8 meters (4m+ 4m) would need to be used for bike paths.

4.3.2 Storefront Area

Storefront space is crucial in order to boost the atmosphere and help with the economic uplift of the area. Through our interview with Thorkild Green, the Municipality of Aarhus' Department Architect, we learned that in Aarhus, 2 meters along the front of stores was reserved for display of merchandise. We will incorporate a similar feature along our storefronts and apartment fronts. 2 meters will also be necessary to provide better privacy for people that live along the route and to keep pedestrian traffic a small distance away from buildings for proper egress (you cannot block entrances and exits). This design feature will take up a total of 4 meters (2 meters on each side) of space along the route.

4.3.3 Pedestrian Walking and Gathering Area

The pedestrian area will mainly be located between the 2 meter storefront area described above in number 4.3.2 and the bike lanes. Its size will vary, because the AA route width changes. This design aspect is necessary because in highly populated areas, a pedestrian walkway is a practical feature. The pedestrian walkway will be made fairly wide to help attract more people and with the hopes that the overall project will draw more people to the area. The Frederiksberg side of the route (the South side) will have a smaller pedestrian area. The

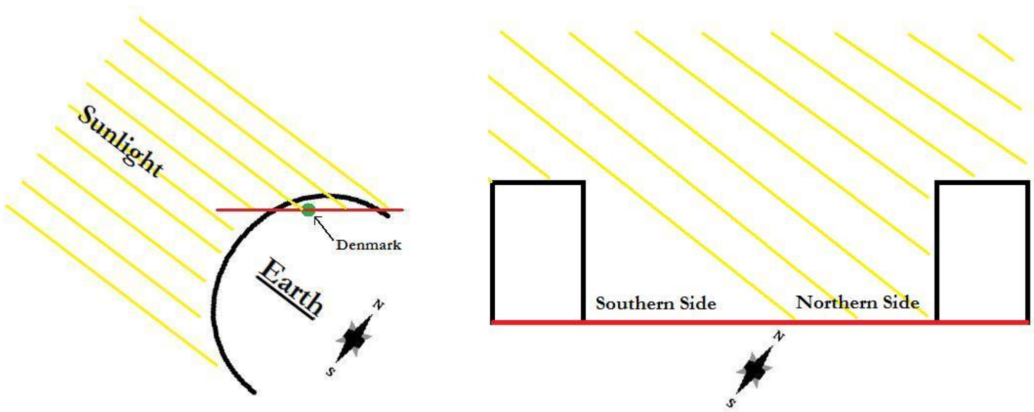


Figure 52: Description of the where the Sunlight Hits the AA Route

reasoning for this is depicted in Figure 52. Denmark, being situated in the Northern hemisphere, has the sun hit it at an angle that causes the Northern side to receive more sunlight during the day (Green 2012). Therefore, the North side will have a larger pedestrian area which will create a more appealing design. This idea of basing designs on sunlight was introduced to us by Green (2012). He explained how the Aarhus River daylighting followed this plan and was very successful. Figure 53 illustrates the much wider North side of the daylighted Aarhus River.

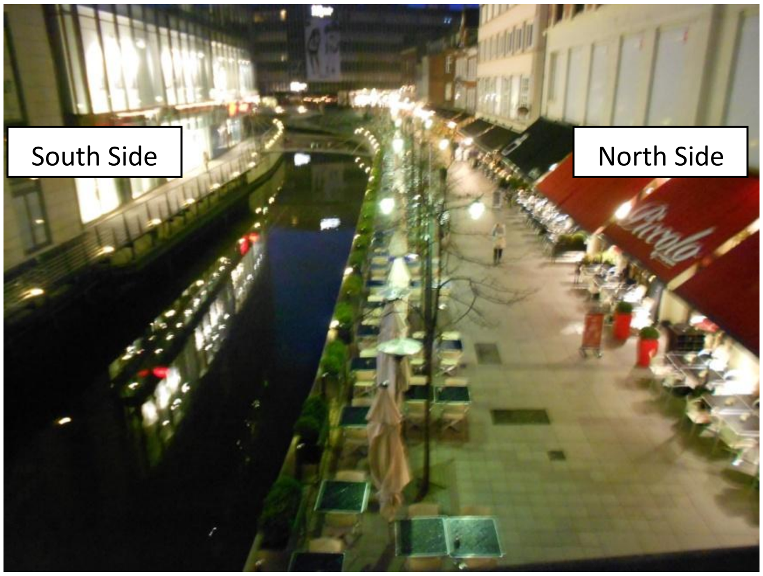


Figure 53: Aarhus North Side Walkway vs. South Side Walkway

These pedestrian areas will serve as more than just walkways; they will serve as a path that can be used by emergency vehicles to reach areas along the canal. In Aarhus, Green explained how the North side was made large enough for emergency vehicles, but fire trucks had to make sure their ladders could reach the tops of the buildings on the South side for this project to be acceptable (2012). For our design, we want to make sure that there is enough room on either side of the canal for emergency vehicles. We determined 4 meters to be the necessary width needed for emergency vehicles and based our pedestrian widths on that. According to the Copenhagen Fire Department, Prevention Department (April 20, 2012), any design that closes down a main traffic passage requires alternative rescue vehicle corridor solutions be implemented. Any major changes that occur in the city wide rescue plan, however, must be assessed by all parties involved, including fire, police, etc. Several parameters are fixed and must be incorporated into all designs; the Copenhagen Fire Department stated that their vehicles are 2.8 meters wide and need 4 meters of space to deploy their ladders (2012). Therefore, for the

South side we will use a pedestrian width of at least 4 meters, but emergency vehicles will be able to drive on both the walkway and the bike path if that is ever necessary. The South side will have a pedestrian area that is at least 5 meters wide, which will be able to fit emergency vehicles if necessary and be larger than the South side. A total of 9 meters will be the minimum requirement for pedestrian area space along the route. This design feature will be able to increase in size at larger areas along the route. There are no set standards for how large these walkways can be, they will be able to fluctuate as the width of the route expands.

4.3.4 Canal

If the tunnel were used as a reservoir during flooding, the canal could simply release the water there as necessary and would, itself, no longer need to handle extreme amounts of rain (described in more detail later on). However, a natural feeling of water flowing would be best. Our dimensions for a canal were based on the work done in the previous Orbicon study. They stated that a canal with a cross section of 1.5 m^2 would need to be provided with 100-200 liters per second of water to create a stream that has enough flow to be appealing (2007). This was a realistic amount of water to be supplied into the canal based on information we had gathered (the sources of water will be discussed further in the design section), therefore, we created a canal channel that was 2 meters wide and 0.75 meters deep to give a total cross sectional area of 1.5 m^2. In order to create a nice atmosphere and allow the canal to still handle larger amounts of water before the tunnel had to be used as a reservoir, we used the double profile design shown in Figure 54. This gave us a total canal dimension of 5 meters, including the steps. These dimensions can fluctuate along the AA route as the width of the route expands. 5 meters will be used for the narrowest areas. When the waterway channel does expand, we will mainly keep the 1.5 m^2 area and simply adjust the depth and width. The design aspects will be described in further detail later in section 4.5.1 of this chapter.

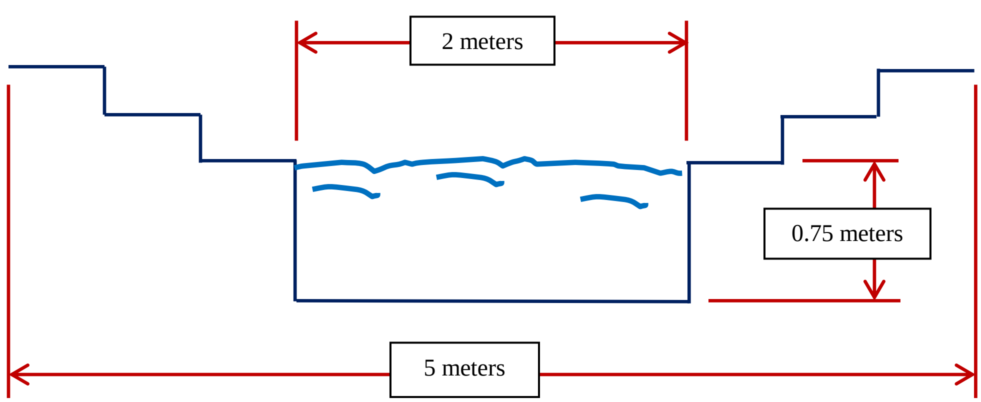


Figure 54: Canal Dimensions

4.3.5 Green Space

Green space is the last feature that needed to fit within the route widths we had determined. The amount of space that would be reserved for green space was based on the amount of space that remained after the first four design aspects had been incorporated. The smallest width along the route was about 33 meters (except for one exception that is described below). Therefore:

2 bike lanes + 2 storefront areas + 2 pedestrian areas + canal + green space = 33 meters

8 m + 4 m + 9 m + 5 m + green space = 33 meters

Green space = 7 m

The maximum amount of space that can be used for green space is 7 meters in these narrower areas, but even more can be used in the wider areas. Similar to the pedestrian areas, this space can increase as the width of the route increases. Figure 55 depicts a simple layout of the route at location #1 (from Figure 50) to show how all 5 design features can fit in a 33 meter wide section of the route.

The areas where the AA route expands will provide much more space to be creative with the design plans. Figure 56 depicts how much space will be allocated for each design feature in an area with a larger width, such as location #3 from Figure 51 (40 meters). The pedestrian walkways can be expanded by a meter each, while the green space area becomes much larger. The canal dimensions will change based on different designs which will be described later.

2 bike lanes + 2 storefront areas + 2 pedestrian areas + canal + green space = 40 meters

8 m + 4 m + 12 m + 5 m + 11 m = 40 meters

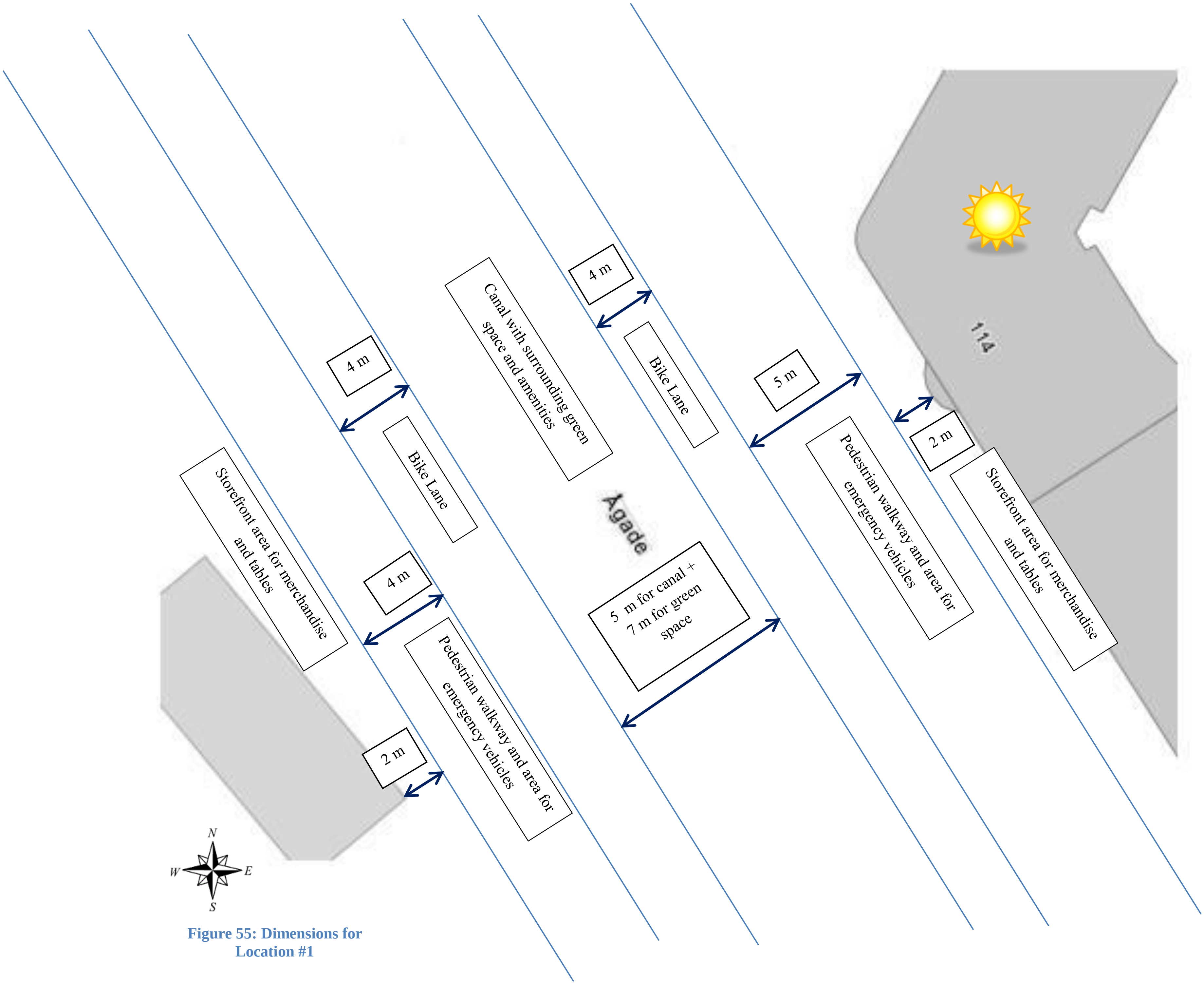


Figure 55: Dimensions for Location #1

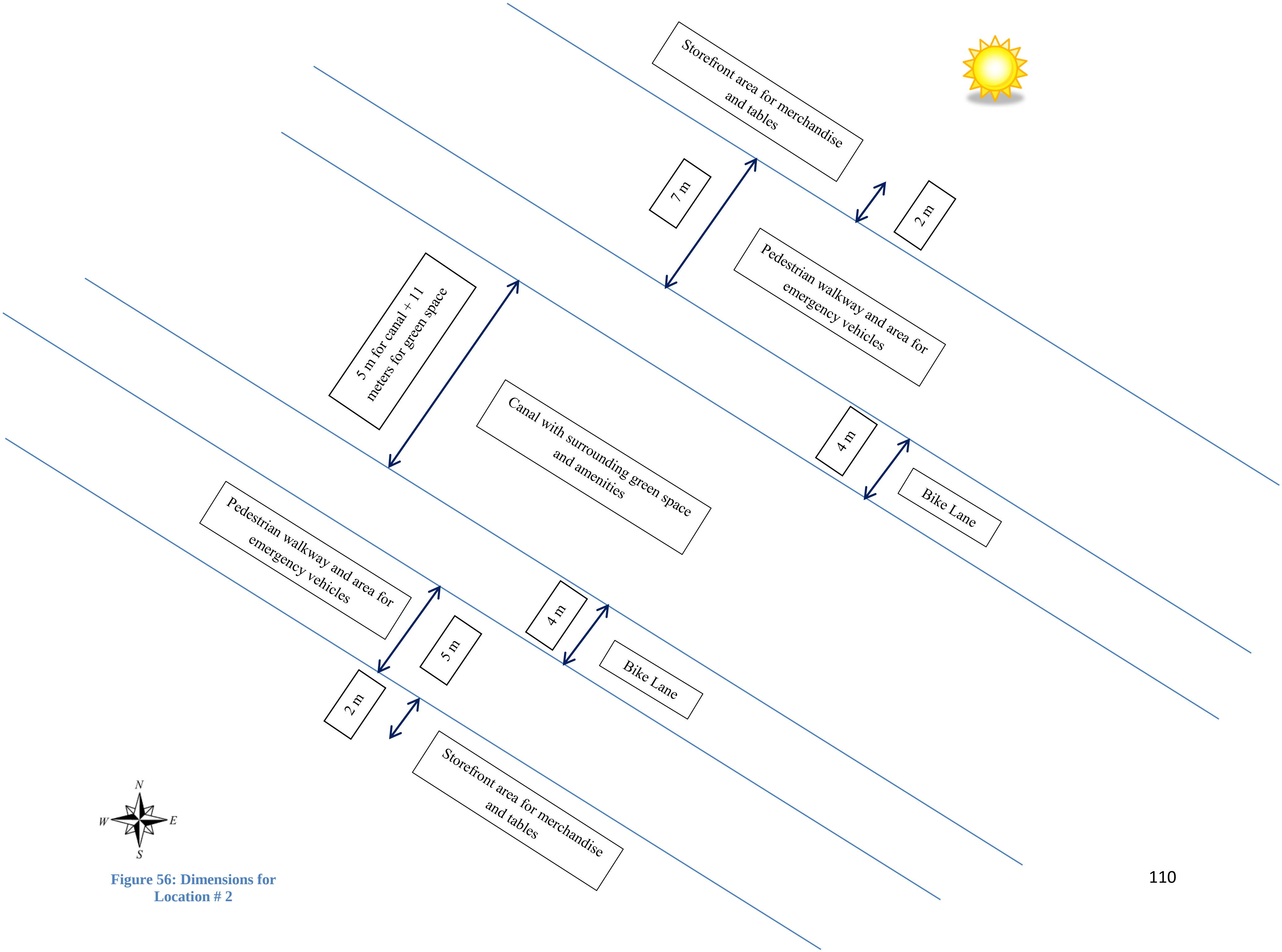


Figure 56: Dimensions for Location # 2

4.3.6 Important Rantzausgade Connection

Because locals driving on Rantzausgade will need a way to continue to the Lakes once the street meets Åboulevard, we decided that it would be necessary to construct a bridge that crosses over the canal from the end of Rantzausgade to the South side of the AA route. It would be a two-lane bridge made simply for automobiles (no pedestrians). A new two lane road will then proceed along the Southside of the route and across the Lakes. Figure 57 depicts the path of the road with a blue line, while the red line depicts where the bridge will be located. This is necessary because this road is and will be used by many locals, and with the closure of traffic along the Åboulevard, they still need a simple way to get across the Lakes, rather than having to cross a bridge over the canal and go around to the Southside of the AA route. This option will keep the sunny side of the route open and help minimize the amount of disruption this project will cause local automobile users.

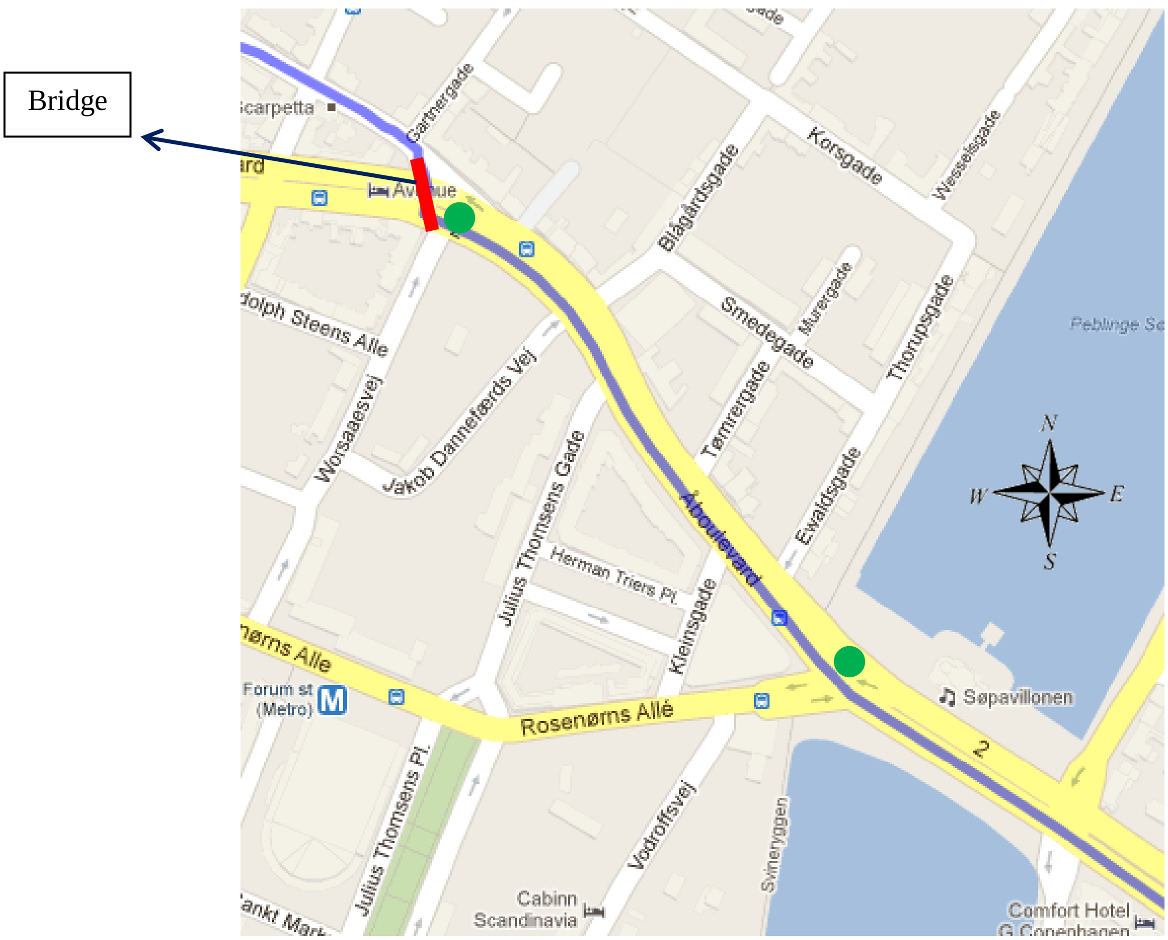


Figure 57: Road from Rantzausgade

The canal route through this section (the area between the green dots), therefore, would have to include a two-lane road, meaning that the design features and dimensions had to be modified for this area. The smallest width along the AA route at location #2 along this section measures 27 meters (as shown in Figure 51). As a result, we created our designs for this plan to fit within a 27 meter width and to include the two-lane road. A rough design is shown in Figure 58. The bike lanes need to remain the same size, taking up a total of 8 meters. The 2 meters in front of the buildings used for privacy and storefront would have to be altered for the brief section between the buildings, and they would have to be used mainly for pedestrian travel instead. This small one meter sidewalk/storefront area would only be used for the area (several meters long) where the buildings jut out toward the canal. Therefore, sidewalk space took up a total of 2 meters. By measuring the car lanes at two different locations along the current AA route, we determined that 4.5 meters would be an acceptable lane width, meaning the two-lane road would take up another 9 meters. Emergency vehicles would be able to use the road for the South side of the canal, and when needing to reach the North side of this constricted section, a mixture of the bike path and sidewalk/storefront area could be used. The canal design would have to remain the same and take up 5 meters, leaving 3 meters for green space. Even in the narrowest location, there is enough room for the canal, green space, bike paths, walkways, and even a two-lane road. This one pivotal location is the only area that will be so tight for space. On either side of this narrow spot, where two buildings jut out toward the road, there is much more space available. Pedestrian walkways could be constructed on either side of this location.

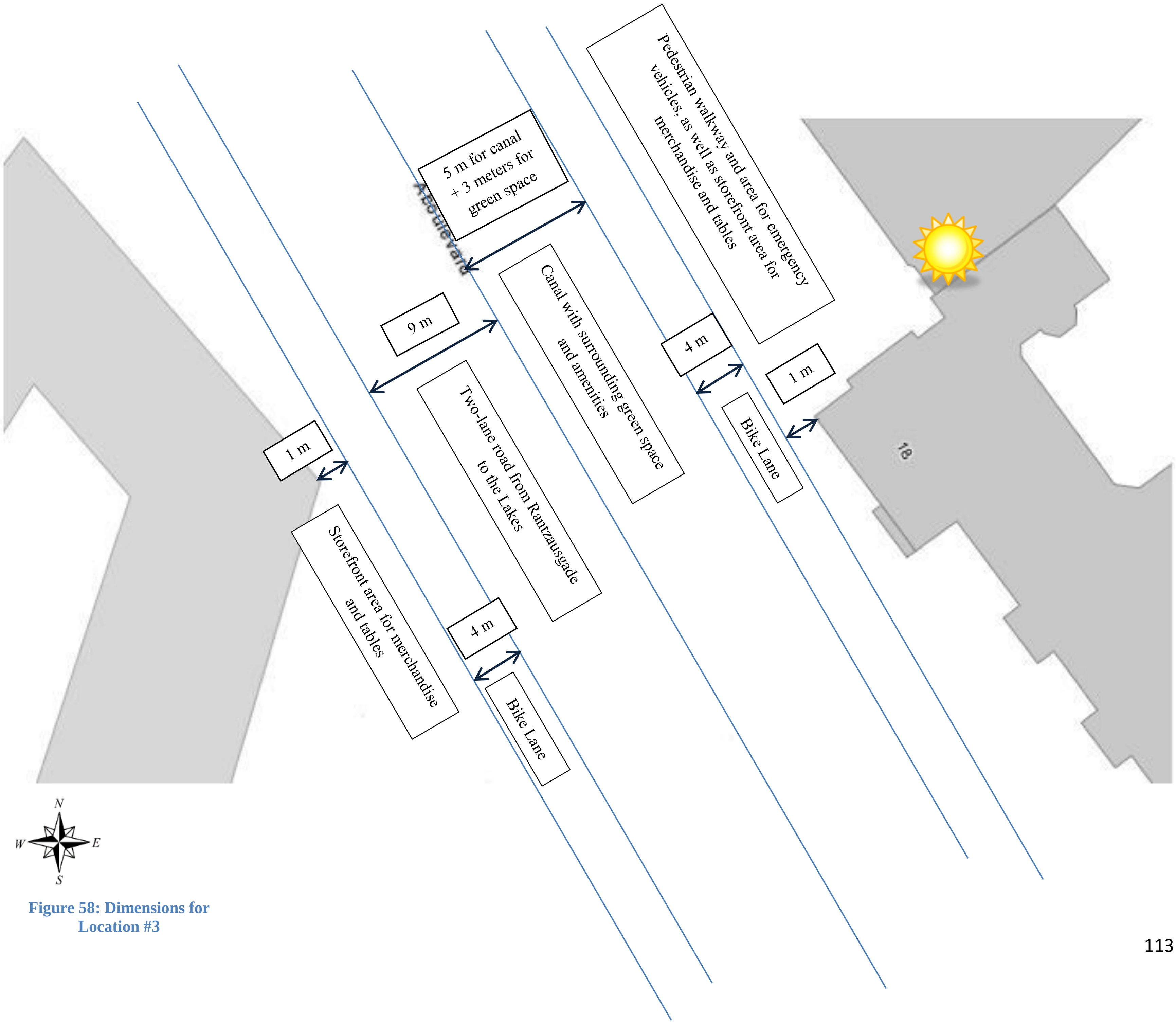


Figure 58: Dimensions for Location #3

4.4 Water Design

In order to incorporate all of these designs, it was very important to make sure there would be enough water to feed the canal year round and to determine where the water would travel to once it reached the end of the canal. We knew that the piped Ladegårdsåen often had very little to no water flowing through it (a steady flow of water is not present in the current piped canal) and that keeping the canal full of water would be a crucial issue to look into. We did not deal with a specific system of piping, drains, and pumps; rather, we suggested possible water sources for the canal and possible uses for floodwater that is stored in the tunnel. It is safe to say that, most of the time, the issue will be making sure the canal has enough water to keep a continuous and appealing flow.

4.4.1 Sources of Water

The canal water will be supplied from several different sources:

1. Current source, which is two lake systems: Emdrup Sø and Damhussøen
2. LAR (Lokal afledning af regnvand) Local Diversion of Rainwater
    a. Rainwater from storm drains
    b. Rainwater collected from rooftops
3. Foundation drains

The most obvious source of water is that which is currently feeding the canal, the two lake systems, Emdrup Sø and Damhussøen. According to Gabriel (2012) and Werner of the Municipality: Water and Parks Division (2012), it can be estimated that from these artificial sources we will be able to supply about 30-125 liters per second of water to the canal, unlike the small amount it receives now. This is a large range, but the amount of water from this source that can be used for the Ladegårdsåen greatly depends on how much water can be reserved for or taken away from the other systems that rely on this source as well. A detailed study on the different water systems should be done to better understand where the water is going from these lakes and how much water each system needs, and therfore, gain a better understanding of the amount of water that can be set aside for the Ladegårdsåen.

LAR (Lokal afledning af regnvand) is the term used for Local Diversion of Rainwater. The goal of the City of Copenhagen is that 30 percent of rainwater should be locally diverted, which will greatly relieve the sewers (Center for Park og Natur, 2012). Local rainwater has the potential to be a significant source of water supplying the Ladegårdsåen. By collecting rainwater and water from rooftops and drains before it can enter the sewers, we can take a large pressure off the sewer system, while also supplying water to the canal. The sewers need to be relieved because, according to Gabriel of Orbicon (2012), 30 percent of the water currently in the them is from an unknown source, most-likely rainwater from drains, and is fairly clean (not sewer water). This water is filling up the already full sewers, which need to be alleviated because expanding the sewer system would be too costly and unpractical.

LAR is a source that has great potential to provide the canal with a large amount of water, while also helping the city make its sewer system more efficient. However, Ove Larsen, an expert on LAR solutions, explained that legal and bureaucratic constraints make it all but impossible to transport water from one property to another, making the transport of rainwater from different areas of the city to the canal impractical at the moment. These constraints will likely be removed, though, due to the political push for dealing with the effects of climate change and an increased awareness of local solutions. This would allow larger LAR solutions the opportunity to be implemented and used. There are two major ways that rainwater can be collected to help meet the 30 percent goal.

One way is storm drains, which can lead rainwater to the rain gardens along the sides of the canals. Storm drains can catch surface runoff along roads and throughout neighborhoods. Werner explained that the water from the roads and around peoples' homes that is collected in the drains is more polluted than that from the rooftops. Therefore, the rain gardens, described below in section 4.5.3, will be used to filter this water before it enters the canal.

The other major source of water will be rainwater collected from roofs. 20 to 30 percent of Copenhagen's area consists of roofs, according to Werner (2012). Water from the roofs has the ability to be moved very far to reach the canal if the pipe design plans that are developed are strategic and efficient (Werner, personal communication, 2012). Using pipes, Werner explained that water from the tops of large 4 to 6 story buildings can be delivered down to the canal by gravity. Orbicon's study (2007) also suggested this idea of collecting rainwater from rooftops, estimating that 1 hectare (10,000 m^2) of roof area would easily contribute 100-150 liters per second of rainwater during heavy rains. The area directly around the route contains a large area of roofs which would make this a great source of water. Werner stated that rainwater could also be collected in storage tanks on the roofs to be used to feed the canal in times of drought in order to keep the canal flowing. Water collected from the roofs is acceptable to use and fairly clean

(Werner, personal communication, 2012). Both of these sources of rainwater show that once LAR solutions become a possible solution, there would be a large amount of rainwater that could be collected from the neighboring area to help supply the canal.

Foundation drains are yet another source. These drains, located around the foundations of buildings and homes, can collect water to be sent to the canal from the surrounding neighborhoods. Some of this water is rainwater, as described previously, but some is groundwater. This third source of water would have to be looked into in greater detail, because pumps and other designs would have to be implemented to collect and transport water to the canal from all of the foundation drains. However, all of these options show that there are many possible solutions to the canal's lack of water.

If the previously described sources can't supply enough water to the canal, it is important that other options are available to keep water flowing at all times. Therefore, we determined that a pump would have to be implemented to transfer water from the end of the open canal back to the start during times when the water level is low. The underground tunnel, which will be described later, will have a pipe that can be used to send the water back to the start of the canal. This reusing of water will allow the canal to maintain a constant amount and flow of water, even during dry periods.

4.4.2 Water Uses

During rainy periods, when large amounts of water are flowing through the canal or being collected in the tunnel reservoirs and supplying the canal with water is not an issue, rather than piping all the water to the harbor, which is not always feasible as described later on, much of the water can be used for other purposes. As new construction and renovations are being done or pipes replaced, this system could begin to be implemented; however, a technical analysis would have to be done to determine how to pipe this water to areas throughout the city. These ideas would take time to be achieved and would be a gradual process. The water in the canal will not be as clean as drinking water, but it will be clean enough to be used for certain things, such as:

- Toilet flushing
- Industries
- Watering local parks
- Supplying the inner Lakes when clean enough

- Fire prevention
- Water for heating homes
- Carwashes
- Washing in hospitals

(City of Copenhagen, 2011)

Throughout the year, the canal will also have to supply the Lakes with water, when it is clean enough, to make sure they remain at the proper levels (during heavy rain periods, the Lakes will receive a large amount of water from rain and surface runoff and may not need any water from the canal). During heavy rains, large amounts of water will be able to be taken from the end of the canal and the tunnel reservoirs and used, rather, than simply getting rid of it into the harbor. Other uses, such as toilet flushing and putting out fires don't need water that is extremely clean. This idea could save money and illustrate the benefits of using semi-clean water. According to the City of Copenhagen (2011), this water can be called sekunda water (non-potable water), referring to water that is not subject to the stricter control measurements necessary for drinking water. This sustainable solution would help save large amounts of clean water for the city and help to create a water system separate from the sewers and other biological systems (such as the Lakes). Figure 59 depicts the complete water cycle for the Ladegårdsåen canal, including where the water will be supplied from and the different sources it will be used for.

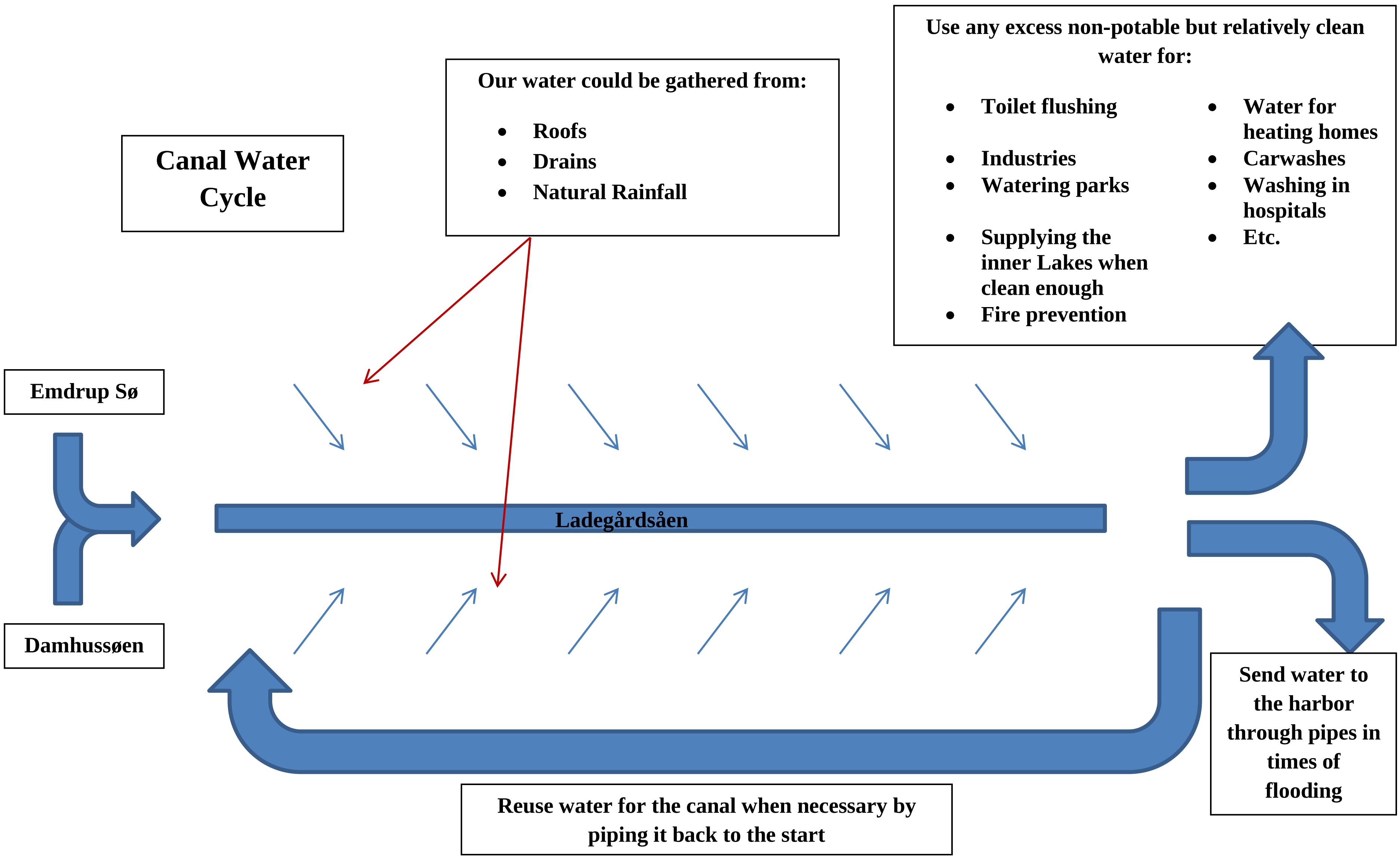


Figure 59: Water Sources and Possible Uses for the Canal

4.5 Design Concepts

Elements for our design features were influenced by the previous proposal by Orbicon (2007) in which Miljøpunkt Nørrebro performed a study on public opinion. Miljøpunkt showcased the different design opinions and plans to re-open the Ladegårdsåen canal in order to gain support for the project and to obtain creative feedback and critiques from the public. People who showed a more serious interest in the project were given a questionnaire. The questionnaires were given to men and women of a variety of ages, some of whom had children and some who did not. Eighty-two questionnaires were completed and returned. The idea to reopen the canal was overwhelmingly positive. However, it was unclear at which sections or areas where the canal should be opened.

- 94% → the canal should be open all the way to the lakes
- 88% → wanted green space to be incorporated with the canal
- 87% → wanted to experience the waterway as a pedestrian or a cyclist
- 71% → the canal should provide areas where people can sit and relax
- 59% → the canal should be used for recreational activities

In respect to the urban ecology aspect:

- 56% → rainwater should be recycled
- 74% → the canal should provide space for shops and pedestrians
- 74% → strong concern regarding cleanliness of the water and the surrounding area if the canal should be opened.

From these statistics, we made sure to incorporate a great amount of green space, large areas for pedestrian walkways near shops, areas where people can closely view the canal very relaxed, a system to help improve water quality in the canal, and bicycle paths. Lastly, our overall design plan will potentially not have a large effect on traffic due to the tunnel placed undergrounds. We incorporated all of these aspects into the goal of reducing flooding.

4.5.1 Water Channel Design

In order formulate a proper daylighting concept, we had to come up with a practical waterway design that could:

- Fit within the route itself
- Handle large amounts of water during extreme rain water events

- Be aesthetically appealing even when small amounts of water are running through it
- Adjust to different amounts of water
- Control the flow of water (not let it get too fast or too slow)

Many of the case study channel's we looked at prior to our arrival in Copenhagen didn't have a strong focus on flooding and were, therefore, not as prevalent in our design plans. Through our interviews on-site, we came up with three main designs that we needed to choose between, making flooding a main priority in our selection. We first considered the double profile design (Figure 60), similar to that suggested by Gabriel of Orbicon (2012) and incorporating several features inspired from the Aarhus River daylighting.

Figure 60: Double Profile Design

For the next design option, we considered adapting versions from a simpler design suggested by Werner of the Municipality (2012), which we called Werner's Water Channel Design (Figure 61).

Figure 61: Werner's Water Channel Design

The third and final design option (Figure 62) that we consider was a simple rectangle. This was the design for the water channel in Aarhus (in certain locations the rectangle had step designs around it, but it was mainly only a rectangle). Most of the case studies we looked at prior to arriving in Denmark were square and similar to Aarhus's water channel design.

Figure 62: Aarhus Water Channel Design

Each design had positive aspects, but some of the negative aspects outweighed them. Table 17 below displays the different features of each design.

Table 17: Water Channel Design Selection

Selecting a Water Channel Design			
Criteria	**Design Type**		
	Double Profile	**Werner's Design**	**Rectangle**
Capacity	Can handle large amounts of water during extreme rains and during normal rain periods the water can flow through the bottom rectangle	Can handle large amounts of water during extreme rains and during normal rain periods the water can flow through the small side channel	Can handle large amounts of water during extreme rains and during normal rain periods the water level will be very low and not very appealing
Recreational Uses	In periods of normal rain, the steps along the sides of the water channel can be used for people to sit on and enjoy	In periods of normal rain, while water is only flowing through the side channel, the rest of the design can be used as a bike path	In periods of normal rain, nothing will change because the water will still be flowing a the bottom of the rectangular channel
Main Use	Recreational and aesthetic value	Practical and technical (simply get the job done)	Practical use to get the water out and keep a similar design from the original canal
Negatives	This design is very wide, requiring more space	Doesn't add any aesthetic or recreational value to our project	Doesn't add any aesthetic or recreational value to our project

We chose the double profile design because it fit with our project goals better than the other two designs. The fact that it could handle large amounts of water when needed, yet still be appealing and give the feel of a flowing stream in times of normal rain was the main feature of this design that led us to selecting it. As explained earlier, this shape allowed the water to flow through the bottom rectangle most of the time, but during heavy rains the water could continue to rise and fill up each of the different steps until it reached the top step. This design could also be easily altered along the route to add in new design features by making the steps wider or adding more of them, for example. The steps would be perfect for attracting people who wanted to sit alongside the canal and it would be a great spot to add benches that could be bolted down so that even during the rare flooding times they wouldn't be moved. The one major negative was the fact that this design requires a large amount of space. The AA route, however, is large enough to encompass this design, as previously illustrated.

The dimensions for this canal had to be based on the amount of water that the canal would have flowing through it. Most of the time, when heavy rains aren't occurring, the amount of water in the canal will be controlled, because water stored in the roofs and water being reused by the canal can keep it at a set flow rate. Therefore, we came up with the amount of water that we would have flowing through the canal using the Oribcon proposal. In Section 4.3.2 of the proposal, it stated that a river with a cross section of 1.5 m^2 must be provided with 100 to 200 liters per second of water to create the feeling of flowing water (2007). We want to be at the high end, keeping a steady flow of at least 200 liters per second. In order to meet these requirements, we designed our canal with the dimensions shown in Figure 63.

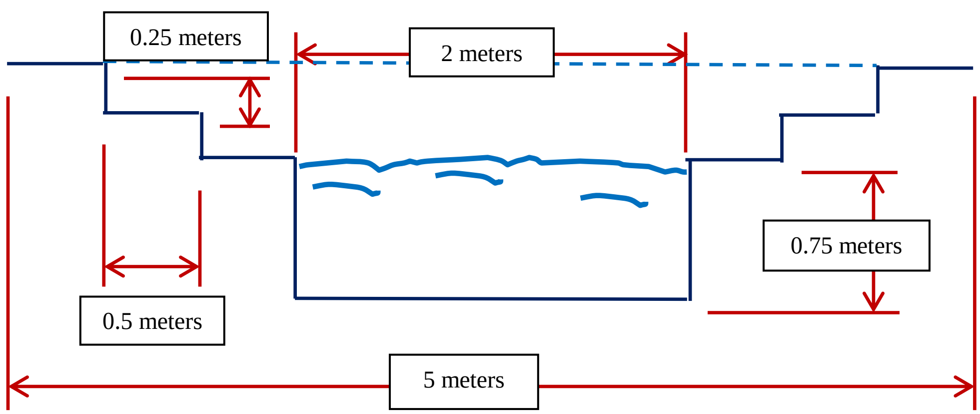


Figure 63: Water Channel Selected Dimensions

Each step is 0.5 meters wide and the risers are 0.25 meters high. You can determine the speed that the water is flowing using the equation:

Flow (L/s) = Area (m^2) x Velocity (m/s)   (University of Wisconsin, 2006)

1 Liter = 0.001 $meter^3$

200 L/s = 0.2 m^3/s = 1.5 m^2 x Velocity (m/s)

Velocity = 0.3 m/s

Assuming the velocity remains the same as the canal fills up to the dotted line shown in Figure 63.

Total area = 4.75 m^2

Maximum Flow = (4.75 m^2) x (0.3 m/s) = 1.425 m^3/s x 1000 L/1 m^3

Maximum Flow = 1425 L/s

These results are illustrating values for the canal at the narrowest points along the route. We will keep the area of bottom rectangle the same size (1.5 m^2). The overall depth of the entire design will remain the same as well. The width of the design (such as the width of the steps), will be able to increase through wider sections of the route (Figure 64). If the water channel width is increased, then the depth of the channel will be decreased to keep the 1.5 m^2 area. If the depth of the channel is decreased, the risers for the steps can be increased to keep the same overall depth of 1.25 meters. By keeping the overall depth the same for each design, the slope will remain fairly constant throughout the entire route.

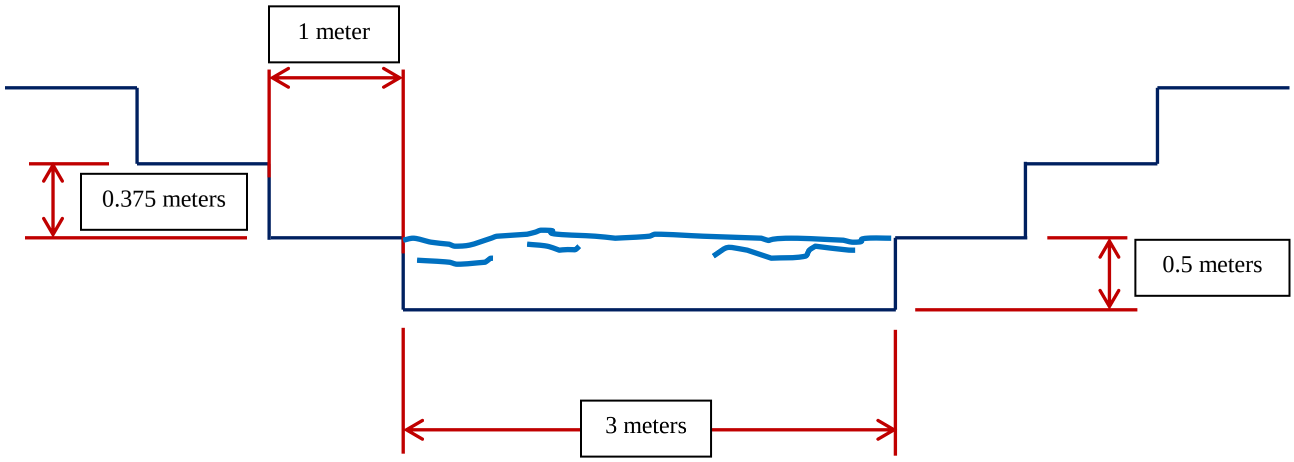


Figure 64: Water Channel Design Dimensions for Wider Sections of the AA Route

The double profile water channel will be constructed out of concrete, similar to the Aarhus River. In order to add green, however, the steps will have grass on them in certain locations throughout the route. This will require that dirt be placed on the steps; Figure 65 illustrates how this would be done using a small lip to hold the soil and grass on the step. Extreme rains may wash away parts of this, but these types of rain are rare. The grass would be easy to maintain and add a large amount of greenery.

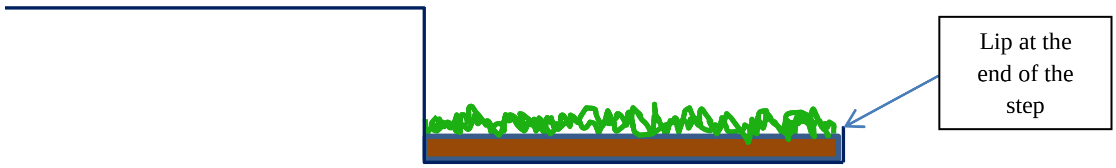


Figure 65: Adding Green Space to Waterway Steps

Having the grass on the steps in one type of design that will be used along the route, but in order to add variety, the designs can vary at different locations. The Aarhus River daylighting gave some very good ideas of designs we could use along the sides of the canal and are shown below. These designs can be replicated to fit the depth and width dimensions of our route to be used. They show that the steps not only can change dimension, but can also change shape. Green stated that the steps shown in Figure 66 are very popular and fill with people during times of good weather.

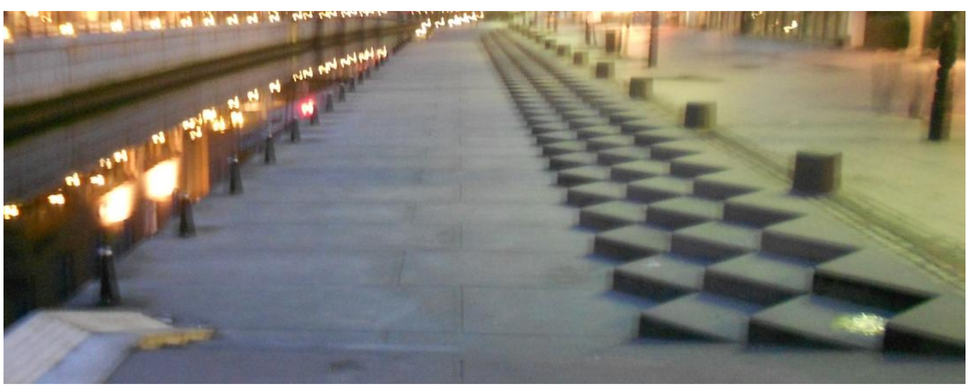


Figure 66: Step Designs Along Aarhus River I

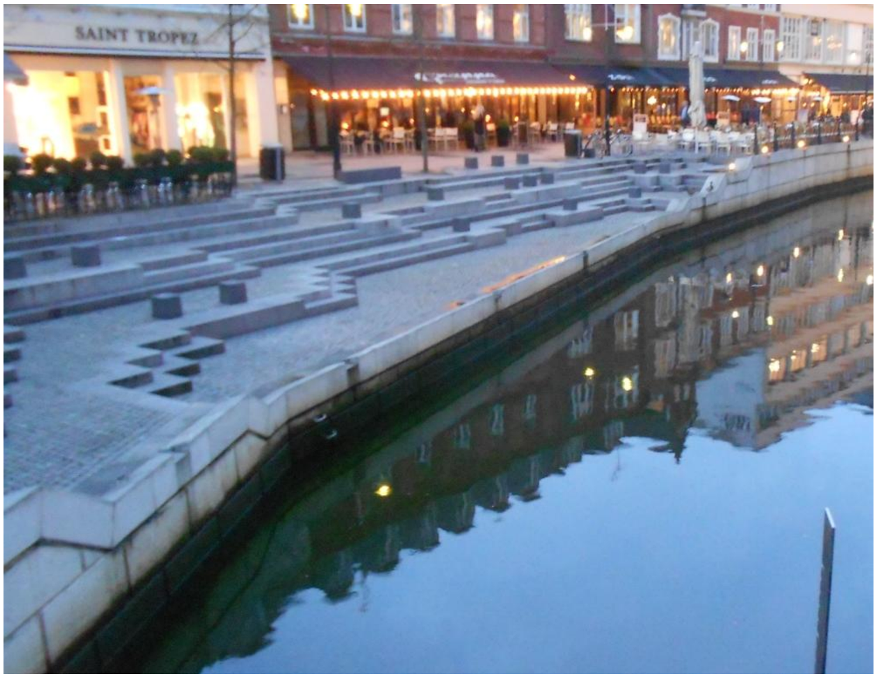


Figure 67: Step Designs Along Aarhus River II

The water in the canal has to be controlled and made sure that it doesn't flow too fast at locations where the slope may get steeper. It also has to look natural and appealing to help attract people to its banks. One way to meet both of these requirements is by adding certain features into the canal itself. The Orbicon proposal analyzed this in their study and came up with several ideas. The river cross section can be reduced by adding obstructions into the channel. This flow resistance will help slow down the water. Small waterfalls can also be used to slow the water down. Figure 68 shows specific examples of how to do this.

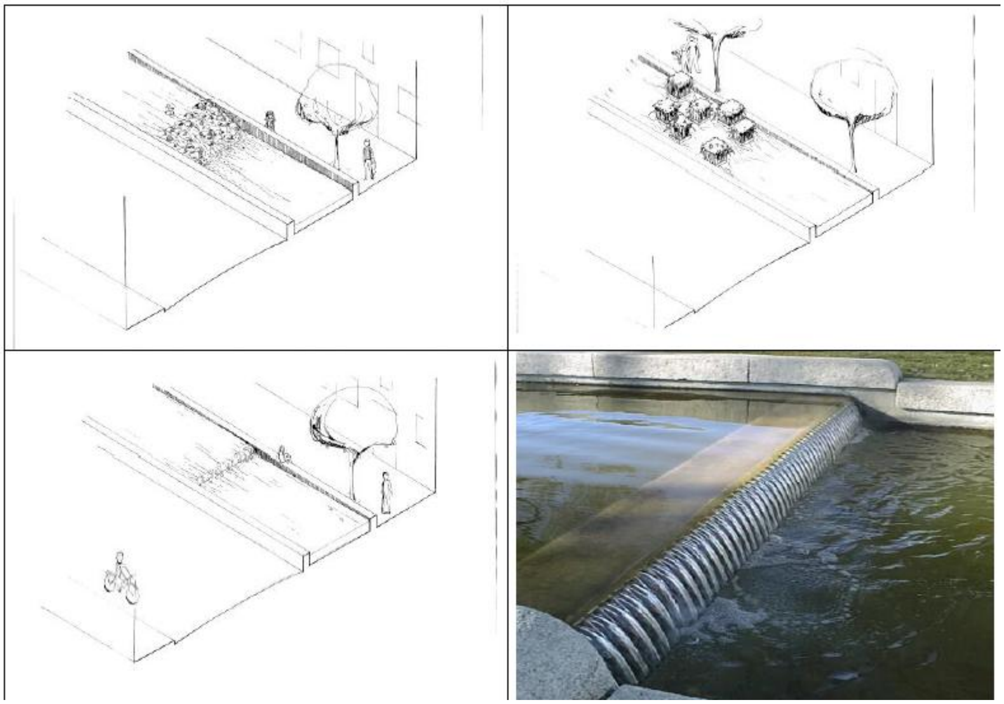


Figure 68: Ways to Create Water Resistance Along the Canal (Orbicon 2007)

A variety of large rocks can be scattered throughout the channel to create the resistance, as well as plant boxes (waterproof) (Orbicon, 2007). These can help make the channel seem more natural, while small waterfalls can add beauty to the canal. These are cheap and easy solutions to be implemented.

4.5.2 Motorway Tunnel and Reservoir Design

Reservoir capacity is a very important feature of flood control. We learned about the huge emphasis on reservoirs during our visit to Aarhus. According to Ole Helgreen, an engineer for the Water and Parks division of the Aarhus Municipality (2012), the city constructed reservoir capacity of 50,000-60,000 m^3 within the city by creating underground chambers, which was surprising, especially because their river's maximum flow (18 m^3/s) was much greater than what the Ladegårdsåen will be able to take. A reservoir was necessary in Aarhus because it is difficult to lead rainwater directly to the sea. Helgreen (2012) explained that rising sea levels, due to global climate change and high tides, reduces the slope of the waterway. He stated that this slope reduction makes it difficult to lead rainwater directly into the sea. Aarhus is dealing with this issue by installing a pumping capacity of 20 m^3/s to help water empty into the sea (Helgreen, 2012).

It wasn't just Helgreen who addressed this issue. Werner and Gabriel (2012) who were previously mentioned, both explained that leading all of the water that falls during extreme rain events into the sea is not practical. The sewers can't handle such large volumes of water and are simply overwhelmed during these events. The solution then becomes one focused on buying time and working with the different flows/waves to use the water carry capacity as efficiently as possible. Therefore, one of the only feasible solutions is the creation of a reservoir in the city to store this water. We had already been considering a car tunnel, so we began investigating designs for a dual purpose motorway/reservoir tunnel.

The use of the tunnel as a source of stormwater management was taken from the Stormwater Management and Road Tunnel (SMART) project completed in Malaysia in 2007. The International Tunneling and Underground Space Association (ITA) (2011) explains how this dual-purpose tunnel was designed to divert floodwaters away from the area where two major rivers meet and begin to flow through the city center, as well as relieving traffic congestion of traffic with its tow-deck motorway (Figure 69). "The SMART system will be able to divert large volumes of flood water from entering this critical stretch via a holding pond, bypass tunnel and storage reservoir. This will reduce the flood water level at the Jalan Tun Perak Bridge, preventing spillover" (ITA 2011 p. 1). This concept is very new, as the tunnel in Malaysia was the first of its kind. It has, however, been very successful, diverting floodwaters 44 times since its completion (Roadtraffic-technology 2011). The ITA (2011) explains how the tunnel has three modes of operation:

Figure 69: SMART Tunnel (ITA, 2011)

1. Normal conditions or little rainfall requiring no water to be diverted into the tunnel
2. Moderate storms requiring floodwater to be diverted into a bypass tunnel which is located in the lower channel of the motorway tunnel. The upper channel will still be open to traffic.
3. Heavy storms requiring the entire tunnel to be closed to motorists. Once all vehicles have exited the tunnel, watertight gates are opened to allow floodwater in. The tunnel reopens

to motorists within 48 hours of closure, once all of the water is sent to a reservoir to be slowly drained.

This tunnel was, and still is, very successful. Inspiration from these designs and concepts helped us to develop plans specific to the AA route.

The AA route is a major "regional transport corridor" (Orbicon 2007) and is crossed by several major roads, such as Jagtvej. Regional transport simply means that the route is used mainly by people commuting to and from the city center. A tunnel will be the solution to the traffic issue, allowing traffic to continue to the city with minimum effects. Local traffic will be slightly affected, as some of the intersections crossing the AA route will be closed and a select few will have bridges (described later on). The tunnel will consist of a large rectangular shape vertically divided in the middle to create two different smaller tunnels. Each side will contain three lanes (3 meter wide lanes) for automobiles, giving a total of six lanes, just like the current route. Each section of the tunnel would be roughly 10 meters wide and 4.5 meters high; the divider between the two sections would be 2 meters wide so that it could encompass the two pipes (described later) and other necessary design features. The most important facet of this tunnel is that it would serve as a reservoir for stormwater during extreme rain events.

Here, we provide only a simple overview of how the AA tunnel could look and the different features it would include. Figure 71 shows how the waterway and the tunnel would be connected. Vertical pipes will be strategically placed underneath the canal at various locations leading down into the horizontal pipes that run parallel to the canal in the center of the tunnel. Water that comes from larger sources around the city can be deposited directly into the vertical pipes to be sent to the harbor or other various places, while smaller sources of water, such as surface runoff and water from LAR, will be sent directly into the canal. Two pipes will be placed in the partition; the top pipe will be used to carry water from the end of the canal back to the start to be reused when the canal needs more water (during dry times). The bottom pipe will be used to carry water to the harbor and to other locations that will be able to use partially clean water (as described earlier). When the bottom pipe is not enough to handle the extreme amounts of rain, both pipes can be used to divert flood water away from the canal and Nørrebro. When the amount of water is too much for both pipes to handle, one side of the tunnel could be flooded, while the other remains open for traffic. The opened tunnel would have to serve as the only road, using two lanes for one direction and the third lane for the opposite direction, as shown in Figure 72, until the flooded tunnel was drained. The bottom pipe, therefore, has to be placed lower than the bottom of the tunnel, so that the motorway tunnels can drain simply due to gravity as the water will flow into the low lying pipe. This will require that drains (pipes) are placed at certain areas along the two motorway tunnels to allow water to drain into the larger pipe when necessary.

In very extreme conditions, both tunnels can be flooded and used as reservoirs until the water can be drained into the harbor. The amount of water that the tunnel could hold was important to determine. The length of the route and where it would begin and end for our design had to be determined. Figure 70 below displays the tunnel route. The route is 2.8 km long with the start of the route being at the top left of the map. The 1 km and 2 km points along the route are marked on the map as well, with the route ending before the lakes at the bottom right. With all of the dimensions known, the volume could be determined.

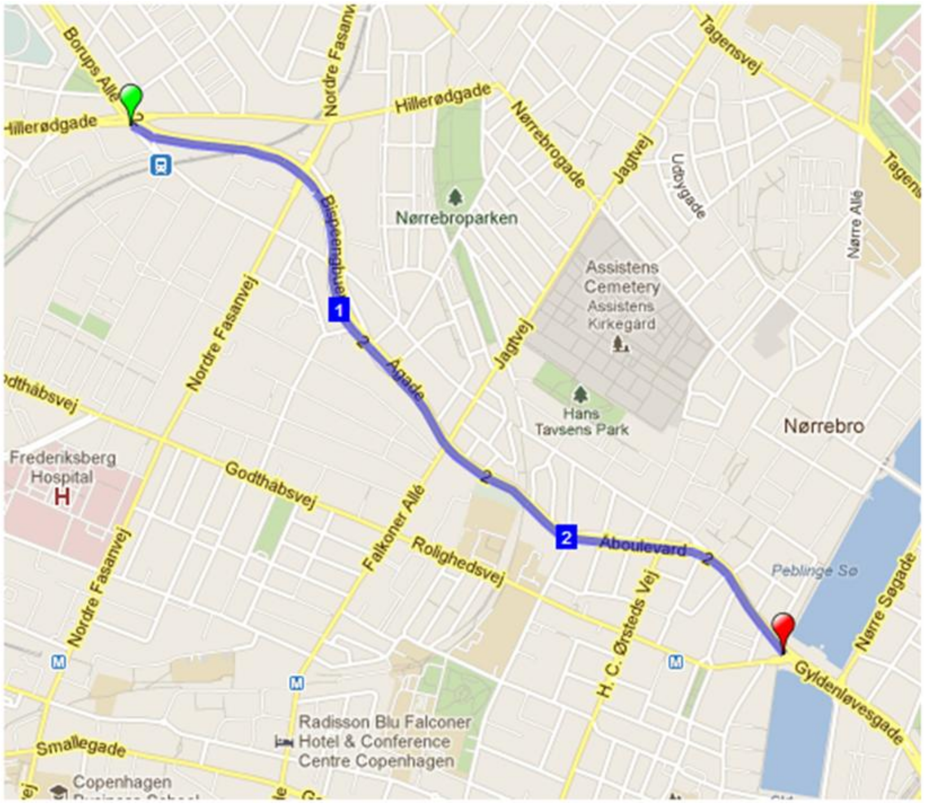


Figure 70: Length of Tunnel (Adapted from RunningAHEAD.com)

Volume for each tunnel section = Length x Width x Height

= 2800 m x 10 m x 4.5 m = 126,000 m^3

1 m^3 = 1000 Liters

126,000 m^3 x (1000 L / 1 m^3) = 126,000,000 Liters

Each tunnel section can hold 126,000,000 Liters of water.

Entire tunnel can hold: 252,000,000 Liters of water

Much more research has to be done on the tunnel aspect of this project, but it has been proven by the SMART tunnel that it is possible to create a tunnel that can serve two purposes, one as a means of transportation and another as a means of flood control.

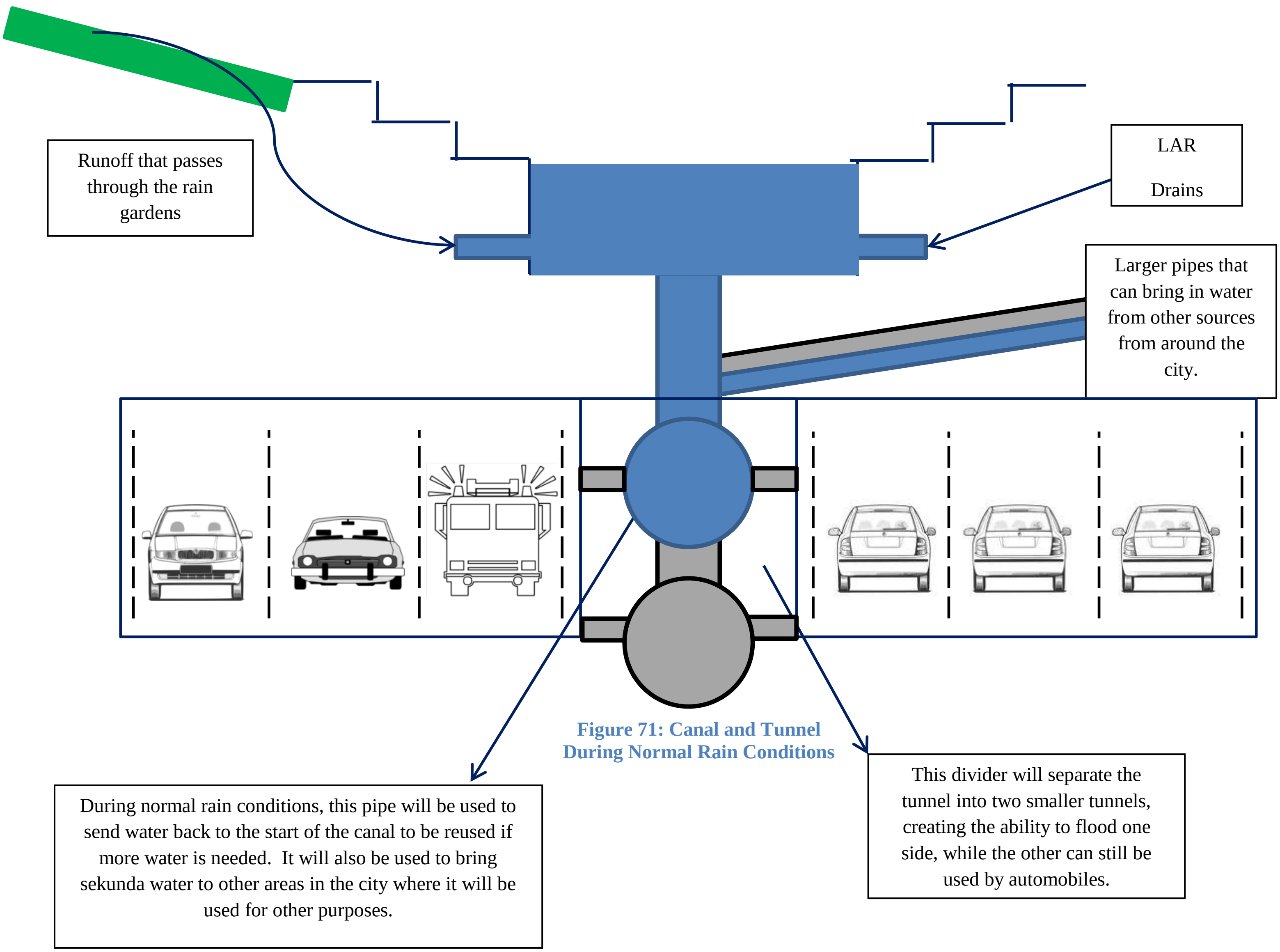


Figure 71: Canal and Tunnel During Normal Rain Conditions

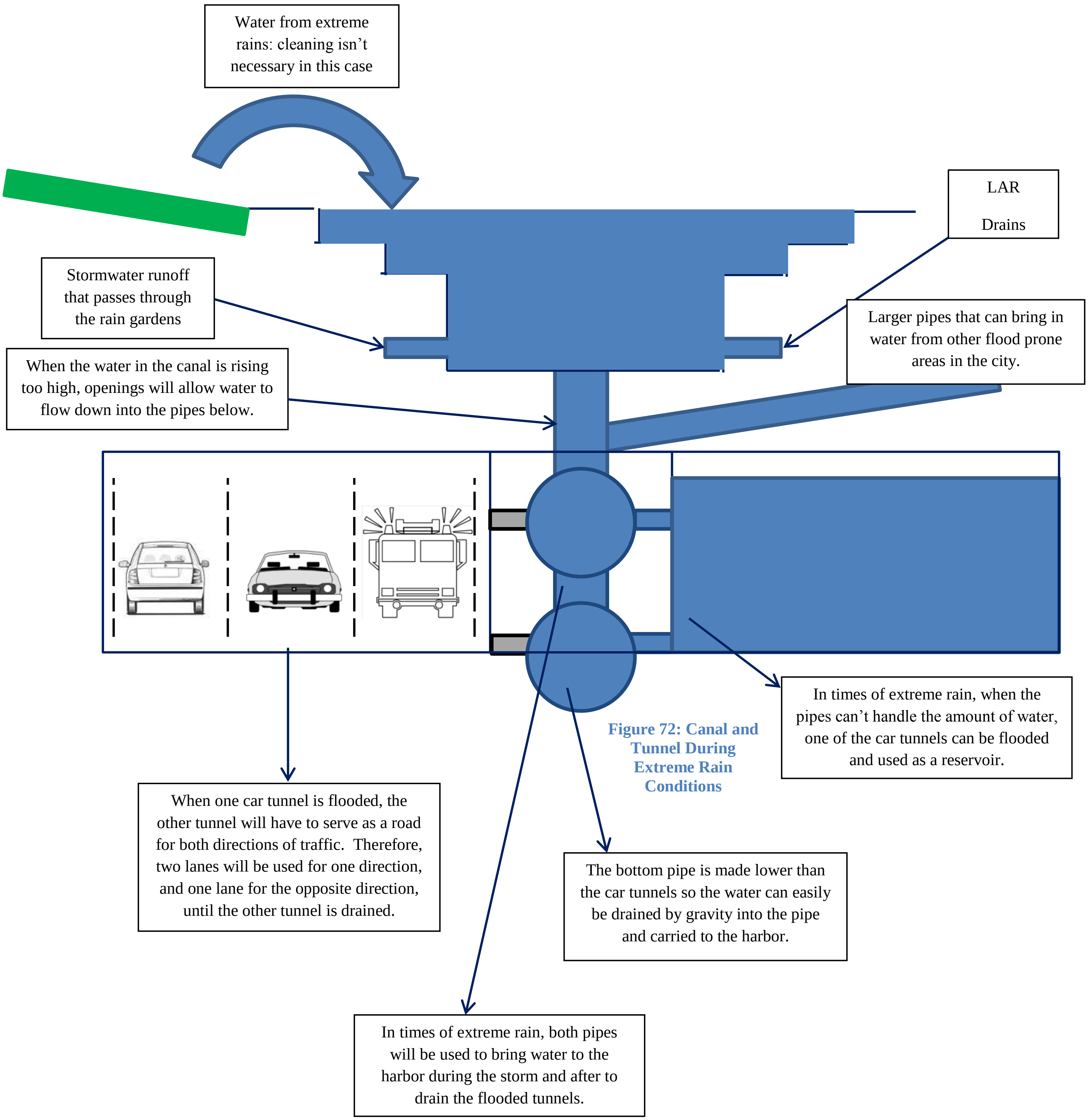


Figure 72: Canal and Tunnel During Extreme Rain Conditions

4.5.3 Green Space and Water Quality

As previously stated in section 4.4.1, we anticipate three sources of water supplying the canal, including the piped tributaries, the foundation drains, and LAR. All three of these sources of water which could potentially end up in the Ladegårdsåen are polluted, which makes it unsuitable for drinking and below the normal biological standards of natural streams (Orbicon, 2007, p. 36). The piped tributaries can be cleaned upstream or at the beginning of the Ladegårdsåen (Orbicon, 2007, p. 36). We believe that local water sources should be cleaned locally as this is a practicable and sustainable option. Our goal isn't to make the water in the canal drinkable, but to make it semi-clean, or sekunda, so that it can be reused for domestic and industrial purposes (City of Copenhagen, 2011). This would remove the additional pressure that has been placed on drinking water and the sewage system (Gabriel, Personal Communications, 2012). We believe that rain gardens, which are a very sustainable design, would fit the task of cleaning the water.

Marina Jensen, professor of Forest and Landscape at the University of Copenhagen, in her article "*Dual Porosity Filtration"* (2011), states that canals are fed polluted water from surface runoff and roof discharge (Figure 73).

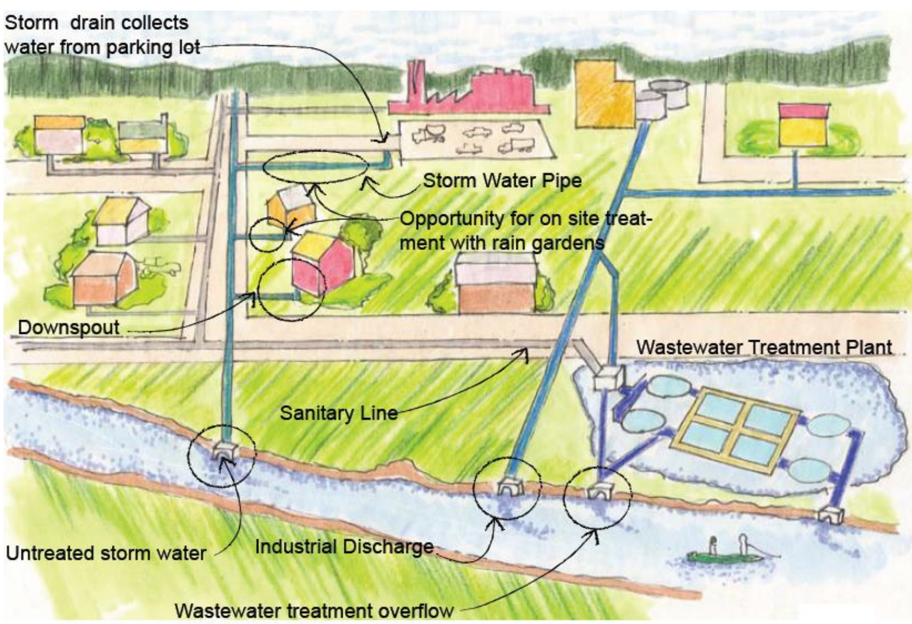


Figure 73: Non Point Pollution (Mill Creek Watershed Council, (n.d))

Figure 73, from Mill Creek Watershed Council (n.d), gives a visual representation of the different access points where pollutants can enter canals. Surface runoff from roads and parks carries oil, pesticides, and heavy metals; roof discharges carries phosphates. The water from these sources is usually collected by storm drains which can discharge it into canals. Industrial waste discharge from factories and waste water overflow are other access points where pollutants can enter the canal. The goals set by the municipality of Copenhagen concerning water quality in canals are very strict (Copenhagen Waste Water Plan 2008, cited by Jensen, 2011). They state that pollutants must be reduced to low, safe levels in order for the water to be non-toxic. The most prevalent and dangerous pollutants are the heavy metals which, are zinc, chromium, lead and copper. The municipality has set specific measurement levels for each of the heavy metals; the concentration for each of these metals must not be greater than what is specified in order for the water to be safe for human interaction.

- Total Zinc < 110 μg/L
- Total Copper < 12 μg/L
- Total Chromium < 10 μg/L
- Total Lead < 3.2 μg/L

(Copenhagen Waste Water Plan 2008, cited by Jensen, 2011, p. 2)

This will be the same situation for the Ladegårdsåen, as the canal will be fed polluted water. Different technologies can help filter the pollutants. Most of these technologies incorporate pumps and filters; however, rain gardens are also used to filter water naturally. Rain gardens have become an increasingly popular landscaping design to help absorb and clean rainwater (Figure 74). Christopher Obropta, an Extension Specialist in Water Resource, in his article "Rain Gardens" (2006), describes rain gardens as a natural depression that absorbs rainwater from roof discharge and surface runoff and then allows it to seep naturally into the ground. Rain gardens help to beautify the community as well as enhance biodiversity in order to promote ecological health. Rain gardens also improve water quality by filtering the pollutants from surface runoff and roof discharge (2006).

Figure 74: A Conventional Rain Garden (Cuyahoga Soil and Water Conservation District, n.d)

A rain garden is beneficial in numerous ways:

- ❖ Absorbs 30% more rain water than a conventional lawn, and can be filtered to supply local and regional aquifers.
- ❖ Acts as a barrier against flooding and drainage issues.
- ❖ Helps to protect streams and lakes from pollutants, such as pesticides, oil, and heavy metals, carried by surface run off from the roads and parks and by roof discharge.
- ❖ Helps to beautify the community.
- ❖ Bolsters biodiversity by providing shelter for birds and insects and is beneficial to microorganisms.

(Obropta, 2006)

It's for these reasons that rain gardens are essential for our project as they fit into the municipality's vision of creating a greener Copenhagen. It's a smart and sustainable design that uses natural sources without harming the environment.

In order to fully justify the importance of the rain gardens, we must elaborate on how they will filter the water and how the filtered water will reach the canal. Karin Cederkvist, a PhD student at the University of Copenhagen, conducted a study on using soil as a filtrate by evaluating the Mulden Rigolen System, a rainwater retention and infiltration system started in

Germany (2012). The concept of rain gardens began in Germany, and the Mulden Rigolen System was used to evaluate the top soil used in rain gardens (Jensen, Personal Communication, 2012). Since rain gardens are constructed to be lower than the surrounding area, surface runoff will naturally flow into the depressed region (Figure 74). The depressed region, or swale, a moist, low tract land designated to capture, absorb, and filter storm water runoff, will facilitate storm water infiltration into the soil (Cederkvist, 2012). Plants' roots also help with the infiltration rate, meaning more roots increases water infiltration. As the water percolates deeper into the ground, the top soil, composed of sand, silt and clay, will act as a filter to remove heavy metals and oil; roots on the other hand absorb nitrogen (Monash City Council, 2009). Limestone has been shown to absorb heavy cationic metals (Jensen, 2011). Therefore, limestone can be used in conjunction with silt, sand and clay to filter suspended solids. As previously stated, the Mulden Rigolen System has been used to evaluate the top soil used in rain gardens. Hence, researchers, using the Mulden Rigolen System, have created several guidelines regarding top soil (Cederkvist, 2012).

Top soil layer should be:

- 0.1-0.3m thick
- pH should be between 6-8
- Covered by vegetation
- Material Composition
  - Clay- Less than or equal to 10%
  - Organic Material- 1-3%

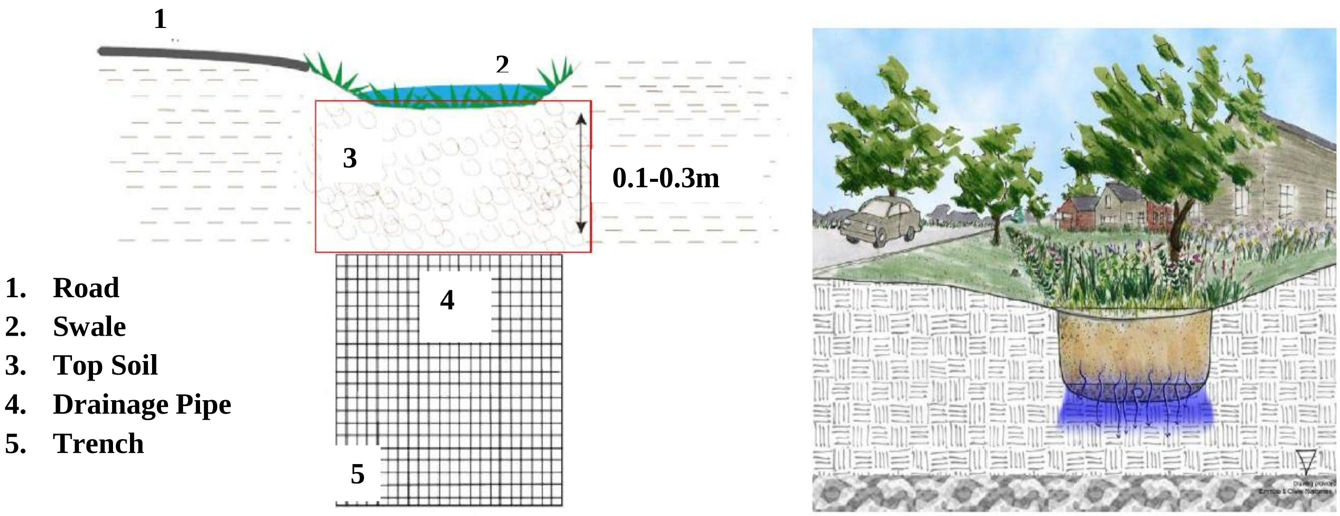


Figure 75: Schematic of Rain Garden Filtration System (Cederkvist, 2012)

As shown in Figure 75, after the water has passed through the top soil layer, it's collected by drainage pipes and then by a trench which discharges the water into the waterway (Cederkvist, 2012). The drainage pipes are needed to prevent the plants from suffocating by removing the excess water. For our design, there will be a slanted plastic or clay barrier (3m), instead of drainage pipes, which will carry the water into the canal (Figure 76). There will be geotextiles (0.3µm x 0.3µm) at the barrier-canal interface to further filter dirt and other suspended solids from entering the canal (Figure 76). Geotextile is a woven permeable material that can be used as a filtrate and as a preventive measure against soil erosion (Franklin, Hampden and Hampshire Conservation Districts, 2003). It's commonly associated with waterway structures (2003). Geotextiles are known to last long, needing changing every twenty years provided that they are treated carefully. To obtain the full longevity of the geotextiles, they must not be exposed to the sun, which isn't a problem for our design because the trees in the green spaces will provide shade to the canal area (Franklin, Hampden and Hampshire Conservation Districts, 2003).

In respect to water quality, Marina Jensen stated that the results from a simulation test, where contaminated water was poured in a cylinder containing sand, slit, limestone and clay, showed that 95% of the pollutants were filtered out of the water (Jensen, Personal Communication, 2012). It's important to note that the slit, clay, limestone, and sand were mixed homogenously and were not layered. Figure 77, shows the different elements that make up the top soil. Over time, as pollutants are absorbed by the soil, the soil's pH will change and become either acidic or alkaline. When this happens, the plants will die. When asked "how often does the soil need to be changed?" Professor Jensen stated that "Researchers working with rain gardens in Germany agreed to test the soil every ten years to observe the effects the contaminants had on it. Sadly this was not done." (Jensen, Personal Communication, 2012). Currently, there is no concrete answer to this question, however we can safely assume that the soil should be changed or tested every 10 years (2012).

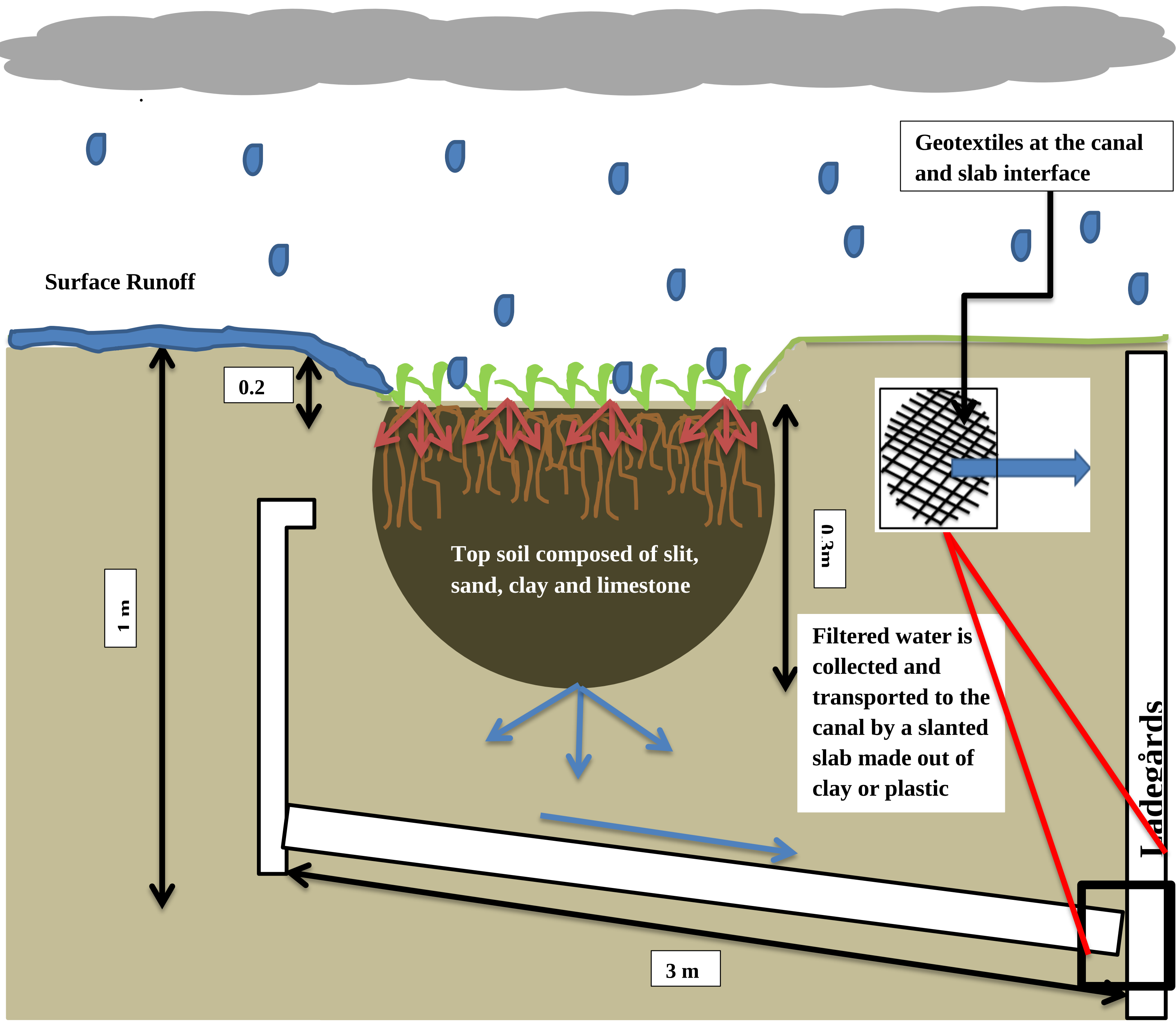


Figure 76: Schematic Showing How Rain Gardens Work and How the Water Discharges into the Canal.

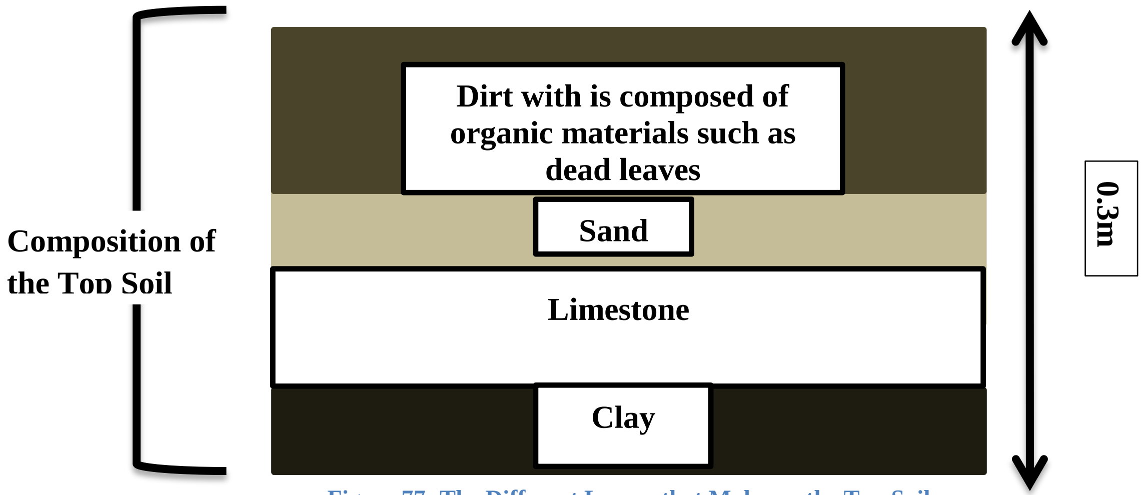


Figure 77: The Different Layers that Make up the Top Soil

Plant selection was vital for the successfulness of the rain gardens. The plants used in creating a rain garden are mainly wetland vegetation such as wildflowers, shrubs, small trees, grasslands, and ferns. Since Denmark has a temperate climate, it's important to use native temperate flora. We recommend using native plants because they do not require fertilization and they absorb water much more effectively than lawns. Plants that are not native to the environment or the soil pH level will invade on native plants (Mill Creek Watershed Council, n.d). It is crucial to avoid plants that have thick aggressive roots, such as willow trees, because they will form small canals within the soil in which the water will simply pass through and not get filtered. Our team developed different parameters to use as a guideline in selecting the plants. They include:

- **Low maintenance**
  - Plants that don't require too much attention, pruning, trimming, cutting, etc. are preferred over plants that require constant attention because it is costly to maintain them.
- **High absorption of water**
  - Plants that can absorb water at a fast rate are needed in rain gardens in order to protect against flooding. Hence, flora that already has a developed root structure will help increase the absorption rate and help to anchor the soil protect against erosion.

- **Attractive to wildlife to promote biodiversity**
    - Colorful and bright plants attract birds and insects such as bees.
- **Able to survive in silt, sand, and clay soil (native soil type and texture)**
    - The plants must be able to survive in neutral pH (6-8).
- **Resistance to the fluctuating dry and wet seasons and diseases**
    - Plants that are susceptible to diseases will leave open tracks in the soil when they die allowing the unfiltered water to pass through (Jensen, April 27th 2012). Also it creates an unhealthy ecological environment and the disease can infect nearby plants.
- **Sturdiness**
    - Plants must be able withstand the pressure exerted by water during the extreme rainfall as well not to rot when the soil is heavily saturated with water.

Using theses parameters, we were able to evaluate several native flora in Denmark (see Table 18 and 19-Lorenz von Ehren, 2011).

Table 18: Different Flowering Plants and Their Blooming Season

Plant Life	Name	Genus	Height (m)	Bloom Season
Flowering Plants	**Spring Heather**	***Erica darleyensis***	**0.2-0.4**	**Oct-Nov**
	Hybrid Witch Hazel	***Hamamelis × intermedia***	**3-5**	**Dec-April**
	Summer sweet	***Clethraalnifolia***	**1.5-3**	**July-Sept.**
	Bush Clover	***Lespedeza thunbergii***	**1-2**	**Sept.-Oct.**
	Flowering quince	***Chaenomelesspeciosa***	**2**	**Mar-April**
	Sweet shrub	***Calycanthusfloridus***	**2-4**	**May-June**

From Table 18, each plant has a different blossoming season which thereby creates a long flowering season to attract birds and insects (Mill Creek Watershed Council, n.d). Each flower is brightly colored and gives of a sweet aroma which can attract both animals and humans (Lorenz von Ehren, 2011). Some of these flowering plants, such as the *Clethraalnifolia*, are specifically designated to be planted alongside canals as they are effective against soil erosion. Some plants like the *Calycanthusfloridu***,** bears fruit for birds to eat and to scatter the seeds for reproduction (Lorenz von Ehren, 2011).

Table 19: Herbs, Shrubs, and Grass and Their Contributions to the Rain Gardens

Plant Life	Name	Genus	Height(m)	Special Features
Shrubs	Black Alder Winterberry	*Ilex verticillata*	1-5	
	Marsh Labrador tea	*Rhododendron tomentosum*	0.5-1.2	
	Elderberry	*Sambucus nigra*	4-6	
	Checkerberry	*Gaultheria procumbens*	0.1-0.5	++
	David Viburnum	*Viburnum davidii*	0.3-1	+
	Common Dogwood	*Cornus sanguinea*	2-6	**
	Common Heather	*Calluna vulgaris*	0.2-1	*
	Red-Barked Dogwood	*Cornus alba*	2-3	
	Siberian peashrub	*Caragana arborescens*	3-5	
	Bearberry	*Arctostaphylos uva-ursi*	0.2-0.3	
Herbs	Judas Tree	*Cercis siliquastrum*	4-6	
	Clustered Bellflower	*Campanula glomerata*	0.2-0.9	
	Purple loosestrife	*Lythrum salicaria*	0.8-1	
Grass	Weeping Sedge	*Carex pendula*	1.2-1.5	
	Great wood-rush	*Luzula sylvatica*	0.2-0.8	

These plants shown in Table 19 are crucial to rain garden designs. The different features for each plant and the reason why they are crucial in rain gardens design is tabulated below (Table 20).

Table 20: Definitions of Individual Symbols Used in the Above Table

Symbols	Meanings
	Can survive in damp and short flooded soils; crucial because the plants used in the rain gardens must be able to survive in damp soil for a period of time without rotting.
	Can survive in damp and short flooded soils as well as long flooded soils; crucial because the plants used in the rain gardens must be able to survive in damp soil for a period of time without rotting.
	Bears edible fruits for wildlife; crucial for attracting wildlife.
++ (Moderately Fast)	Flat-growing plants which are used for long-lasting, and low-maintenance greenery of large areas. However, fast growing plants can compete and cripple other plants, so it's important to choose a plant that grows slightly to moderately fast.
+ (Slightly Fast)	Flat-growing plants which are used for long-lasting, and low-maintenance greenery of large areas.
**	Efficiently resists industrial pollution; this is important because Nørrebro experiences air pollution; therefore, we need plants that can survive in these conditions.
*	Resists industrial pollution; this is important because Nørrebro experiences air pollution; therefore, we need plants that can survive in these conditions.
	Perennial plants are known for their deep, extensive root structure which plays a crucial role in protecting the soil against erosion, capturing dissolved nitrogen before it can contaminate the soil and underground water, and reducing the need for herbicides by outcompeting weeds.
	Nitrogen-Fixing plants; plants that absorb nitrogen from the air and ground and provides a natural fertilizer to other plants. Helps to improve living conditions for microorganisms, because they enrich the soil.
	Plants that secure embankments, dams, and slopes; therefore they lines the banks of the canals or dams. These plants have extensive root structure which help anchor the soil.
	Rampant perennials are excellent for creating greenery safely and quickly. Since they are perennials they are instrumental for soil erosion.

After we selected the apporiate plants (Tables 18 and 19), we evaluated plant layouts within the rain gardens and the dimensions and location of the rain gardens along the canal. When designing the landscaping of the rain garden, it was important to consider the height and width of the branches, the plants' colors, and the bloom season of the selected flora (Mil Creek

Watershed Council, n.d). It was crucial to mix flora of different heights and color to give the garden depth and dimension (n.d). We suggested planting flora that blossom in different seasons to create a long flowering season, attract different species, and beautify the area by making it aesthetically pleasing to the eye (Figure 78) (n.d).

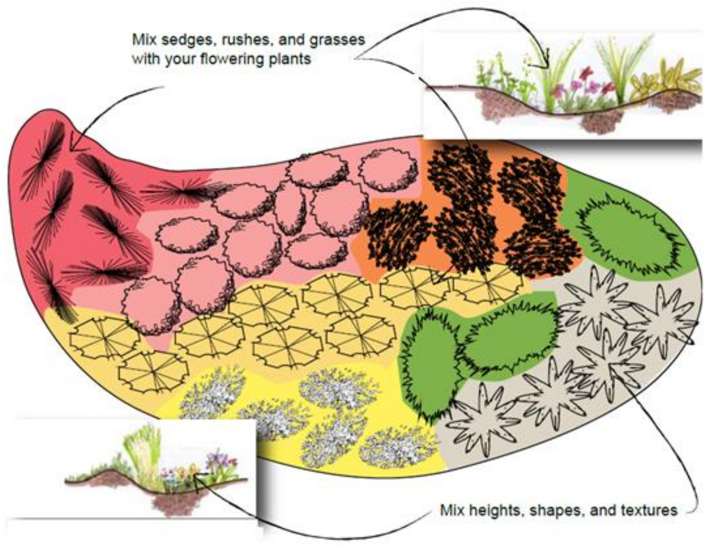


Figure 78: Layout of Plants in a Rain Garden (Mil Creek Watershed Council. Rain Gardens, (n.d)).

The rain gardens will be placed along the canals's banks at sections where area for green space is largest (Figure 51) and at areas more prone to flooding (Jensen, Personal Commuication, 2012). As previously stated, we wanted to make the water semi-clean, not drinking water quality. Since rain gardens offer protection against flooding, its more logical to place them at low elevated regions (Figure 79). However, its important to note that even though the rain gardens protect against flooding, they can only alleviate normal rain conditions. In the events of extreme rain, the water would just flood over the rain gardens, which is acceptable, because the tunnel and canal reservoir can contain the capacity of water.

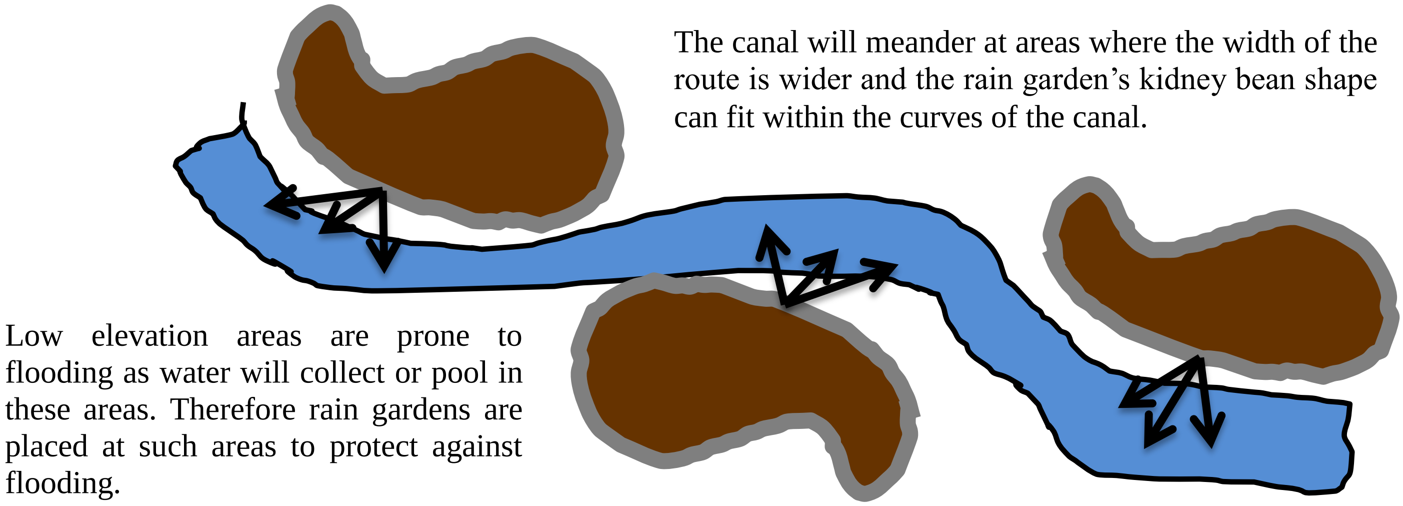


Figure 79: Aerial View of the Canal at Low Elevated Areas

After evaluating the dimensions along the canal, we could incorporate the standard dimensions for designing large rain garden: (3.1m x 6.1m x 0.2 m) *(h* x *w* x *d)* (Obropta, 2006). A rain garden that is 6.1m is ideal for areas that have silt and sandy soils and areas exposed to both full and partial sunlight (Bannerman, 2003). Since the north side of the canal receives more sunlight than the south, due to Denmark's location in the northern hemisphere, this dimension is suitable for both northern and southern rain gardens. Stone or wooden pathways would be used as access points to the canal, because we do not want the citizens to step on the rain gardens. Behind the rain gardens would be larger trees, providing a canopy to help cool and beautify the area. All of these elements are incorporated into the creation of more green space in Norrebro (Figure 80).

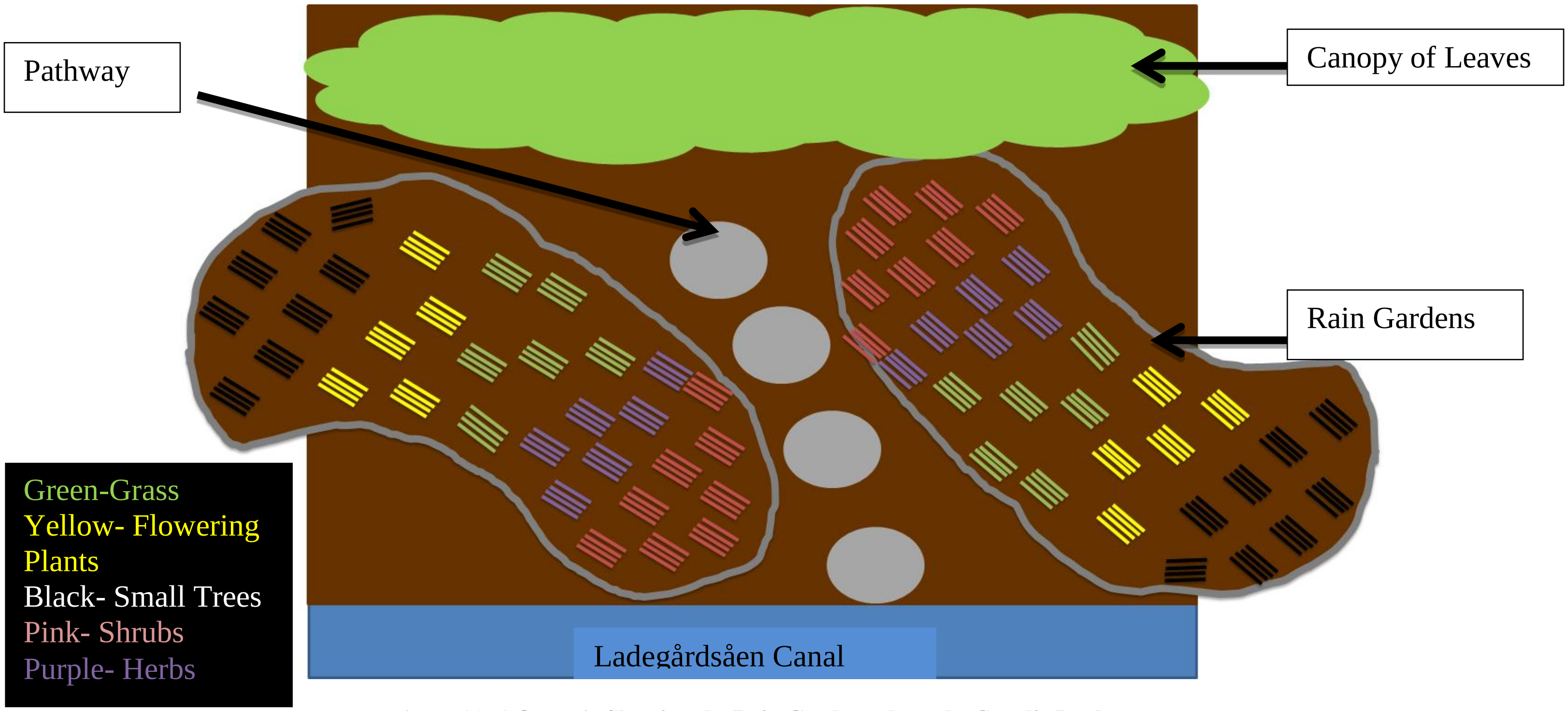


Figure 80: Schematic Showing the Rain Gardens along the Canal's Banks

Along with the rain gardens, in order to create more green space throughout the city, we determined that it would be best to use a combination of tall and low layer trees. A large tree is categorized by a minimum height of 20m while a small tree is categorized by a height between 7m to 12m (Lorenz von Ehren, 2011). This arrangement is similar to the seven layer forest garden (Figure 81).

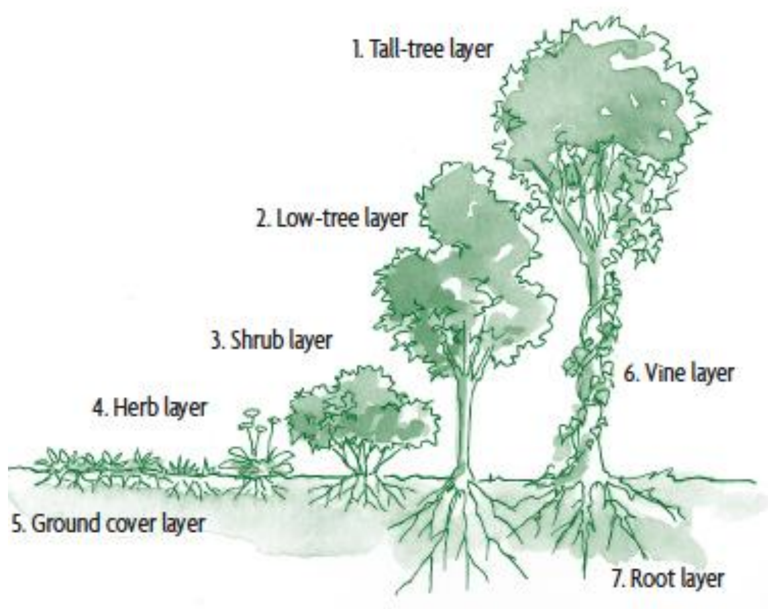


Figure 81: Seven Layers of the forest Garden (Gaia's Garden: A Guide to Home-Scale Permaculture. Toby Hemenway, 2009)

A simple forest garden consists of three layers: trees, shrubs and ground plants. However, a more exquisite garden consists of seven layers of vegetation (Figure 81, Hemenway, 2009). Please note that we are not planning a forest, we are just incorporating the tall and low level trees from the forest garden design in conjunction with our rain garden design to create our overall green space design. Our green space design makes use of the Earth's natural resources (Mark Fisher, a Permaculture designer, Rain Gardens (n.d)):

- **The tall and low layer Trees (Table 21):**
    - The canopy layer; it provides shade and the leaves help intercept rain drops to prevent erosion. Shade helps to cool the area during harsh summer months.
    - Provides a habitat for birds and other organisms
    - Nitrogen Fixation plants absorb nitrogen for themselves and the soil. When the leaves fall, they provide nourishments to the soil; hence they act as natural fertilizers

Table 21 indicates the tall and low level tress that have met our parameters.

Table 21: Tall and Small Layer of Trees

Plant life		Name	Genus	Height (m)	Width (m)
Trees					
	Large/Tall	King's Oak	*Quercus robur*	20-30	15-25
		Small-leaved Lime	*Tilia cordata*	20-30	10-20
		Silver Birch	*Betula pendula*	8-30	6-8
	Small/Low	Pear Tree	*Pyrus regelii*	5-9	3-4
		Italian Alder	*Alnus cordata*	9-12	3-6
		Chonosuki Crab	*Malus tschonoskii*	8-12	4-6

We suggested planting a few of the larger trees listed in Table 21, at the beginning edges of the green space, forming the outline of the green space design. The smaller or low trees would be placed next (Figure 81) followed by the rain gardens. In areas where the rain gardens are absent, we would still use the plants that we would use in the rain gardens (Table 19). The distance between each plant life, trees, shrubs, etc. would vary because the widths of the branches for each tree as well as the root structure for each plant life is different. These trees meet our aforementioned parameters of high absorption, sturdiness, etc. Oliver Buhler, professor of Forest and Landscape at the University explained that the larger trees may be pruned to only grow to 15m in the city (2012) and have no competition as in a forest where they must reach high altitudes to obtain sunlight. Each tree has sturdy bark that can resist rotting and can withstand extreme rainfall. These trees are easy to maintain; trimming can be done once every a few years (Buhler, 2012). None of the roots are aggressive and therefore can thrive in urban settings near buildings and other structures (2012). These trees can absorb water at a fast rate and can survive in heavily saturated soil for about a week, corresponding to flooding conditions. Many of these trees support wildlife by providing a habit to birds and insects.

Another green space design element is:

- **Herbs and Shrubs** - Perennial Plants (apart of the rain gardens):
    - Nitrogen fixation plants or natural fertilizers
    - Flowers attract bees and insects (biodiversity)
    - Soil Builders

Another important element to our green space design is that it will attract a diverse range of species including birds, insects, and microorganisms (living in the soil). This term is called biodiversity. According to Larsson (2001) “Biodiversity Evaluation Tools for European Forests,” biodiversity consists of different species interacting together within the biological environment in order to sustain life (2001).

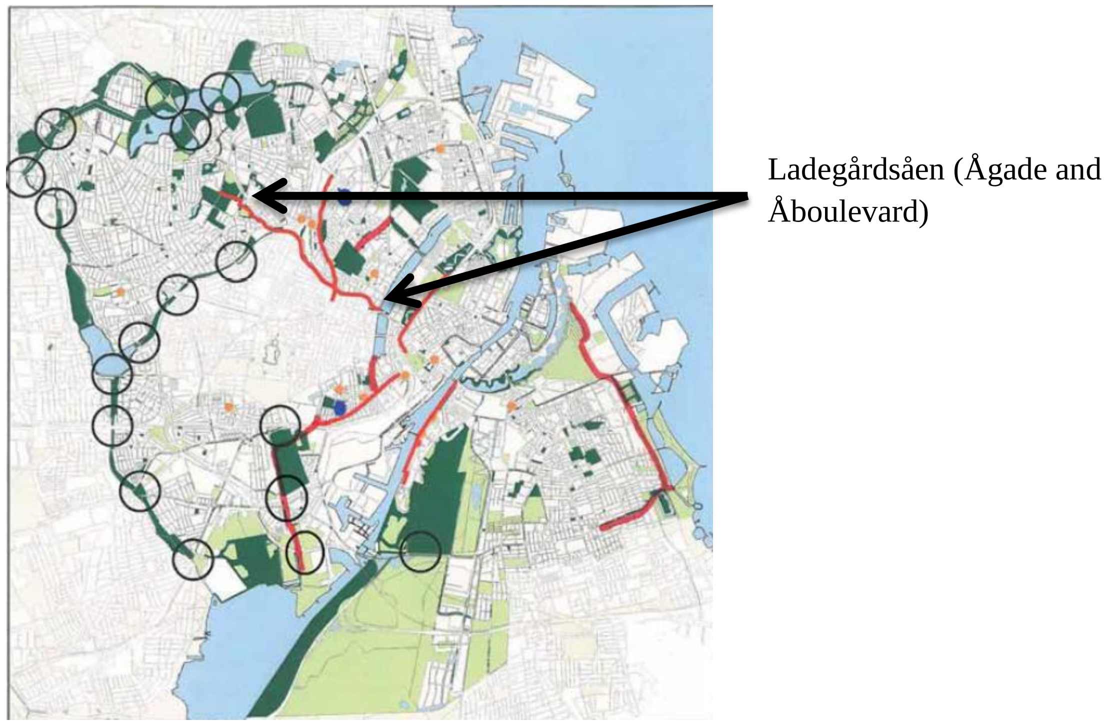


Figure 82: Municipality Goals to Establish Green Corridors (highlighted in red) Throughout Copenhagen (Room for Nature p 15)

The municipality has expressed interest in establishing green corridors on the AA route (Figure 82). Specifically the municipality report, "Room for Nature" (2011), stated that reopening the Ladegårdsåen canal under the Ågade would be a "big win for Copenhagen" (Room for Nature, p. 13). Creating a green path on the AA serves another purpose; it could be considered a missing link in a chain of green pathways. By opening a green corridor via the AA route, it would connect other green paths thereby forming a grid. By integrating green space and the daylighted canal, we would create a super green corridor running through the city and enhance biodiversity.

Finally, the final green space design element is:

- **Root Systems**
    - Anchors the soil to prevent soil erosion
    - Absorbs water to alleviate flooding

Our green space design has an extensive root structure that helps to anchor the soil to prevent erosion (Hemenway, 2009). In essence, our green space design acts a water management system by providing a permeable surface. Since there is a combination of tall and small trees, the leaves also help to prevent soil erosion by intercepting the rain droplets therefore reducing the chance of flash flooding (Conner, 2007). The fallen leaves act as natural fertilizers, hereby reducing the need for pesticides (Benefits of trees & the urban forest, 2012).

Through evaluating the benefits that the rain gardens and the forest gardens can provide to Nørrebro, we hope that our green space designs will not only benefit the citizens, but the environment and biodiversity.

Figure 83 below shows the green space in relation to the buildings, the bike lanes, and a pedestrian walkway with lighting. The canal, itself, would be in the foreground of this illustration, as well as the rain gardens along its bank.

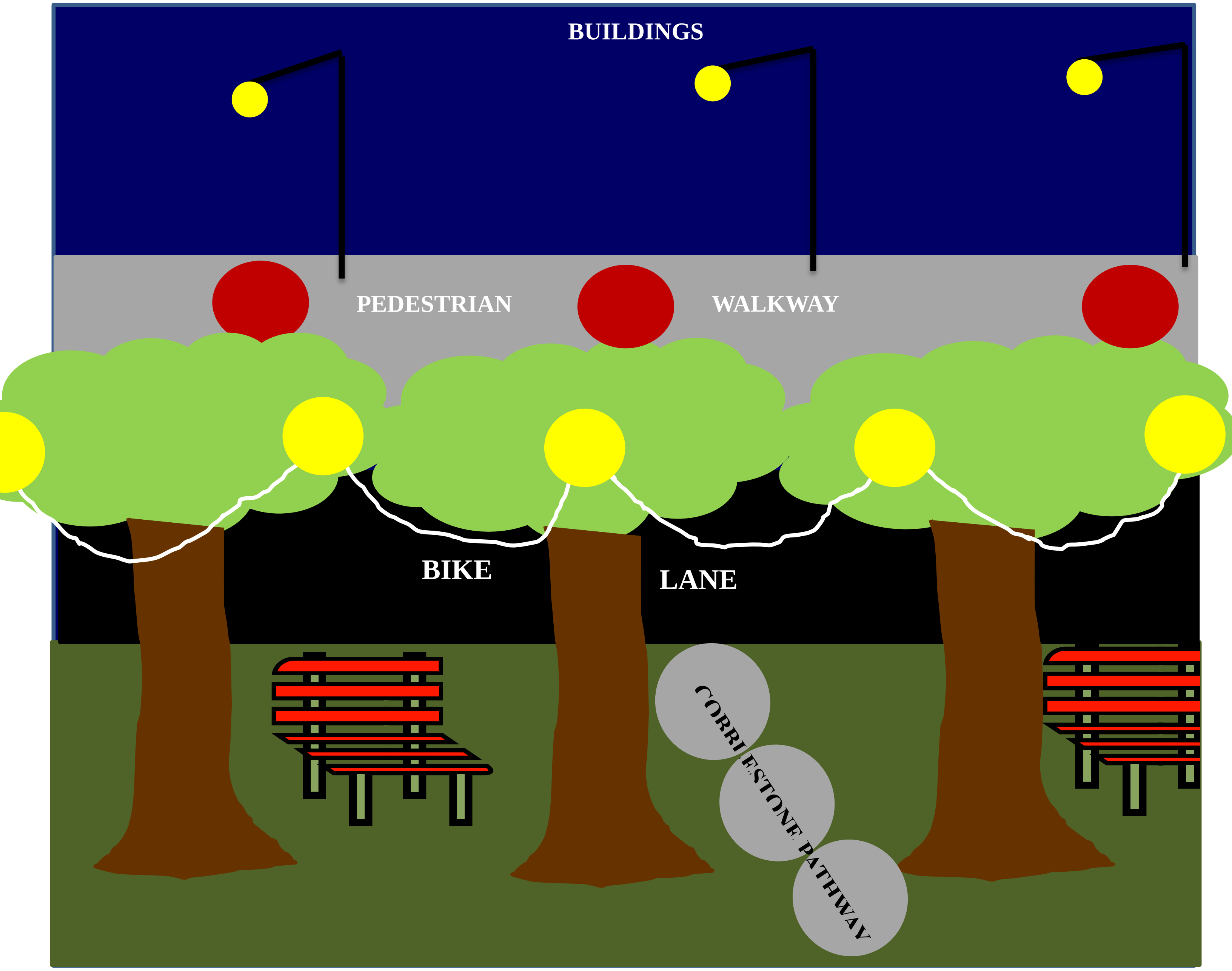


Figure 83: Illustration of how the Green Space is Incorporated into the Surrounding Area

At the outline (or the beginning) of the green space area could be benches for people to sit, relax, read, or just admire the beauty of the canal. Cobblestone pathway or wooden pathways would be placed every few meters of each other to allow access to the banks of the canal. There could be lights on the trees, for example drooping lanterns, to brighten the area. These along with the street lights would give off a warm inviting feeling, which would bring people to the area, as shown with the Aarhus River design (Figure 84).

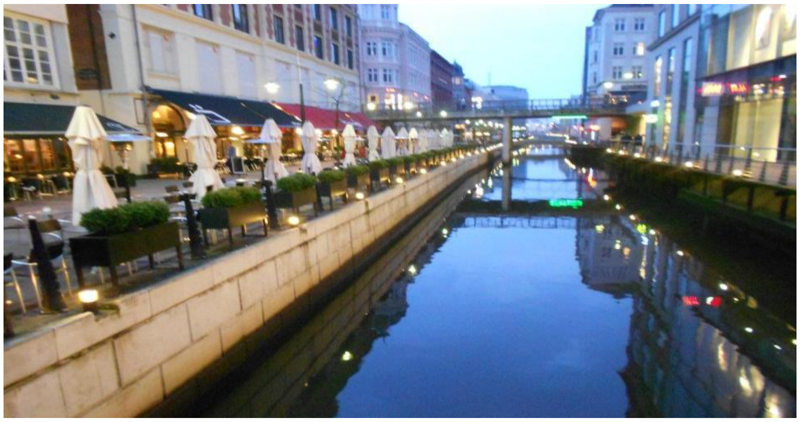


Figure 84: Aarhus Canal Walkway

4.5.4 Bike Path Design

The bike paths along the route will be constructed so that bikers can travel in both directions on either side of the canal. With the canal acting as a divider there will be, fewer ways to get from one side of the Aboulevard to the other, so this design will help the project have as little impact as possible on bikers. As stated earlier, the bike lanes will be 4 meters wide. They will contain a dash line down the center to separate traffic, but similar to a road, cyclists will be able to move into the other lane to pass slow bikers. Figure 85 shows this design. The bike lanes will be made of pavement and will be at the same level as the neighboring pedestrian walkway and green space. No curb will divide the bike path. This is because we want to allow water to flow freely from the sides of the routes down to the canal with as little interference as possible. No curb or change in elevation will also allow for emergency vehicles

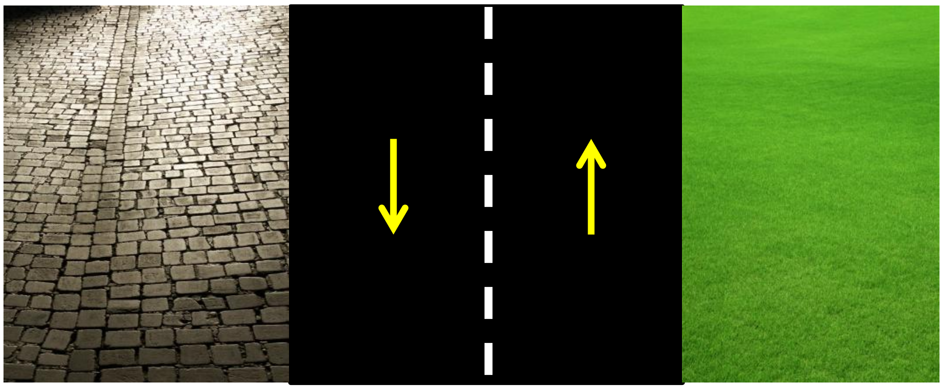


Figure 85: Bike Path

to easily drive on both the pedestrian walkway and the bike path without any issues. The new bike routes will have fewer intersections as before because many of the smaller crossings of the Aboulevard will be closed. This will allow bikers to travel very quickly along the route, with few obstacles or stops, greatly improving efficiency.

4.5.5 Bridge Design

In order to be able to cross over the Ladegårdsåen, bridges will be needed along the route. Different types of bridges will be needed, such as pedestrian bridges, bicycling bridges, and automobile bridges. The locations of these bridges will depend on a number of factors, such as the locations of important roads crossing the AA route, the locations of significant businesses along the route, the locations of different green spaces, etc.

In the previous proposal done by Orbicon, several sketches of pedestrian bridges were presented, as illustrated by Figures a through e:

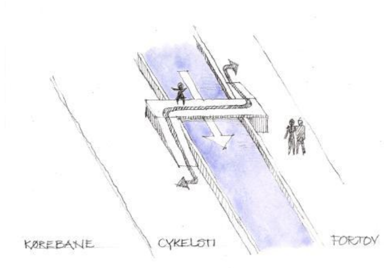


Figure a: Pedestrian Bridge 1 (Orbicon, 2007)

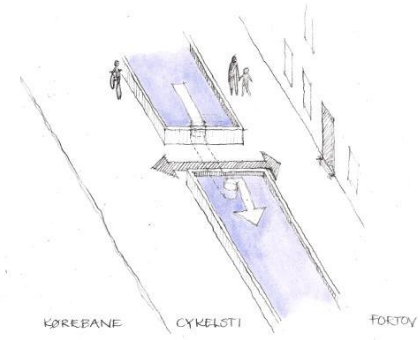


Figure b: Pedestrian Bridge 2 (Orbicon, 2007)

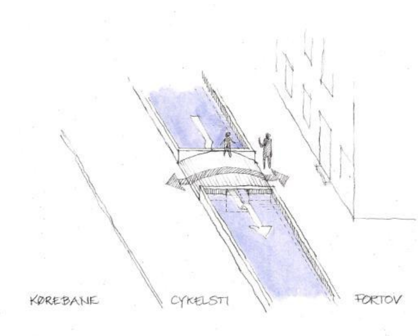


Figure c: Pedestrian Bridge 3 (Orbicon, 2007)

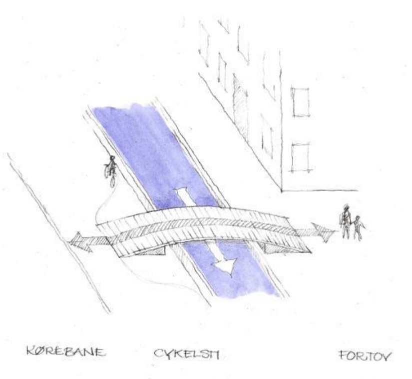


Figure d: Pedestrian Bridge 4 (Orbicon, 2007)

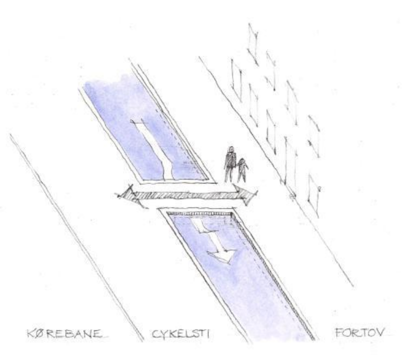


Figure e: Pedestrian Bridge 5 (Orbicon, 2007)

Figure 86: Orbicon Bridge Designs (Orbicon, 2007)

Some of these designs travel straight across the stream, remaining flat, (such as Figures b, c, and e). The water travelling in the canal would need to flow down under these bridges in a small channel and then rise up again to the canal on the other side. However, in order to allow for flood water to be properly transported by the Ladegårdsåen, the water would need to continuously flow. Therefore, the most feasible designs would have to rise up and arc over the canal, (such as in Figures a and d). Therefore, altercations of these two designs could be incorporated in the Ladegårdsåen.

During our trip to the Aarhus River, we were able to see some of the pedestrian bridges there in great detail. We had taken photographs for documentation, as seen in Figures 87 and 88:

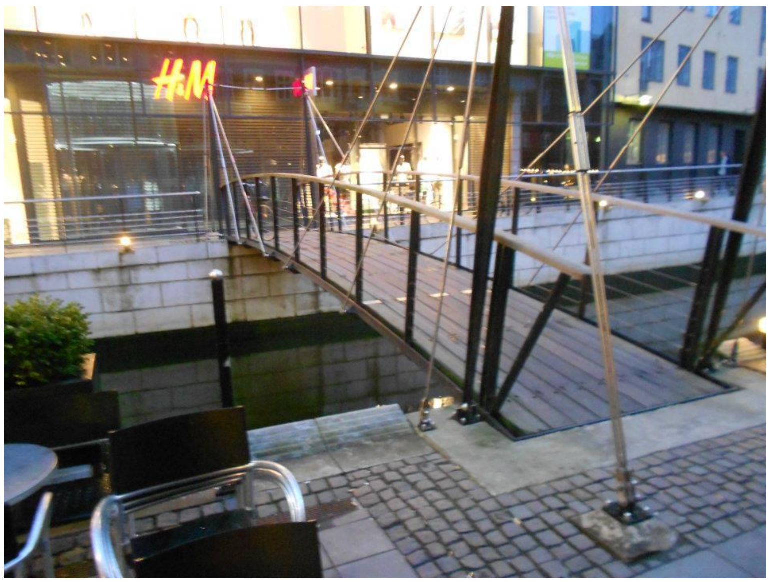


Figure 87: Aarhus Pedestrian Bridge 1

Figure 88: Aarhus Pedestrian Bridge 2

The two bridges shown in Figures 87 and 88 are of the same design. This design is a good example of one which rises up and arcs, instead of remaining flat. It incorporates a thin floor base and uses cables for strength and support. The frame of the bridge, the guard rails, and the support cables are made out of metal, while the floor and hand rails are made of wood. Its design is very cool and interesting, and provides a modern feel. The floor is not very wide, only allowing for minimal pedestrians to cross at one time. This bridge design is to allow for people to cross from one sidewalk to the other. However, cyclists could cross over if it was clear of pedestrians

The Ladegårdsåen will need many bridges similar to this design, which are to be used to transport pedestrians easily from one side of the canal to the other. Their placement will depend on the locations of significant businesses and roads. We suggest providing an ample amount of distance between them. After viewing the bridges of the Aarhus River on Google Maps, we were able to measure from bridge to bridge with the provided distance scale in order to gain a reasonable idea of how far away the bridges are there from each other. Screenshots of the maps can be viewed below in Figures 89 through 91:

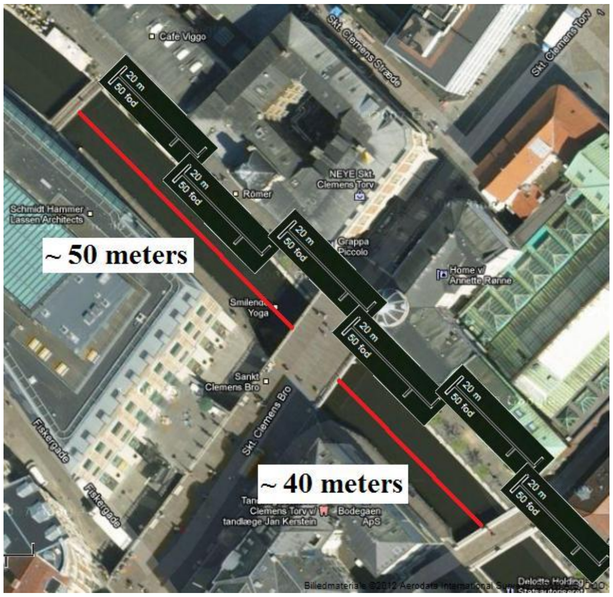


Figure 89: Aarhus River Bridge Distances 1 (adapted from Google Maps)

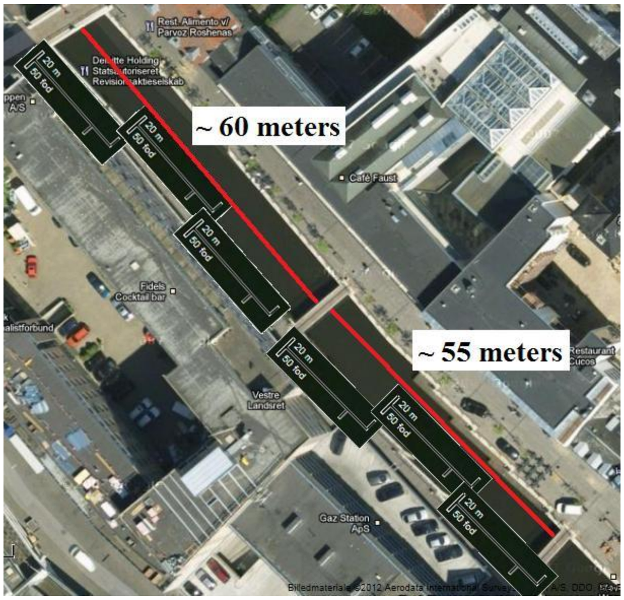


Figure 90: Aarhus River Bridge Distances 2 (adapted from Google Maps)

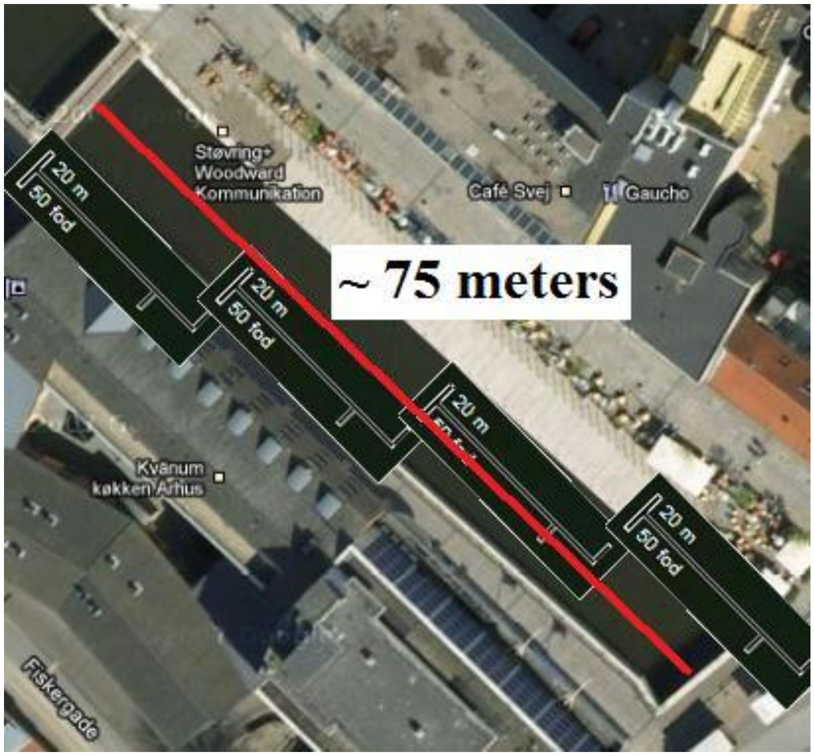


Figure 91: Aarhus River Bridge Distances 3 (adapted from Google Maps)

We learned from these measurements that the bridges along this certain section of the Aarhus River range from roughly 40 meters to 75 meters apart. Therefore, there is not a precise distance between bridges that is consistently used, but a reasonable range exists.

Our team developed the idea of using pedestrian bridges as an attraction for residents and tourists. This will consist of creating a vast amount of different types of bridges which incorporate different design aspects as well as different cultural aspects, providing an interest and intriguing sense of wonder to passersby. Some possible designs for such bridges our team came up with are illustrated in the sketches below:

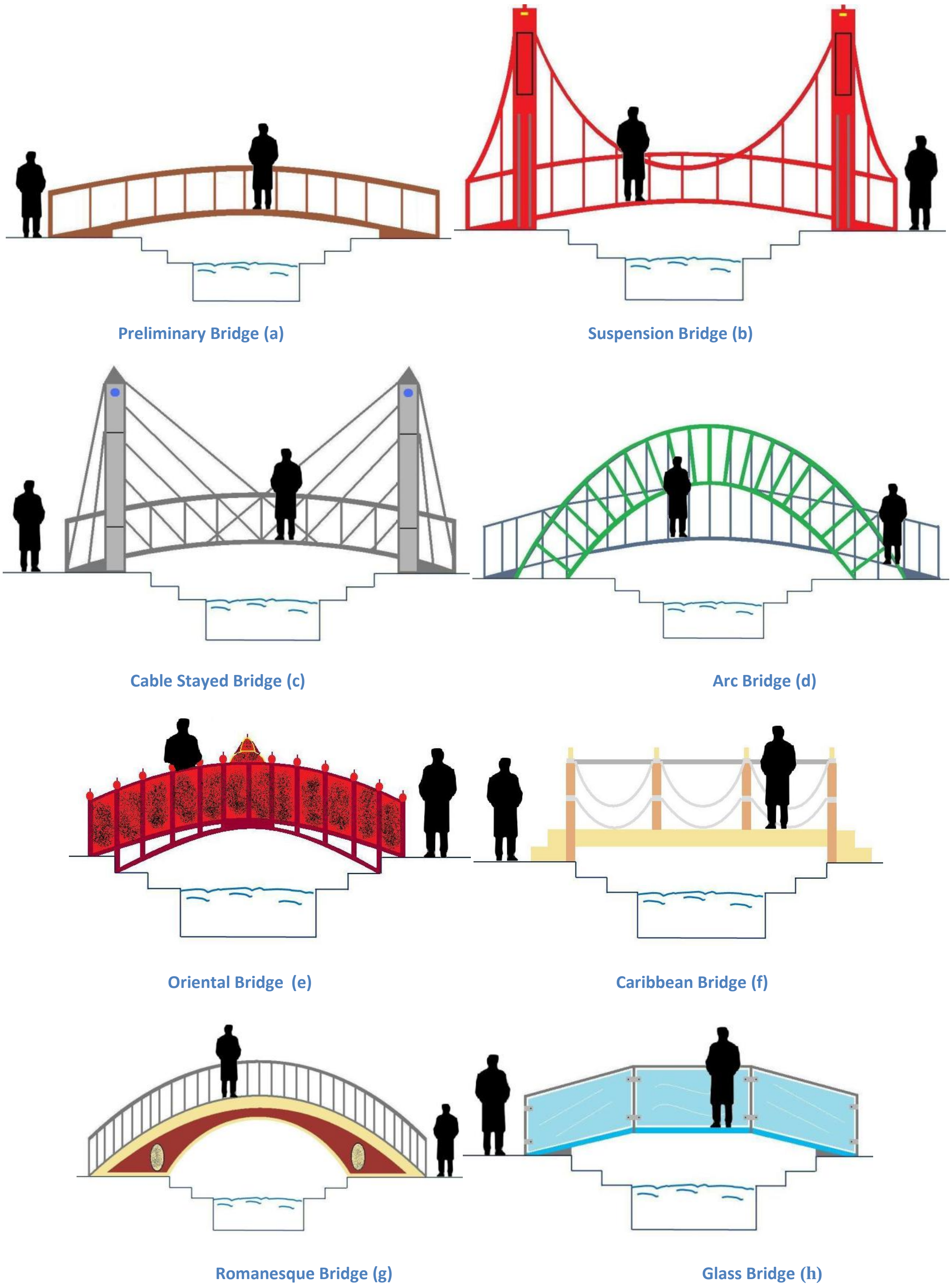


Figure 92: Pedestrian Bridge Examples

Our team had to view pictures of different bridges in order to get visualizations of each before sketching them. Figure a shows the most basic of bridges which we nicknamed the "preliminary bridge" and used to build some of the other designs from. It does not provide a technical or cultural aspect, however, being extremely basic and rather boring. Figure b shows a representation of a suspension bridge design which resembles the Golden Gate Bridge in San Francisco, California. Figure c is a cable stayed bridge design, modeled after the Zakim Bridge in Boston, Massachusetts. Figure d represents an arc bridge, such as one that crosses over a valley from cliff to cliff. These three sketches were built from the preliminary design. They encompass technical aspects of extremely large bridges on a much smaller scale, providing a sense of interest. They will most likely need to be made of steel, possibly with wooden floors.

The next three bridges represent different cultures. Figure e represents an oriental bridge, modeled after those in China. Figure f shows a design of a Caribbean bridge, resembling a boardwalk made out of wood. Figure g, resembles old roman architecturally design bridges, incorporating large arcs. These three bridges could provide different sense of culture in citizens and tourists. They could probably be made out of wood and stone, with steel for supports.

The final bridge is one that our team thought of on our own, which we call the "glass bridge," as seen in Figure h. This design incorporates a thick glass floor, enabling those who use it to look straight through into the water. The sides will also be made of glass, providing a very modern feeling. The frame will need to be made of steel, for a strong support.

As previously stated, these designs could act as an attraction, drawing in people to see them. Signs which explain the different aspects of each bridge could be installed in order to inform people of what they model or incorporate. They will have to cut through the green spaces on either side of the canal in order to allow from proper pedestrian traffic.

Apart from pedestrian bridges, another bridge design we viewed in Aarhus is shown in Figure 93:

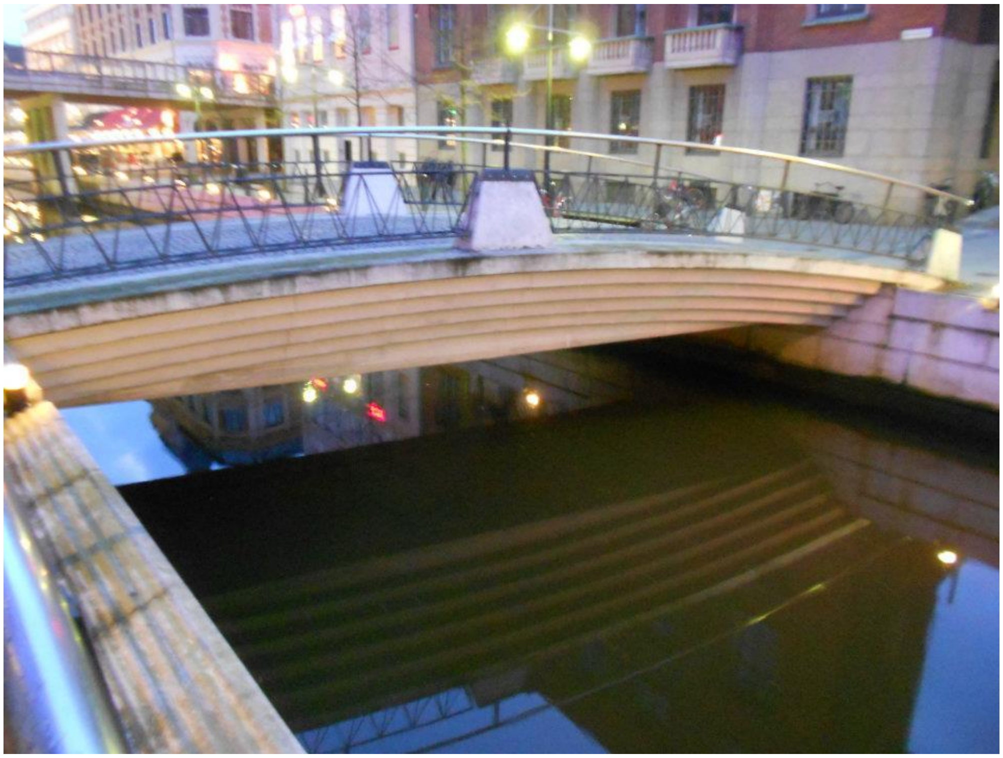


Figure 93: Aarhus Pedestrian Bridge 3

The design above is also an example of a bridge that rises and arcs, even though its bottom is flat. However, it is much different than the previous bridge both in design and use. This design incorporates a very thick floor base, being sturdy enough to not need cables for support. Its underbelly is layered with different widths, providing architectural beauty. This design is also wider, being able to hold a much greater amount of people and weight than the previous design. Its base seems to be made of stone and concrete, most likely being reinforced with rebar. The railings are made of metal and the floor is made of stone tiles. This bridge, also unlike the previous one, is used to connect the streets that continue on either of its ends. Therefore, it is not only used for pedestrians but for cyclists as well. Automobiles are not allowed on these bridges. On the Ladegårdsåen, bridges like these will need so barriers placed at the ends of the streets that the bridges connect in order to block motor traffic. Some streets that cross the AA route which might need a cycle bridge like this are shown in Figure 94:

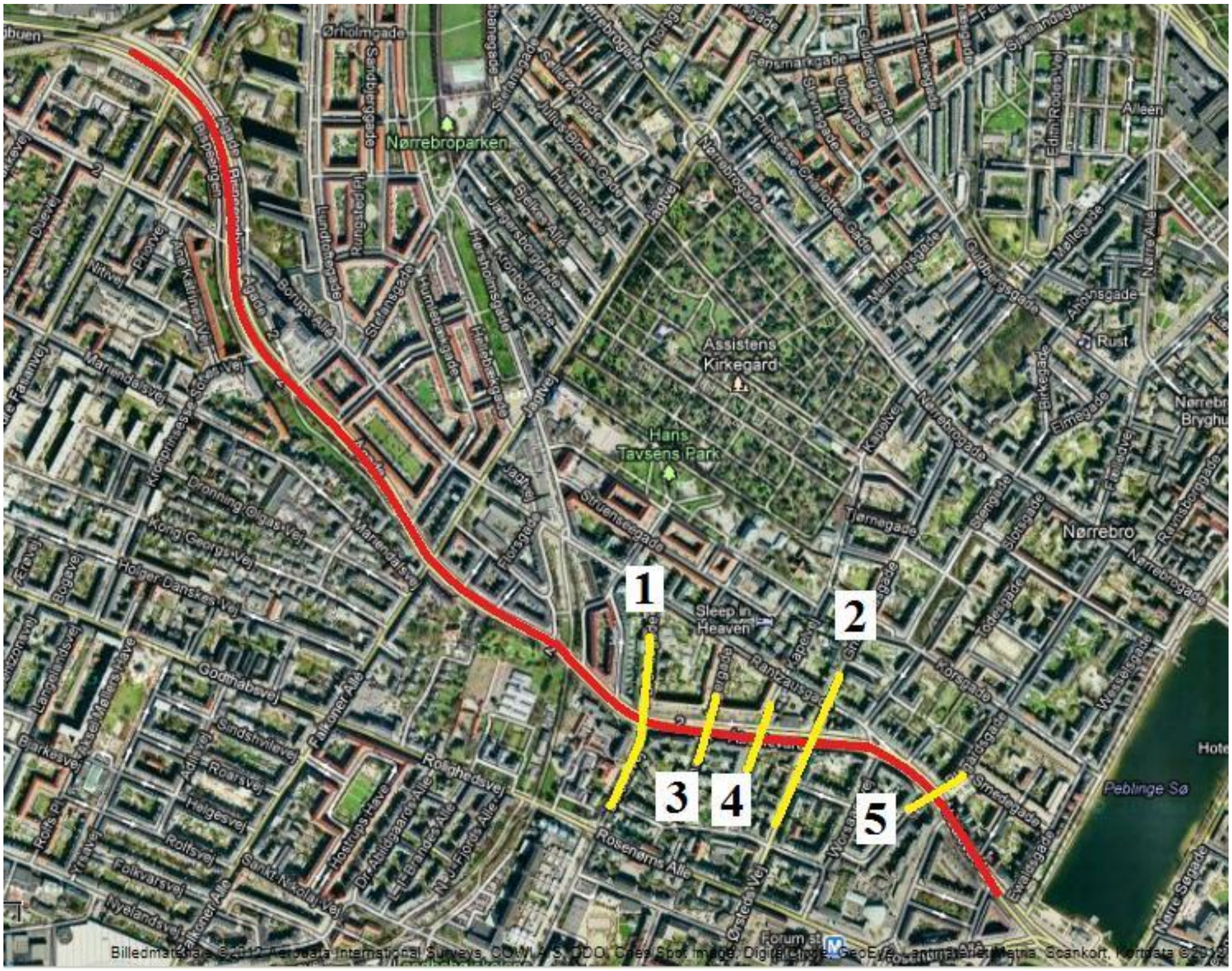


Figure 94: Possible Bicycle Bridge Areas (adapted from Google Maps)

The long yellow line on the left (1) represents the streets of Bülowsvej in Frederiksberg which continues to Brohusgade in Copenhagen to the north. The other long yellow line (2) represents the streets of H.C. Ørsteds Vej in Frederiksberg and Griffenfeldsgade in Copenhagen. These streets were mentioned in the previous proposal by Orbicon (2007) as important roadways to consider for bridges. Therefore, they will most likely need bicycle bridges to connect them. The other three smaller yellow lines (3, 4, 5) represent other street crossings which also might need bridges as well, but were not deemed important by Orbicon.

Along with creating bicycle bridges to connect roads crossing the AA route, bicycle bridges will have to be placed in areas along the Ladegårdsåen in order to transport cyclists from one side of the canal to the other. Although cyclists can easily dismount their bike and simply cross using the pedestrian bridges, our team came up with the design which we nicknamed the "cross bridge" shown below in Figure 95 which could potentially allow cyclists to stay on their bicycle while crossing.

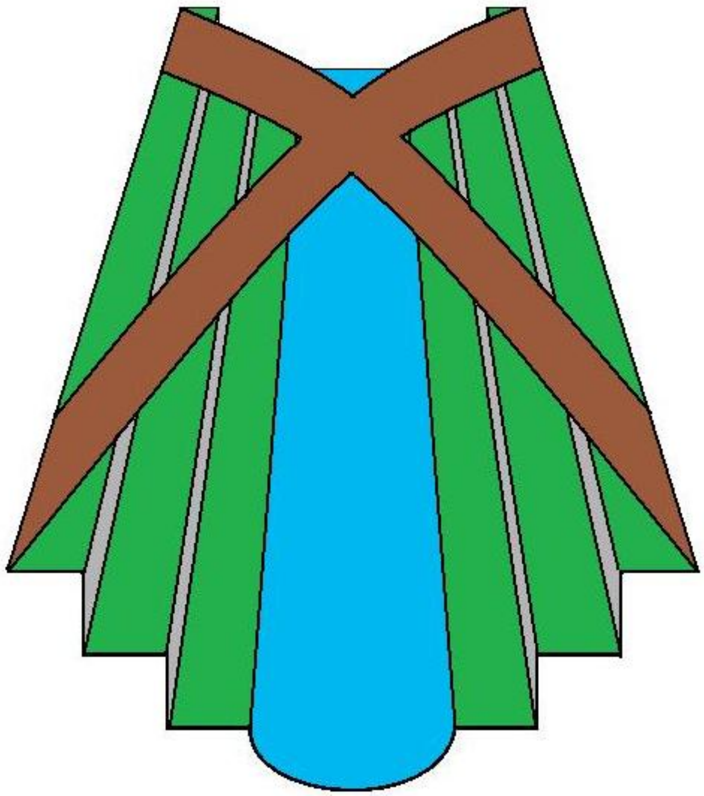


Figure 95: Preliminary Bicycle Bridge Sketch

This design could potentially allow for cyclists on either side of the canal to simply turn onto one of the bridge lanes and ride across. An aerial view of such a bridge can be seen in Figure 96:

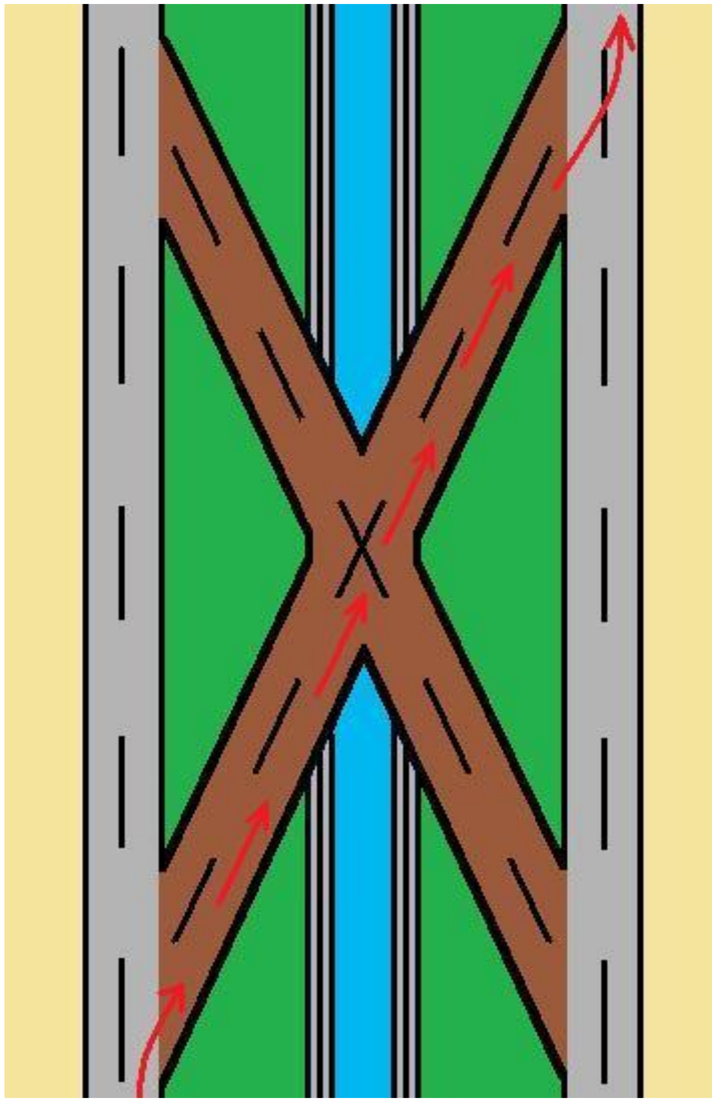


Figure 96: Aerial of Bicycle Bridge Design

As seen from the red arrows, cyclists could possibly continue on straight over the bridge and to the cycle route on the other side without ever dismounting. The width of the lanes on this bridge design would have to be at least as wide as the normal bicycle routes, but might have to be slightly wider due to the confined space provided while on the bridge. In order to provide ample head space for pedestrians underneath, it would have to rise while it crosses through the green space, therefore arcing and being high enough as not obstruct the pedestrians underneath the bridge. Having cables on top might interfere with the cyclists; therefore there will have to be supports underneath the bridge in order to hold it up. Guard railings will need to be included for safety and possibly a traffic light in the center to prevent collisions as well. This bridge might be too accident prone, therefore, only one lane could be built instead of having two lanes cross.

Similar to the pedestrian bridges, they will be located near significant businesses and roadways and separated at reasonable distances.

The final types of bridges which will need to be incorporated across the Ladegårdsåen are automobile bridges. We viewed such bridges across the Aarhus River, but could not acquire any photographs of them. Due to the need to have enough strength to support cars, buses, cargo trucks, etc, these bridges will be much larger than those previous discussed. They will need to rise and arc over the Ladegårdsåen in order to provide space for the water to flow continuously. Also, depending on whether or not people will be allowed under them, another reason why they will need to rise is to not obstruct pedestrians underneath the bridges on the banks of the canal. This might not be the case, in light of the limited amount of space available to do so. The green spaces on either side of the canal will most likely have to stop once the bridges cross through them due to placement of the bridges' supports in the green space. Also, vegetation will have difficulty living underneath the bridges without much sunlight. However, the bicycle routes will have to cross perpendicular over these bridges instead of going underneath in order to allow cyclists to follow the crossing streets, as seen in Figure 97:

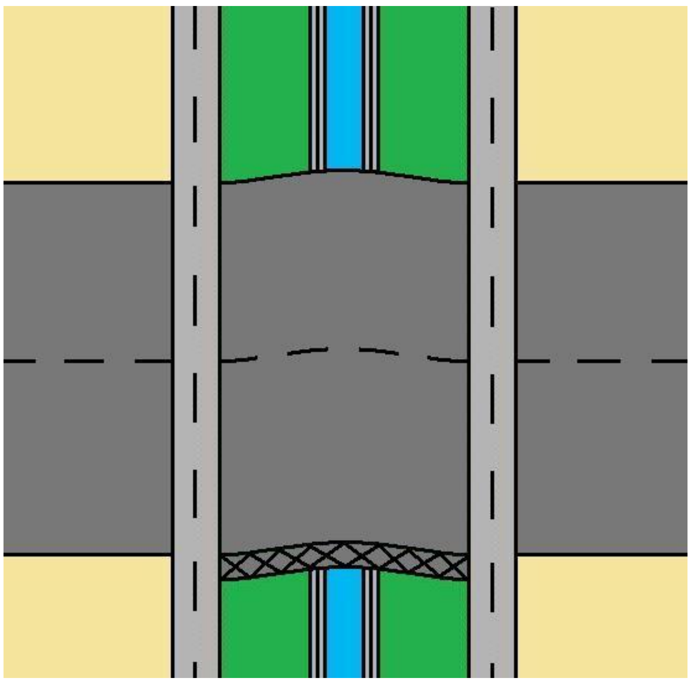


Figure 97: Aerial of Automobile Bridge Design

Fortunately, only a couple of these bridges will need to be implemented. Figure 98 below shows the different roadways which will possibly need these bridges:

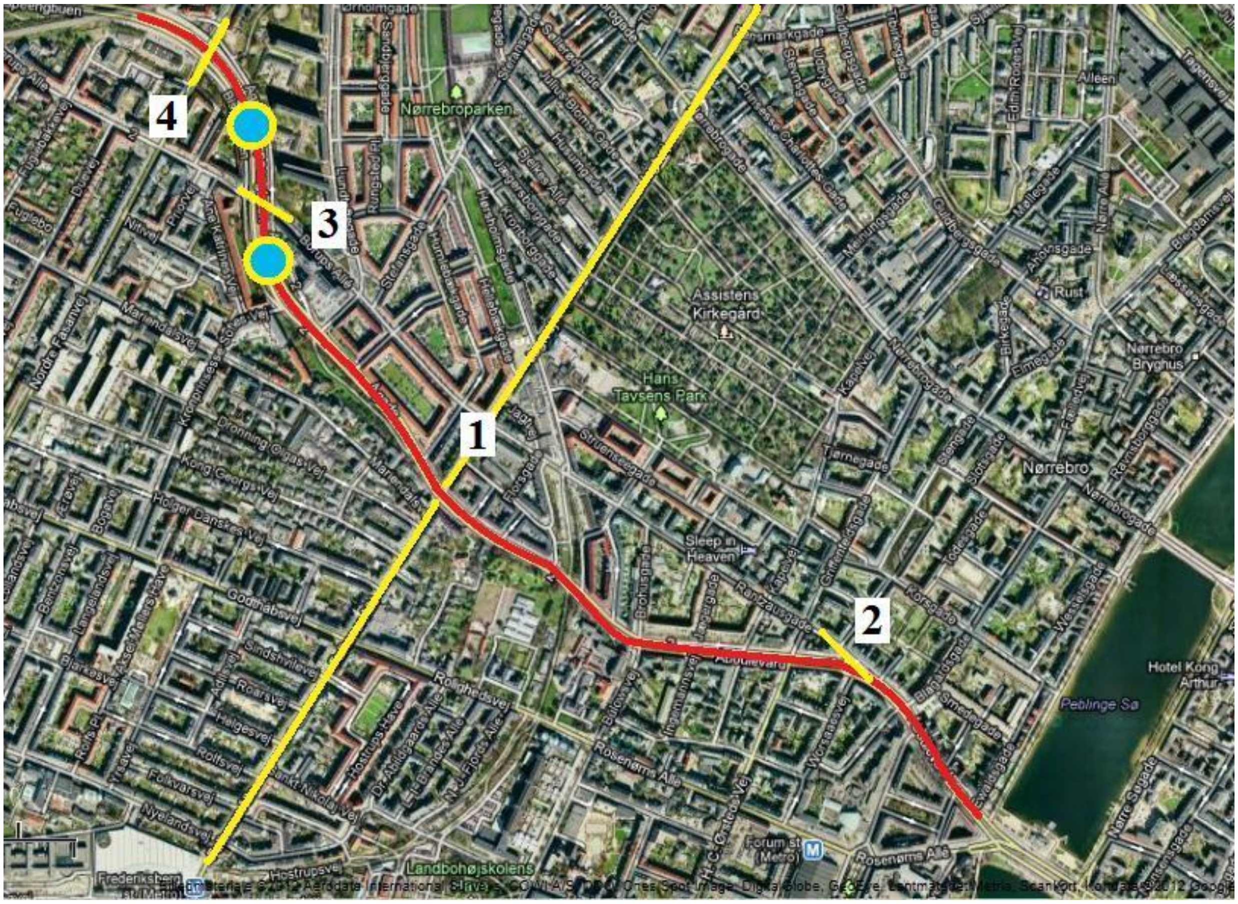


Figure 98: Possible Automobile Bridge Areas (adapted from Google Maps)

The long yellow line (1) in the center represents Falkoner Allé in Frederiksberg which continues to Jagtvej in Copenhagen to the north. Anders, who is a resident of Nørrebro, explained to us that this is the most trafficked route crossing the AA route and exists as a main route running through Nørrebro and Frederiksberg. Therefore, it will definitely need an automobile bridge. If these roads were to be used as drains, transporting rainwater to the canal, then drainage ditches or pipes will have to be present before their bridge on either side in order to direct the runoff water into the canal. The small yellow line (2) in the bottom right area of the map shows the bridge that will connect to Rantzausgade from the roadway on the AA route in that area, as previously stated. The two blue dots represent the possible beginnings of the Ladegårdsåen, while the red line represents the tunnel. Therefore, the yellow line (3) in between the blue dots, which represents Borups Allé, may or may not need a bridge depending on where the water in the canal will begin. The small yellow line (4) in the top left represents another main road, Nordre Fasanvej, which will not need a bridge but will travel over the tunnel. Due to the different amounts of lanes on each route, the widths of the bridges will alter accordingly.

4.5.6 Pedestrian Walking and Gathering Area and Storefront Area Designs

Figure 99 below shows the bike lanes, pedestrian walkways, and store fronts during the day. The pedestrian walkways could be made out of brick, cobblestone, concrete, or asphalt. They could vary at different areas along the AA, where the smallest area is around 4m and the widest area is on average 8m-9m. The pedestrian walkways are between the storefront areas and bike lanes, where the pedestrians can easily access their homes, shops, and restaurants or quickly transition from walking to biking. The tables and chairs, placed in front of cafés and restaurants, would not be bolted down, because we would want this space to be used for emergency vehicles.

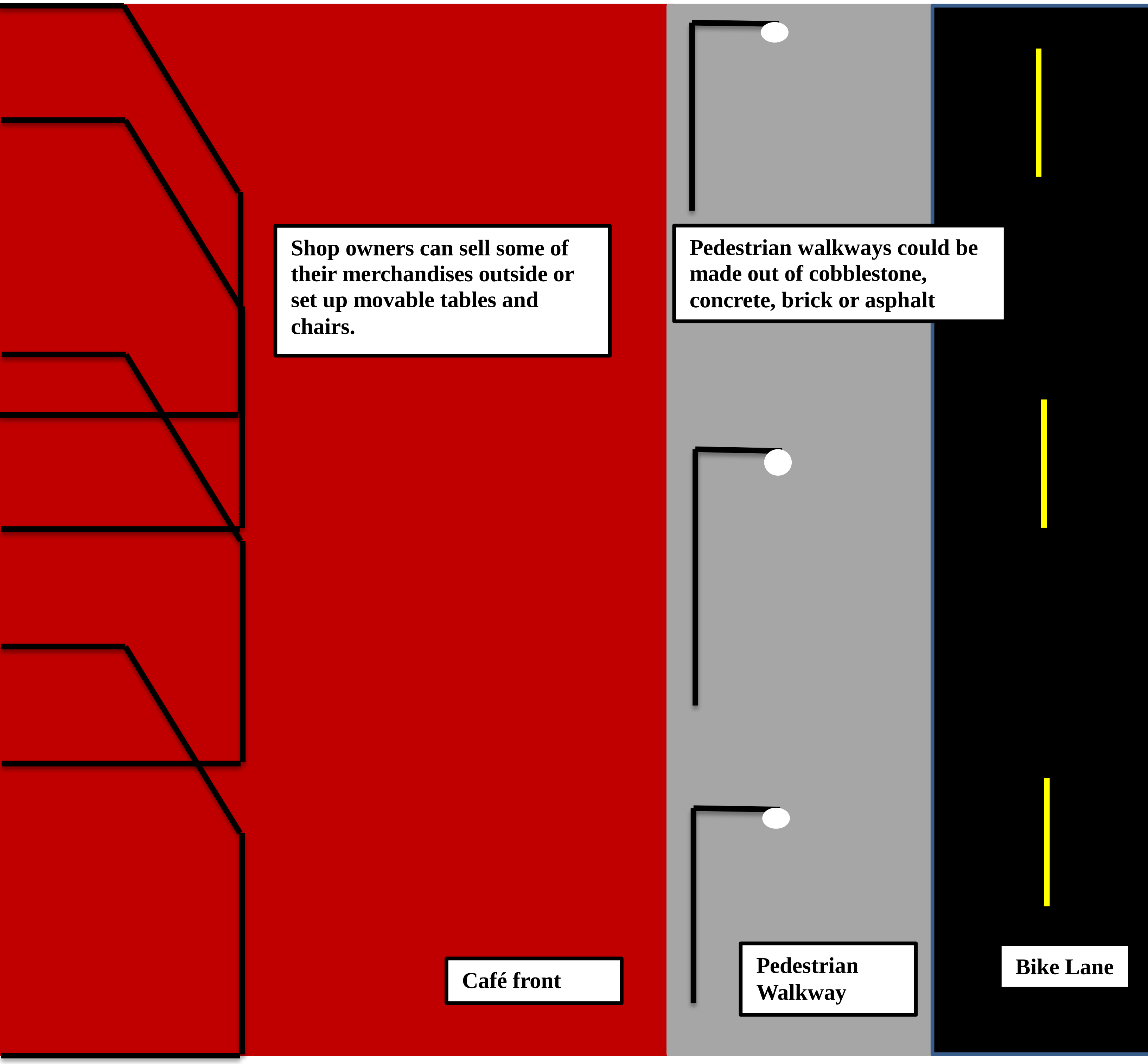


Figure 99: Pedestrian Walkway

The storefront area will differ along the entire route. 2 meters will always be reserved; in areas where stores, restaurants, and cafes are located, this space can be used to display store merchandise or for tables and chairs. In front of residential areas, this space can be used for bike racks, entrances into buildings, for plants and benches, and to create space and privacy between the pedestrians and homes. Some examples of this are shown in Figure 100 below. This area will be connected and blended to the pedestrian walkways in some areas.

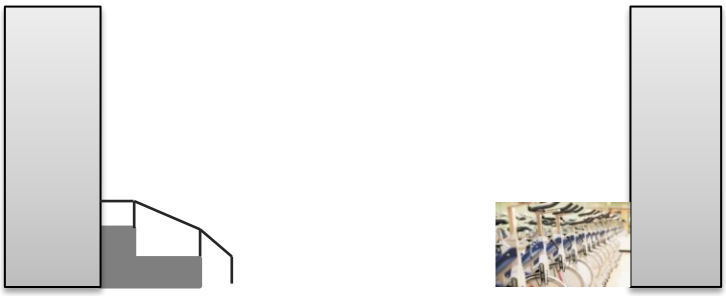
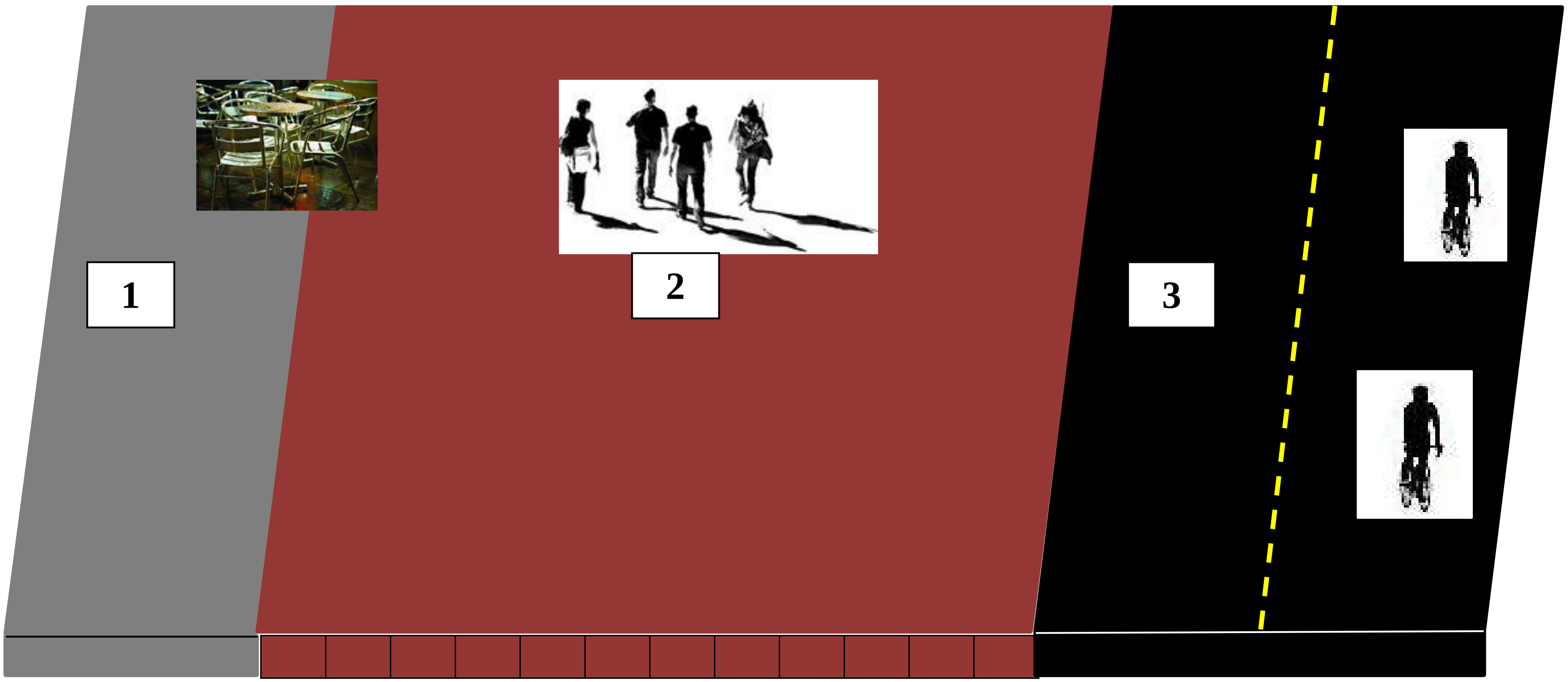


Figure 100: Storefront Area

4.5.7 Brief Overview

Figure 101 is a visual summary of the entire design process. Starting with the gray area, labeled 1, to the canal itself, each major design feature is given a number and briefly described below. All of the different parameters of our plan can be connected like this to make one, unified design.



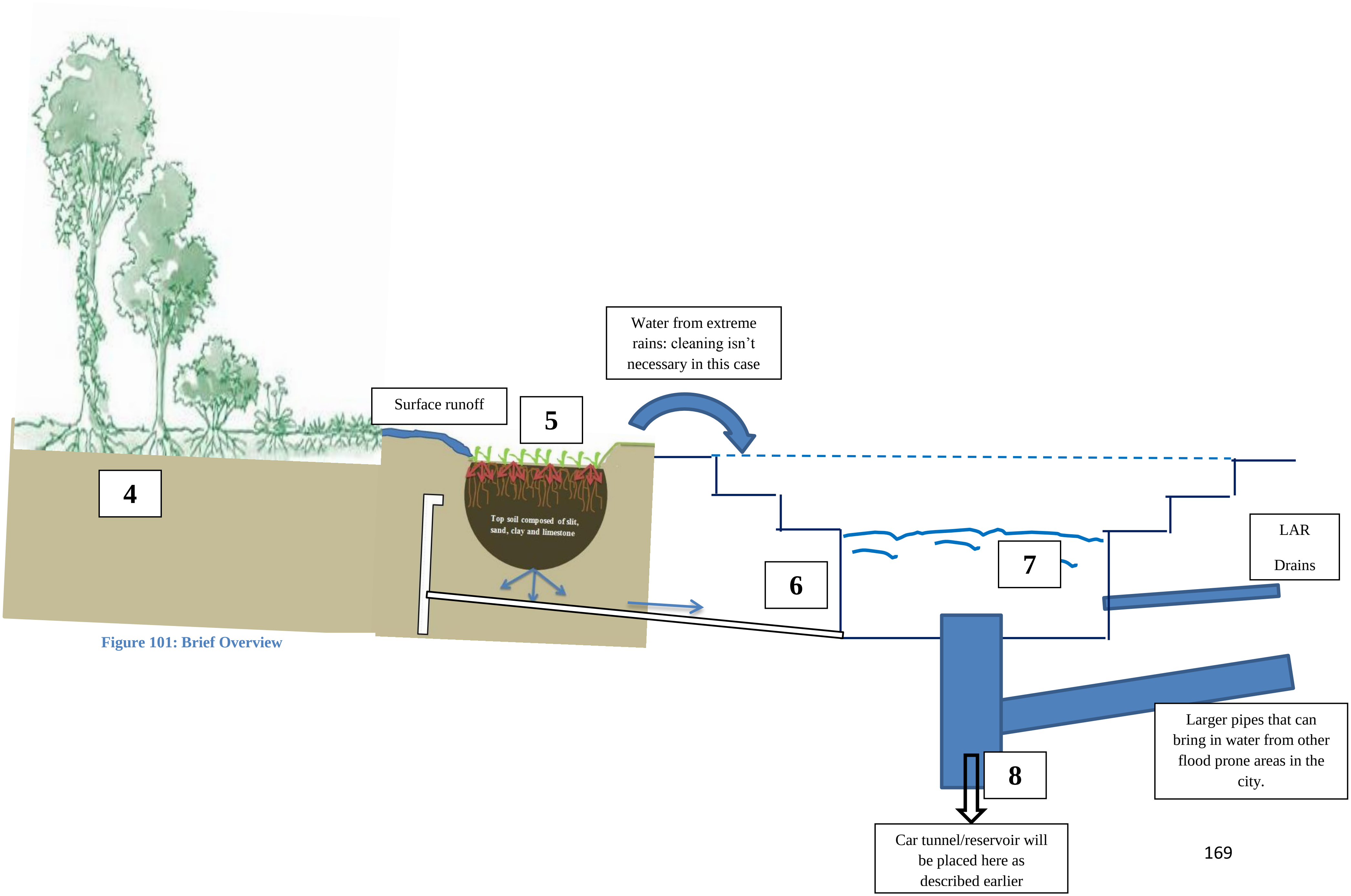


Figure 101: Brief Overview

1.) The area closest to the buildings will be 2 meters wide on either side of the route and will be used for storefront merchandise, café and restaurant tables and entrances, residential entrances, bike paths, and an area to create some space for privacy for those living along the route. We have referred to this area as the storefront area. This area can be made with cobblestone, concrete, brick, etc.

2.) The area alongside the storefront area is the pedestrian walking and gathering area. The width for these walkways will vary depending on the width of the route. The North side of the route will, however, always be slightly larger than the South side because it receives more sunlight throughout the day due to Denmark's location in the Northern hemisphere, as explained earlier. The designs of this feature can vary along the route, but they will all serve the same purpose, which is to provide a large amount of space for people to travel along the route and shop and eat, as well as simply gather and hang out. In larger areas, this feature can be used for benches and more café and restaurant tables, similar to Aarhus.

3.) The bike path will be alongside the pedestrian walkway and will be 4 meters wide. A bike path will be constructed along each side of the canal, and will, therefore, take up a total of 8 meters. Each path will be used for travelling in both directions meaning that a lane for one direction will be 2 meters wide. The bike paths will be made of pavement and will not be raised or lowered so that they do not interrupt the flow of rainwater from the surrounding streets as it makes its way to the canal.

4.) Green space will be the next design feature and will be between the bike paths and the canal. Similar to the pedestrian walkway, the design of this area will fluctuate along the route depending on the amount of space available. Larger trees, as well as shrubbery, grass, and flowers will make up this area. Benches, cobblestone walkways, and other fixtures can be added throughout this area. Making sure there was room for green space was a huge focus of our project and one of the most beneficial outcomes of our design. In wider areas of the route, over 10 meters between buildings will be reserved for green space.

5.) Rain gardens are connected to the green space and very similar to it, except their main function will be to filer rainwater that runs from the streets before it enters the canal. They will serve this function only during normal rain events, during extreme rains there will be too much water for the rain gardens to handle and the focus won't be on cleaning the water with the gardens, rather it will be on simply getting rid of it. The rain garden will be indented into the ground to collect water and the ground will consist of a mixture of soil, silt, clay, and limestone to best filter the water (Jensen, personal communication, 2012). Once water passes through the rain garden, it will be directed into the bottom of the canal.

6.) Geotextiles (woven, permeable polymers) will be used to do a final filter cleaning of the water, making sure that no soil is

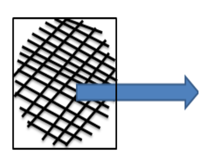


Figure 102: Geotextiles used to Help Filter Rainwater

carried into the canal (Franklin, Hampden, Hampshire Conservation Districts, 2003). Wherever there are rain gardens, geotextiles will be present along the bottom edge of the water channel on both sides.

7.) The water channel double profile design will allow water to flow through the small channel at the bottom during normal rain conditions. The steps create a gathering spot for people and leave many options for design. During extreme rain conditions the steps could be flooded to the top allowing for much more water to be held by the channel if necessary. We made the area of the main bottom rectangle in our design to be 1.5 square meters. This will hold many different sources of water, including LAR, water from drains, and stormwater runoff.

8.) Underneath the canal, at various locations, will be large vertical pipes that can carry the water from the canal down into the parallel pipes running through the center of the tunnel. These pipes will be opened in extreme rain events and will be able to keep the canal from overflowing. Water from other flood prone areas of the city will be sent to these pipes to be used elsewhere or be reused by the canal. The car tunnel will be directly under the canal. This design was previously described.

4.6 Possible Beginnings and Ends of the Canal and Tunnel

Our team decided that the tunnel should start north of Ågade's intersection with Borups Allé where a high rise highway flows into the AA route. The high rise will need to be place underground, therefore, the tunnel will have to start somewhere before it. The canal will have to begin somewhere in that general area as well. However, there will need to be enough distance between the start of the tunnel and the start of the canal to allow ample room for the tunnel to reach a proper depth in the ground.

As previously stated, once the canal reaches the lakes these are two different possible routes it could follow. Our team did not go into great depth on these matters because once the canal reaches the lakes, the geographical area of focus is outside of Nørrebro and, therefore, outside the jurisdiction of Miljøpunkt Nørrebro. One scenario involves crossing under the lakes at the end of the AA route and continuing on H.C. Andersens Boulevard until reaching the harbor, being channeled underground throughout the entire stretch. The other involves a route that flows south along the lakes and through the meat packing district in the south of Copenhagen until reaching the harbor.

Our team discovered that H.C. Andersens Boulevard rises slightly and is crossed by an obstructing rail line, making it seem rather impractical for a flowing canal. The latter route seems more feasible due to its lower elevation and vulnerability to flooding (S. Werner, personal communication, 2012). The canal could possibly be on the surface for a decent stretch and then might need to be channeled later on its course.

Apart from the canal water, the tunnel will need to continue along H.C. Andersens Boulevard, but could either emerge to the surface just before the lakes or travel underneath them and emerge closer to the city center in H.C.A. Figure 103 below shows the two alternative stage 2 routes as well as general areas where the tunnel will enter and emerge from the ground (the black dots) and where the canal will begin on the surface and flow into an underground channel (the blue dots):

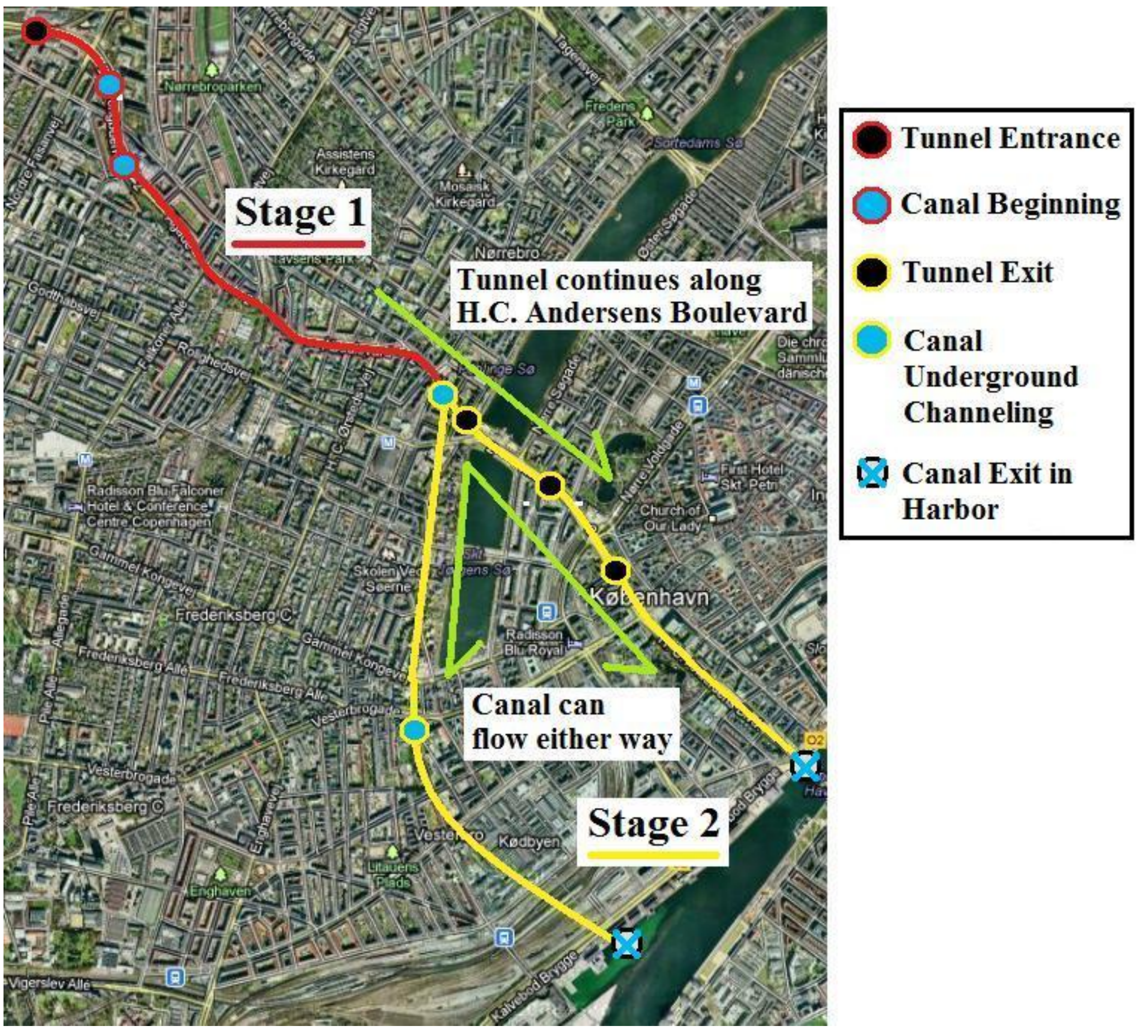


Figure 103: Stage 2 Alternatives and the Possible Beginning and End Areas of the Canal and Tunnel (adapted from Google Maps)

Chapter 5: Conclusions and Recommendations

This project focused on increasing green space, reducing flooding, and uplifting the area along the daylighted route. In light of the results of a previous community involvement study performed by Miljøpunkt Nørrebro, in collaboration with Orbicon in 2007, our team realized we needed to focus highly on creating green space and using rainwater runoff. Not only do the citizens of Nørrebro desire an increase in greenery, but Miljøpunkt Nørrebro's mission is to promote greenery through sustainable systems. However, our team understood that daylighting the Ladegårdsåen will not become a reality without thoroughly encompassing the possibilities of reducing flooding. Meanwhile, we kept in consideration using the entire Ladegårdsåen project to uplift the AA route and Nørrebro recreationally and environmentally, as well as economically, similar to what occurred with the Aarhus River daylighting.

As previously stated, our selected route for the Ladegårdsåen was along the Ågade to Åboulevard towards the lakes, with a motorway tunnel placed underneath. This decision was influenced mainly by the available space on the route and the ability to place the motorway underground. Having no traffic on the surface provided more space for the canal, large amounts of space for greenery, wide bicycle paths, and pedestrian walkways, and it allowed for minimal disruption of the regional traffic.

We addressed the flooding issue by using the canal as a means to transport rainwater out of the area. Also, by using the tunnel as a reservoir (similar to SMART in Malaysia) during times of extreme rain we created a significant amount of storage space for floodwater. Apart from these beneficial factors, the route also had the most potential to help with the reduction of environmental problems affecting Nørrebro. The AA route experienced substantial amounts of flooding, noise, and air pollution. The areas surrounding it are quite hot due to urban heat and contain very little green space. This route also fits in geographically with Copenhagen's plan to implement green corridors throughout the city. All of these issues were addressed by the Ladegårdsåen daylighting, using relevant ideas that had worked well for the Aarhus River.

The elevations surrounding the route and the slope of the route itself allowed for ideal rainwater runoff collection and transport. The areas surrounding the AA route are much higher in altitude, allowing water from an enormous watershed area to flow to the Ladegårdsåen and the tunnel reservoir. The slope of the route is good for transporting water towards the direction of the lakes and to the harbor and can be made perfect by being placed upon the tunnel and reconstructing the land. For all of these reasons, our team has concluded that the AA route with the motorway tunnel reservoir is the best choice for daylighting the Ladegårdsåen.

We delivered design options for the main features of the route. The “double profile” section view of the canal, shaped as a reverse pyramid, which incorporated steps on either side, was chosen because it provided a way for citizens to view the canal up close in a relaxed manner and allowed for a large increase in water capacity. The tunnel reservoir, designed as a six lane highway split in the center by a vertical barrier containing drainage pipes, provided a means for the regional traffic passing through the AA route to continue having access to the center of the city, and created a means to collect and store an immense amount of storm water from an enormous area (during extreme flooding) in order to reduce flooding on the surface.

The green areas along the sides of the canal were given high priority in terms of space provided. They were designed to have a large variety of vegetation being able to withstand an urban environment and provide beautification to Nørrebro. Rain gardens were implemented to collect and clean normal rainwater before being directed by an underground barrier into the canal. Bicycle lanes on either side of the green spaces were given enough space for travel in both directions, allowing cyclists to be close enough to experience the greenery and the canal safely. Pedestrian walkways beyond the bike paths were designed to be close to café, restaurant, and store fronts in order to promote socializing and business growth and development. The northern side of the AA route will have a wider pedestrian area because it experiences more sunlight due to the fact that Denmark is in Earth’s Northern hemisphere. These pedestrian areas were designed wide enough to have enough space for emergency vehicles to travel on, as well as delivery transport trucks.

Separate bridges were designed to allow for easy transport of pedestrians, cyclists, and automobiles. Such bridges will connect the sides of the canal at specific locations, such as important street crossings and business areas, providing ample space between them. Some bicycle bridges will allow cyclists to easily cross over the canal without stopping or performing drastic turns. The pedestrian bridges were designed as an aesthetic, as well as practical attraction, allowing citizens and tourists to experience the engineering provided by scale model designs of much larger bridges and to experience the atmosphere provided by different cultural bridges from around the world. Together, all of these design features will help create green space, reduce flooding, and uplift the area.

Along with benefiting Nørrebro, this daylighting project fits in with the environmental and sustainability goals of the entire City of Copenhagen. The canal and its green space could act as one of the new green corridors, connecting other green sections of the city together in a criss-cross pattern (Københavns Kommune, 2011). Having green space run along the canal intertwines the blue (water) and green grids in the city, something Copenhagen wishes to pursue further (Københavns Kommune, 2011). The idea to provide a large variety of plant life in the green spaces of the Ladegårdsåen ties in with the city's goal to increase biodiversity (Københavns Kommune, 2011). The trees planted along the canal correspond to Copenhagen's efforts to dramatically increase the amount of trees within the city (Copenhagen's Green Accounts 2010). With all of these efforts to make the city greener, the reduction of particle and noise pollution is a possible benefitting result. Another possible result of daylighting the canal could be a reduction in urban heat, a problem well understood by the city (City of Copenhagen, 2011). Separate from the environmental benefits, the Ladegårdsåen could create a new bicycle corridor which could hopefully increase the total number of cyclists in the city, aiding two desires of Copenhagen related to bicycle transportation (Københavns Kommune, 2010). The idea of using water collected by roofs and collection drains ties in with the goal to reuse as much rainwater as possible in order to save drinking water, an effort made known to us by Ove Larsen, an expert on LAR solutions (personal communication, 2012). Related to this idea, the Ladegårdsåen's water could be used for many different practical purposes, relating to the desire to use "sekundavand," or non-potable water, in several benefitting ways throughout the city (Københavns Kommune, 2011). By promoting all of the Ladegårdsåen's potential benefits which correspond to the goals and desires of the City of Copenhagen, the daylighting of this canal could hopefully become a reality in the near future.

However, there is still much to be done by Miljøpunkt Nørrebro in order for the daylighting of the Ladegårdsåen to become a reality. Therefore, the following is what our team recommends for the future success of this project. Although we mentioned and briefly described where to obtain water and what it can be used for after it flows through the canal, we did not go into great detail on this matter. There is still much to be discovered about how to transport water from all the possible sources into the Ladegårdsåen, how the flow of water in the canal could begin, how to regulate a constant flow of water, and how to transport the water at its endpoint to be recycled in various ways.

Although our team mentioned using a ventilation system in the tunnel which removes the pollution particulates from the air, further research needs to be performed on how to implement such a system in a tunnel which can be flooded. For instance, the system might have to be closed from the rest of the tunnel if it cannot be submerged. All of these questions need to be researched and discussed in order to have an entire route planned out for the Ladegårdsåen canal and tunnel. From there, our general design ideas can be further evaluated on a technical level.

After leaving Copenhagen, Miljøpunkt Nørrebro can use our report and designs to gain public support through street events and through the promotional website created by Anders Jensen, a Miljøpunkt Nørrebro employee. They can promote the AA route with the tunnel by showing the benefits gained by daylighting the Ladegårdsåen, such as creating green space, reducing flooding, and uplifting the area, and by showing that the AA route is prone to the aforementioned environmental issues. Pamphlets with the website URL can be handed out at the street events. Once on the website, viewers can read our entire report or relevant sections of it and complete a survey in order to provide their feedback and ideas on the project. Miljøpunkt Nørrebro will then be able to alter the project to please the most people. Gaining community input is valuable in daylighting projects as our research of similar projects has shown.

With this public support, gaining municipality support of Copenhagen and Frederiksberg will possibly be easier. This could be achieved by creating a poster containing an aerial view of the AA route with different pull-outs illustrating the design sketches of the canal and rationale, as well as results from the community involvement. This could be presented to the municipalities and potentially get them interested and excited on how this project fits in with their environmental goals and could benefit their citizens. Once they know of the project, its potential benefits, and challenges, they will be able to provide their input. If they wish to pursue daylighting the Ladegårdsåen, they can then consult Orbicon or other engineering firms to technically analyze the entire project, providing feasibility studies and cost analyses. From there, the municipalities will be able to discuss the implementation and payment of the project. Hopefully sometime in the near future, the daylighting of the Ladegårdsåen will become a reality. Moreover, our team hopes that our efforts with Miljøpunkt Nørrebro will make a great impact in the beginning phase of this extensive and wonderful project.

Appendix A: Interview Summaries

Interview Summary of Lars Barfred, Project Liaison: January 24, 2012

Comments in bold are changes or additions made on our initial interview summary upon review by Lars Barfred.

Lars Barfred's Background:

-Barfred has an economic and marketing background. He has previously worked for both Microsoft and Coca Cola in Denmark.

-For the last couple of years he has been working with sustainable and urban development.

-Currently, Barfred works for Miljøpunkt Nørrebro (formerly known as Agenda 21) in Copenhagen.

-He is working with Anders Jensen on the Ladegårdsåen project (trying to get more financing for said project).

Goals to be Accomplished by this Project:

-Overall, the goal of the project is to make the city greener, more sustainable, and more livable for the people living in the area.

-The opening of the canal would practically get rid of an automobile street and automobile parking and, therefore, make the area less polluted from traffic and more enjoyable for its citizens.

-Copenhagen has a low percentage of car ownership, 20% of inhabitants owns a car, equal to 30% of all households. Yet 80% of city space is reserved for cars. More space is wanted for bicycling, walking, and recreation.

-Copenhagen has a healthy economy and it is important to keep families in the city. When families move to the suburbs, it creates a very low tax income in the city. This project will make the city more pleasant to live in.

Pollution Reduction

-Due to the large amount of traffic, noise pollution is a big concern. Many exisiting buildings **would** not be allowed to be built, did they seek approval today, because of the high noise pollution. Copenhagen seems to have no chance of reaching its goal to have all housing below 58 decibels.

-Copenhagen is heavily polluted. The EU has set standards for how much pollutant you can have in the city, and Copenhagen is halfway from reaching their 2015 goal.

-It is important to reduce noise pollution because this type of pollution can lead to sickness and even death. Noise pollution also makes workplaces very inefficient; it can be extremely loud or you may have to keep windows closed. It can also affect schools in the city. Noise pollution leads to a loss of production to those it affects.

-Property values drop by huge amounts when affected by noise pollution.

<u>Incentives for Opening the Canal:</u>

-The project is very tangible. It is an easier project to promote to the public than many others because it has a lot of reasons to be opened.

-The canal is one of the main reasons the city of Copenhagen is situated where it is. It was built around the canal and the harbour, which is why the canal has a large amount of historical value.

-Over the last few years, Denmark has experienced a lot of rainfall which has induced many floods in Copenhagen, costing billions of kroner and leading to much damage and destruction. The canal could be a possible solution to some of the flooding.

The Heavy rains has created awareness that high density of hard surfaces, creates an enormous pressure on sewage and drainage systems, and awareness of the fantasilions it cost to upgrade.

-The new government is going to make a toll ring around Copenhagen, which will reduce car traffic inside the ring by around 30%, which will make the project much more feasible.

-In terms of funding, Odense (third largest city in DK) has received a donation of USD 50 million / Kroner 255 mill. for a similar project, from a foundation, which might well wish to fund the Canal.

In Aarhus (second largest city in DK), the city itself developed and financed a similar opening of a canal in the city center, which actually was the origin of the city name, which means "by the canal"

<u>Original Incentive</u>

-Before flooding added even more incentive to open the canal, a better city space development was one of the first reasons to start this project. The original idea was developed more creatively than technically. It was presented to the city municipality, and they decided that there were not sufficient funds for a project like this.

Geography

-The canal is buried under the most trafficked road in Denmark.

-The road will be diverted into nearby streets to make the opening of the canal possible. (It would be good research for our group to look at maps and determine possible routes and alterations to make the closing of this road possible.)

-The lakes (4 big lakes) in Copenhagen were originally made as water reservoirs in case of fires in the city.

-The possible area for the part of the canal that will be opened will be one long stretch, with two bridges over it, starting at the border of the city and going to just about 200 meters before the lakes. It would then go under some streets until it reached the lakes.

Pipes and Drainage

-We will look further into the technical aspects of the project, such as the amount of water that flows through the pipes today and the amount of water that can be absorbed by the canal to reduce flooding.

-The Copenhagen drainage system is highly developed with much underground chamber space that can take in large amounts of water, but still not enough for the very heavy rainfalls.

-The name of the man who is very knowledgeable about the Copenhagen drainage system will be sent to us by Lars Barfred.

-Ove, can be reached at; ag21.Ovel@gmail.com

Public Opinion

-Many people who own cars don't want a project like this because it takes away from their parking and streets in the city.

-The awareness of the project isn't very high.

-What are some of the main factors that would help keep people living in Copenhagen (from a public research study)?

1. 50%: Cheaper property and transportation
2. 38%: Less traffic and traffic noise
3. Better biking and bike parking
4. Better public transportation
5. Better green areas
6. **Affordable housing**

7. Better handling of socio-economic problematic neighborhoods

Interview Summary of Suzanne LePage, Worcester Polytechnic Institute Civil and Environmental Adjunct Professor: February 3, 2012

<u>What is Runoff?</u>

-All rainfall that is not evaporated. It doesn't infiltrate due to pavement, sidewalks, and roofs. It is not abstracted (held in vegetation). It is basically anything that does not go through the water cycle.

-Realistically, we should define the watershed (the area the water comes from) by using a contour map, define the runoff coefficients (lower ones are better ~0.4), and study the geography and rain data by contacting some sort of National Weather Service.

-It depends on what is upstream and what is downstream. Try to track down someone from their equivalent of a Department of Public Works.

-She showed us what a hydrograph is: Amount of Runoff vs. Time. The amount of runoff will hit a peak at first and then start to slowly drain.

-A good case study is Providence, where they opened a canal.

<u>Engineering Structures to Help Decrease the Runoff</u>

-Storage or detention pond. This kind of structure contains the water and lets it out slowly, therefore making the initial volume of water affecting an area much less. It also creates a steady flow of water into an area, instead of an extreme quantity all at once.

-Collection systems and pipes can transport the water to where it is needed.

-One possible disadvantage is that the runoff water which flows into the canal would contain contaminants from the urban area. This would therefore have to be treated.

-She gave us magazines about stormwater runoff and management containing general background on the subject.

<u>Is Certain Vegetation Better for Absorption?</u>

-The denser the better. More vegetation will use more water. Also, trees will hold water up in their leaves allowing it to evaporate.

-Lawns are not the best because they can pool up and run off.

-Rain gardens are a possible solution. Plants in such gardens can be extremely flooded as well as dry.

-Try to find a greenhouse, landscaper, or architect to interview. What kinds of plants are the contractors buying for rainwater?

Overflowing Drainage Systems Solutions

-Try to keep the water out of it.

-Low impact development. Small cheap fixes that have a cumulative impact.

-MA water coalition has resource links. They try to educate people in towns about how fixing stormwater drainage doesn't have to be expensive.

Disadvantages

-As previously stated, the runoff water which flows into the canal would contain contaminants from the urban area. This would therefore have to be treated.

-Capacity problems. We don't want the canal to overflow. How much is water coming in and going out?

-The green space might not help the problem, but rather lead the water into the basements of the surrounding buildings.

Interview Summary of Ove Larsen, Miljøpunkt Nørrebro employee: March 20, 2012

Sewer System

- It is an old system which takes on both sewage and rainwater. Most of Copenhagen has this system, only some areas divide the two.
- Rainwater accounts for up to 80% of what flows through.
- There is no possibility of acquiring enough kroner (15-35 billion) to upgrade the system.
- They could use 6 billion kroner over the next 10 years to reduce the pressure on the sewer system. This would not be done by building bigger draining but would involve using the rainwater for something good for the public.
- The people of Nørrebro want more green space. Nørrebro is 3 square kilometers consisting of 175,000 people with 7 square meters of public green space.
- They don't want any more pocket parks, but they want 'green corridors' which connect green sections.
- They see the water not as a problem, but as a resource. They need to show this to the people.

Routes

- Miljøpunkt doesn't think last year's rain was a 1000 year rain. According to Clime Scenario A2, they need to account for an increase in 30% of rainwater, which totals now to 750 mm per year in Nørrebro. If it is a 1000 year rain, then there is no system that can cope with it.
- Miljø doesn't know statistically what areas experienced the most flooding, but they have an idea of where. Åboulevard is the lowest area where the water flowed to in its direction along Jagtvej from the top of the hill. Also, Copenhagen is 1.5 degrees hotter than places around it.
- Miljø wants to make sustainable systems which will need to be able to take on 750 mm + 30% more rainwater, such as the canal which will allow citizens to use the water in their daily life.

- They cannot go into private property, therefore, need to use public spaces. The canal will need a bike lane because that is what the people want and will need trees because they are the best to use for rainwater collection and runoff. Don't worry about the cars because "we just throw them out" (Ove really hates cars).

Existing and Potential Uses for Rainwater

- Toilets and Washing Machines
- Virtual Gardens on the sides of buildings
- Green Roofs – new buildings with roofs of 30 degrees slope and less need to have these roofs, the existing buildings' structures are too weak to hold them.
- Cooling

Rainwater

- Miljø says that climate is changing, therefore, it is becoming unstable. The trends according to Climate Scenario A2 are now apparent.
- There is more rain in Copenhagen than the areas around it (Cope has 750mm per year, outside has 550mm, this is not a statistic though). This might be due to the heat from the city makes the clouds dump the water. They are looking for more explanations, however.
- Politicians and bureaucrats don't think the right way, which is why we need to show them how and give them ideas that they understand. The bureaucrats said that the open canal on Åboulevard would be too expensive, which is why we are looking at Rantzausgade. However, they probably planned on saying this. Miljø believes that the traffic on Åboulevard could easily be moved onto Rantzausgade.
- Rantzausgade does not need to have any cars, which are just parked on the street all day long. The street could be turned into an awesome shopping center, which would be an uplift compared to the recent crime dealing with soft dope sales and large black SUVs on the street. Also, no cars on the street could help stop these drug deals. There could be a problem if the water is not clean enough.

Closing Thoughts

- Miljø does not have a plan for what to say to us because they are still in development. Therefore, to start we need to think about sustainability + 30% more rainwater and about a lot more green.
- There are two different desires: (we should focus on the first one)
    1. What do we need in order to create a good project for a good grade?
    2. What would be nice to have?
- Åboulevard is out of the question. This was determined by the Section Head?
- Therefore, Rantzausgade will be used for the canal with no cars. Therefore, we need to figure out what to do with Borups Allé. Miljø wants to close it off from cars but they are not sure if it is feasible. How can we divert the traffic?

Interview Summary of Søren Gabriel, Orbicon engineer: March 23, 2012

Background of the Previous Proposal:

- There are no open streams in this part of Copenhagen (Nørrebro), so they wanted to improve the nature quality of the area.
- At that time there was no issue with flooding, therefore they did not take into consideration the use of the canal for storm water runoff.
- The sewer systems had been sized for regular heavy rain. However, the system could not withstand the storm on July 2nd, which caused much damage. The climate has changed.
- The previous proposal did not have any focus on storm water events. In fact, no rainwater was supposed to enter the stream because rainwater is very polluted, especially on the streets.
- The 'canal' they designed was basically going to be a 2km long 'fountain' which would pump the water it used back to the top. It was designed to be raised, 3 meters wide, 0.5 meters deep, with water almost at the top of its opening, with a velocity of 10cm per second. It was designed to be used as an architectural improvement to the area of Rantzausgade.
- The report was an 'idea project' for the politicians and the municipality who wanted to establish some natural environmental element in the city. These people didn't know where they wanted the Ladegårdsåen to flow, so they wanted Orbicon to make a project on how to construct it, providing a precise cost.

Problems Encountered:

- The municipality wants a good water quality in the lakes, therefore the water in the opened canal would destroy the quality of the lakes, creating massive algae outbreaks and ruining the quality of water which has been created over the past couple of decades.
- The Ladegårdsåen pipes are closed for most of the year. They are only opened for roughly 3 months in the winter to raise the elevation of the water in the lakes, and then are closed for the rest of the year in order to let the level of the lakes naturally fall.
- A stream will never be able to be built in the city with the sole purpose of stopping (reducing) traffic.

How the Situation has Changed:

- The new storm event situation has created the need for the capacity for handling storm water.
- Normal heavy rain water can go in pipes, but the extreme rains need to be dealt with on the surface, therefore improving the capacity of the sewer system has been ruled out.
- Solutions are needed that have the capacity for retaining the water and the ability to lead the water away from the area. Such solutions involve reservoirs and stream. The lakes can be used as the reservoir capacity, therefore the need for streams is pertinent.

Possible Solutions/Designs:

- Tunneling the traffic.
    - It is possible, but most likely will not happen in the next 20 years because the damaging flooding has changed the funding.
    - They thought of covering the Åboulevard somehow, but that is not feasible.
    - However, if it is a storm water project, the sewer company could end up having to pay for it. Otherwise, it would be the municipalities' responsibility.
- Opening Åboulevard.
    - Would be the best option because of its space and capacity.
    - Could use three lanes for the canal and green space. The other three lanes could transport traffic into the city during the morning, and then reverse direction in the afternoon when traffic is leaving the city.
    - For heavy rainwater, the canal would have to be able to transport at least 500 liters per second.
    - *He then gave us a visual of the canal, with the steps on either side which could provide the capacity needed for heavy storm water, and with greenery on the top of the sides which would clean the runoff water entering the canal.*
- Opening Rantzausgade.
    - *He did not touch upon this option to a great extent, but it does not seem feasible in respect to the reduction of flooding due to its small size.*

- <u>Note:</u> *the previous proposal was completely different and chose Rantzausgade with the sole purpose of improving the area.*

Interview Summary of Stefan Werner, Copenhagen Municipality employee, Water and Parks Division: March 26, 2012

About Him:

- Stefán: works for the Municipality of Copenhagen in the Water and Parks Division (started working for the city of Copenhagen in the summer 2011
- he focuses mainly on climate change, extreme rain stormwater
- opening up the large pipe, called Ladegårdsåen, is one of his favorite projects

History of Water System:

- The only natural river system around Copenhagen is Harrestrup Å
- A dam was built creating the lake Damhussøen
- As more and more people began populating the city of Copenhagen years ago, when the city was centered within the water boundary, the lakes were built to supply the people with water.
- A dam was also built to the North of Copenhagen creating the lake called Emdrup Sø.
- As the city grew, all of the waterways that had been dug to make the water flow to the lakes were put into pipes. The natural path of the water was changed in order to supply the city with water.
- The channel encompassing the Utterslev Mose area was built to protect against the German about 100 years ago.

The Lakes: their Clean Water and Outlet:

- Water can't simply be added to the lakes because the water in them is very clean and many of the waterways get pollution in them from overflowing sewers mixing with them, which could destroy the lakes.
- All the water in the lakes is controlled or else they would run out of water. For the past 10-20 years the lakes have been getting cleaner to the state they are in now, so no water should be added to them and destroy what has been accomplished so far.
- A lot of money is spent to clean the water before it is place in into the lakes through the pipes.

- You can't push all the water that would be flowing into the canal into the lakes because the outlet from the lakes is too small to handle it.
- The outlet goes to the military channel so it can handle a lot of water.
- The water from the road gets a lot of heavy metals so isn't good for the lakes and harbor. It has to be put to the sewer system.
- If there is an extreme rain event, however, the water from the roads can be placed to the lakes and harbor because it is better there than in peoples' basements.
- Avoid adding water to the lakes because they only want good water.
- The water would be a little polluted, but if you keep it away from sewage water, it would be ok to send it straight to the harbor.

The Climate Change:

- The summer experience more heavy rainfalls. In the summer of 2011, 15 cm of rain fell in two hours.
- Climate change says that there will be more water in the winter and less water in the summer. In the winter it is not as hot so not as much water will come at one time.
- When it is warmer and there is more moisture in the air, the rain can come more violently (extreme rain).
- When Orbicon created their project, politicians weren't paying much attention, but now with the new extreme rain problems, politicians are trying to do something to solve this issue.

Slope and Topography:

- Copenhagen is very flat with only about 6 meters of elevation change from the area above Ågade (8m) down to the harbor (bottom right of the 5th lake by the train tracks) (2m).
- The water will always go to the lowest point, so we know where the water will go.
- A little ways after the Ågade and Borups Allé the land is 8m above sea level, but by the bottom right of the 5th lake by the train rails the elevation is only 2m above sea level. It's about 1m/km slope.

Lack of Water and How to Get It:

- Think of water as a resource.
- The clean water being sent to the city is split into many different pipes and is therefore scarce in the summer. This is a big problem.
- They have started to think about how to reuse rain water, such as collecting it from the roofs and having storage bins on roofs to hold rainwater, such as those in NYC.
- Water from the roofs is acceptable to use and fairly clean. Roofs make up about 30% of the area in the city.
- It may even be a good idea to create reservoirs to have extra water for times of draught.
- By definition, the soil in the city is polluted from industries and other things being done. Using water from around the house might not be the best because it isn't as clean as water from roofs.
- When water is coming from roofs, it has the ability to be moved very far if you are strategic with your design.
- You could use storage tanks on the roofs to hold water and then use this water to feed the canal to counteract the lack of water in the city.

His Design, Possible Plans, and the Routes:

- His plans portrayed a super cycle path that ran along a small waterway, but in extreme rain the whole bike path could be flooded. The dimensions for this path were 5m x 1m.
- With a 5m x 1m canal it can handle 15 cubic meters of water per second
- The city has a plan of making a green cycle way along Brorsonvij.
- One thing to look at is how blue structure can be supplemented by green structure. It would be good for biodiversity and the city to connect these different green parks and waterways.
- He preferred AA over BR
- Once you get to the meat market, you would have to put in a pipe because it would have to go under the railroad. In order to get to the harbor, you will always encounter a railroad.

Closing Thoughts:

- The best thing to do when opening a waterway is to not dig too deep because there are so many pipes crossing underground. Don't go deeper than 1 meter or you will face immense problems.
- It is important to think about getting rid of urban heat.
- He said to think wild; if we want to move houses or buildings do it.

Interview Summary of Thorkild Green, Municipality of Aarhus' Department Architect: April 13, 2012

The team had the opportunity to interview an Architect from Aarhus in order to gain a deep yet concrete understanding of the challenges, the benefits, design options and the different factors considered during the planning phase of the project. This interview was a bit different than the previous ones due to the fact this interview deals with a successfully daylighted waterway, thus was crucial to our project. Through the interview we discovered the similarities and the difference between the daylighted Aarhus River and recommending features for the Ladegårdsåen Canal.

Similarities

- Both were situated under the busiest road in their respective cities.
- The areas surrounding the waterways faced several environmental issues, such as air and noise pollution
- Both have similar namesakes: Åboulevard (Copenhagen) and Åboulevard (Aarhus)
- Support for the project was well received by the public
- Both projects faced an issue with traffic
- Uses natural resources to clean the water
- Aims to create a recreational lift to the community

Differences

- Unlike Nørrebro, Aarhus does not have an issue with lack of green space
- Aarhus does not experience an issue with extreme rainfall; however this element was still factored into the design criteria.
- Green space was not a design parameter for the river
- The route selected to daylight the Ladegårdsåen is much wider than the route chosen to daylight the Aarhus river
- The Aarhus river dimension, length and breath, is much greater than the dimension for the Ladegårdsåen canal.

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