Envisioning a Tunnel on Amager

An Interactive Qualifying Project
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ABSTRACT

The city of Copenhagen in Denmark suffers from traffic congestion and Storm water flooding, and the city has begun to develop solutions to these problems. The Harbour Tunnel is a proposed plan to divert traffic around the central city before placing it on the Island of Amager to the south. Our sponsor Miljøpunkt Amager does not believe this is best possible solution and has a vision for a tunnel that would connect the highways to the north and south of the city. The group will work to create a plan that could become an alternative to the Harbour Tunnel. We will examine the traffic and storm water situation through interviews and field observation and then gather information on the public opinion of residents before eventually producing a deliverable to Miljøpunkt Amager. The final deliverable will attempt to include suggestions for a tunnel plan as well as a comparison of the Harbour Tunnel and new tunnel suggestions.

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INTRODUCTION

Copenhagen has been troubled by the changing needs of urban planning. Being at sea level, Copenhagen is susceptible to flooding just like other coastal cities. Over the past few years there have also been two super storms and several cloudbursts that have forced Copenhagen to address flooding on a more serious level (Braw 2013). Copenhagen's current major objective is to be the world's first carbon neutral capital by 2025. Despite the nation's attempts to reduce emissions, transportation continues to be the largest contributor to emissions, especially in Copenhagen. The country is making efforts to limit vehicle traffic by increasing traffic policies, while working to reduce emission. The city is developing to manage floodwater and traffic as flooding increases, and their neutrality goal of 2025 approaches (Gerdes, 2013).

Currently in Copenhagen, the government has created an effort to develop a tunnel seeking to decrease traffic in the northern regions of the city including the regions of Østerbro and Norrebro. The most support proposal, the Harbour tunnel, will divert from the heavily trafficked northern regions and the central city and place it directly into the southern Island of Amager. A concern is that the proposed tunnel could reduce traffic in Nørrebro and Østerbro, but merely divert the traffic and lead to heavier traffic in the region. (Ole, Koefoed, and Pedersen 2000). The tunnel has been discussed for the past ten years and has been gathering more support recently as it is one of the only solutions. (Ole, Koefoed, and Pedersen 2000). However, The Harbour tunnel takes little consideration into storm water control and is an overly expensive plan due to the nature of the tunnel and leaves little room for incorporation into a metro system. A secondary issue is the lack of green space consideration, as there is also a large focus on a green initiative in the city. Overall, while the proposal has solved the current traffic issue in the city, the proposal has left much to be desired.

In 2012, another WPI Interactive Qualifying Project proposed a tunnel that would aid in traffic relief in the northern city. The project investigated the day lighting of the underground Ladegårdsåen waterway, which runs under Ågade and Åboulevard. The project successfully considered flooding, traffic, and the incorporation of green space into the day lighting plan. In the fall of 2013, the government set aside money to evaluate the feasibility of the project and allowed for continuing design of the proposal (Christiansen, 2013). The project would lead to high

functionality, but would increase diversion of traffic to Amager in conjunction of the Harbour tunnel as the projects both take traffic from the northern city and divert it to the lower regions.

With the introduction of the Harbour tunnel plan, there have been concerns that the tunnel proposition does not address the public opinion and needs of residents in Amager. The public opinion and effect on Amager has not been addressed, nor has the severe storm water flooding been addressed. Miljøpunkt Amager is a small non-profit environmental company that wishes to represent Amager and aid in any project to benefit the region. They are currently focusing on developing a tunnel design that would be an alternative to the Harbour tunnel and address many of the concerns. The proposed tunnel would relieve traffic while aiding in storm water management and hopefully produce secondary benefits such as increased green space and reduction of pollution in the regions.

The eventual aim of this research is to devise a possible plan for a tunnel that can be an alternative to the Harbour tunnel. The new tunnel will aim to control air and noise pollution through control of traffic while simultaneously attempting to prevent flooding due to storm water. These are main concerns of the city, and a new plan could more readily produce usable green space than the Harbour tunnel. The research will focus on the current pollution, storm water, and traffic congestion and then envision a tunnel design that seeks to solve the problems most efficiently. Miljøpunkt Amager is dedicated to the research as the Harbour tunnel plan is the main proposed tunnel to solve the traffic problem in central Copenhagen. However, it does not focus on the all of concerns and needs of the city, and it inconveniences residents of Amager. A new tunnel plan could address all of existing problems while being a better investment and benefit to a greater majority of people. The tunnel could reduce storm water and better control it throughout the area. The storm water control would lead to reduction in damage to the city as greater storms arise. All citizens in areas of traffic would benefit by a reduction of noise and air pollution that would be controlled by traffic diverted through a tunnel directly connecting main highways. Amager is dedicated to making a tunnel plan to rival all others and benefit all citizens of Copenhagen. We, as a group, will envision a tunnel by surveying the existing traffic and storm water situation while also studying the social opinion of Copenhagen residents and the general opinion of existing plans versus other plans.

LITERATURE REVIEW

Introduction

Throughout history, cities have had to adapt to increasing populations, changing climates, plagues, and the advancement of technology. Copenhagen is a city that has successfully adapted over the course of time, from being a fifteenth century fishing village to carrying out the Five Finger urban planning that was initiated in 1947. Now, with its population and the number of cars on the road increasing annually, the urban planning landscape must adapt to cope with motor traffic congestion. In addition, the recent increase in powerful downpours has caused major flooding and significant material damages to the city's infrastructure. To combat these problems while striving to achieve its goal of being a carbon neutral city by the year 2025, Copenhagen is pushing the idea of using dual purpose underground tunnels for traffic diversion and storm water drainage. These tunnels not only address the primary problems of traffic and flooding due to storm water, but moving traffic underground blocks noise and harmful air pollutants from reaching the surface while creating space above ground for parks and green space. The purpose of this chapter is to give a background on Copenhagen's urban planning, as well as examples of current infrastructures being considered. A discussion of the primary problems, traffic congestion and storm water, will provide a better understanding as to the need for this project. Finally there will be a description of the secondary problems, air and noise pollution and lack of green space, which stem from the primary problems.

History of Urban Planning

Many major cities struggle with the difficulties related to urban planning. This involves the technical planning of an urban environment considering land use, transportation, community development. Cities have changed throughout history, and urban planning has changed similarly. Large amounts of rainfall and their drive to become a city of the modern age has caused discussion regarding future urban development in Copenhagen. Copenhagen adopted the Five-Finger Plan in 1947, which was meant to shape the city in order to integrate green space and transportation. Presently, there are many different visions of city infrastructure that would benefit the city by increasing mobility through the city.

Industrial Revolution

Cities have existed throughout history, but there was not a strong emphasis on the planning of them until the 19th century. Prior to the Industrial Revolution, there was little forethought put into the design of cities. As a result, cities were unhealthy and inefficient, despite their greater levels of wealth and energy when compared to suburban and rural communities (Campbell, 2012). During the Chicago World's Fair in 1893, the City Beautiful Movement was introduced. This movement was the United States' first attempt at modern urban planning; the movement focused on improving living conditions and civic virtues through the beautification of the city. Washington D.C., originally designed by L'Enfant, was later refocused on the monuments of the capital by the McMillan Plan, which was based off of the City Beautiful Movement. The Industrial Revolution was the defined turning point in the planning of cities. After this point there were several movements that took shape, including the Garden City movement proposed by Ebenezer Howard in 1898. The idea behind this movement was that cities would be surrounded by parks and would incorporate areas of mixed residence and industry (Hall & Mark, 2011). The Garden City movement became the model for many cities.

Five-Finger Plan

In the mid-19th century Copenhagen was surrounded by ramparts, limiting the city to 130,000 inhabitants within 3 square kilometers. After the Industrial Revolution, the city expanded by utilizing transit oriented development, and creating a tram system which would enable development outside the city. The tram system spread into neighboring towns which allowed the areas to develop into a middle-class sector. In 1947, architect Peter Bredsdorff developed the Five-Finger plan which the government has enacted through local zoning decisions (Andersson, 2014). The Five-Finger plan states that the public should have easy access to green space, bike paths, commuter rails, and motorways (Cahasan & Clark). The Five-Finger plan focuses on having community growth within linear corridors that resemble fingers, as seen in Figure 1.

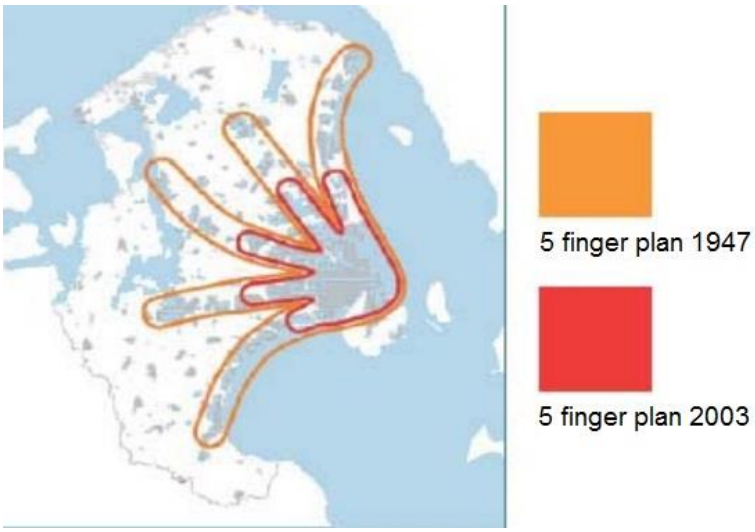

Figure 1 – Image of the Five Finger Plan courtesy of Cahasan and Clark

The areas between the fingers would be reserved specifically for green space. The skeleton of the fingers is made by the transportation that runs along the corridors. Along each finger runs a major highway as well as a subway, S-Tog, line as highlighted below in Figure 2.

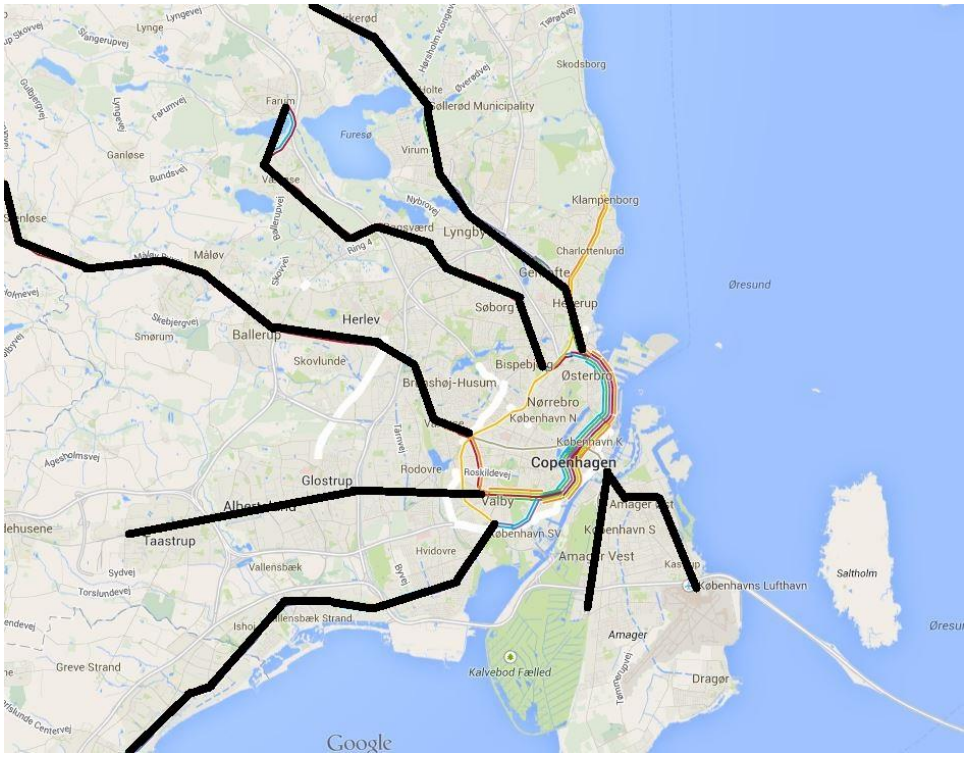

Figure 2 - Transit Map of Copenhagen courtesy of Google Maps

The figure above shows the train lines, including the train line to the airport on Amager.

Development has occurred along the railways to the airport, similar to the development of the other fingers, causing the growth of an extra finger (Knowles, 2012). With the incorporation of the airport and the Øresund Bridge this new finger is an international finger. The train system attracts more travel to Copenhagen Airport than any of the other stops along the line (Knowles, 2012). The most recent developments are that of Ørestad, in west Amager, which has developed along one of the Metro lines completed in 2003. The purpose of Ørestad was to renew the tax base, which was on the collapse due to the relocation of citizens to the five fingers outside of Copenhagen (Knowles, 2012). Ørestad is the sixth finger that was purposely created by the government to introduce more residential and business zones within Copenhagen (Knowles, 2012).

The Five-Finger plan focuses on regional planning more than urban planning. The effects of the plan are evident within the city despite its regional focus. Copenhagen has focused on replacing spaces for cars in the city with places for people to walk. The Five-Finger plan allows for commuters to take trains into the city rather than motor vehicles. Walking space is being developed in order to allow for a more inviting, vibrant and healthy city (Cahasan & Clark). The plan has driven development for over 60 years, and is expected to continue growth. Over the course of the next 20 years there is an expected growth in the areas that occupy the fingers, of 10,000 people per year, an additional 75,000 homes, and the extension or thickening of the corridors of development (Cahasan & Clark). A large focus has been on the improvements of the harbour zone and the development of Ørestad by By & Havn ("Vision and Mission,"). By & Havn is a company whose mission is to create a vibrant neighborhood that is attractive to both live and work in ("Vision and Mission,"). The company is owned by the city of Copenhagen and the state, which means that the land development is driven by the desire of the city to develop these areas into residential and business areas.

Ladegårdsåen Tunnel Project

The Five-Finger plan created five major suburban areas outside of Copenhagen. The two most northern fingers contain nearly 400,000 inhabitants. These two fingers stretch along the Hillerødmotorvejen [16] and the Helsingørmotorvejen [19] as seen in Figure 3.

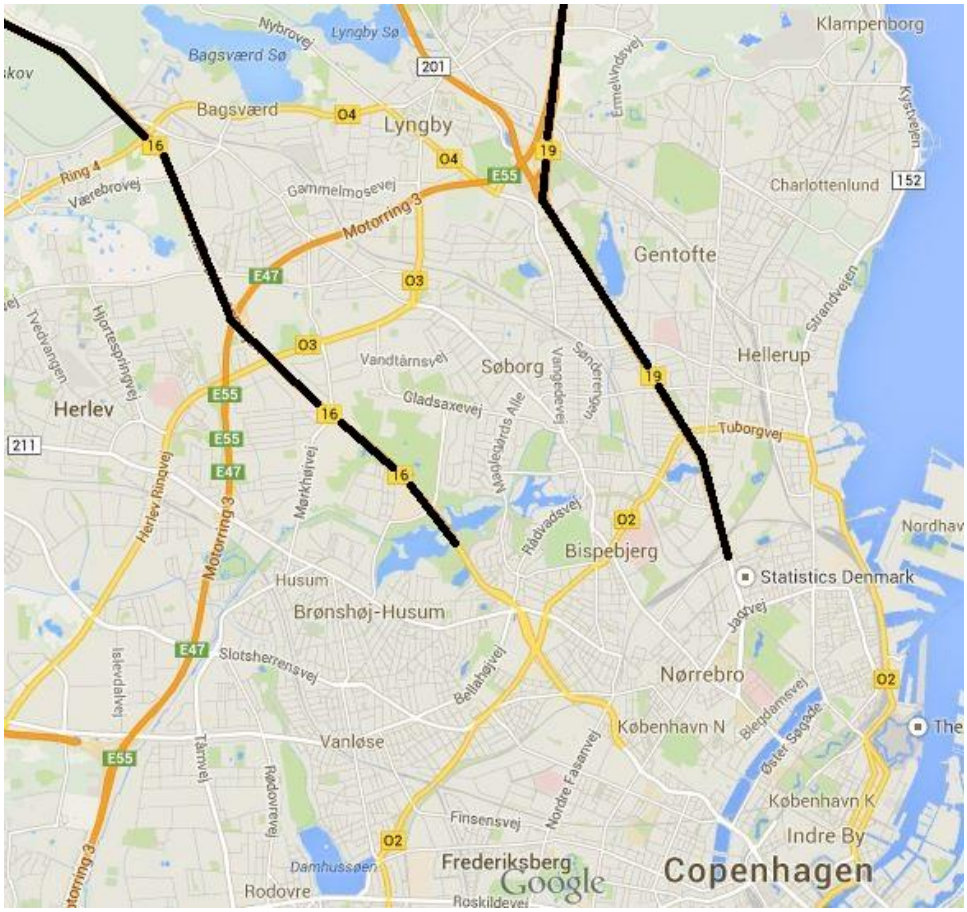

Figure 3 - Map of Norrebro, Frederiksberg, and Northwestern Copenhagen courtesy of Google Maps

The two highways lead directly into the center of the Copenhagen. The most direct route from the highway to either Copenhagen airport or Sweden is by traveling across HC Andersen Boulevard, and down along Amagerbrogade. Hillerødmotorvejen turns into Åboulevard which then leads to HC Andersen Boulevard. In 2012, a Worcester Polytechnic Institute project team studied the possibility of daylighting a canal under Åboulevard, the Ladegårdsåen Daylighting would involve removing the existing road and bringing the piped canal that once existed on the surface back to the daylight, while the traffic is either diverted on other streets or in a newly formed tunnel underneath he canal. This project ended up winning the 2012 Best Vision of Copenhagen by Politiken. The goal of the project was to assist Miljøpunkt Nørrebro with selecting a pathway for the reopening of the piped canal, and in doing so the WPI team would identify design options that would meet the city's goals to add green space and alleviate flooding along the route (Christiansen, 2013). The team compared the feasibility of daylighting along two different routes, Ågade and Åboulevard or Borups Allé-Rantzausgade. In order to provide a sufficient answer, the project team

researched a multitude of issues including, green space usage, flooding zones, pollution, the history of Nørrebro and the Ladegårdsåen, the daylighting project in Aarhus, and on-site studies.

Their research on flooding focused on which of the two areas in question was more affected by flooding. They discovered that the Ågade and Åboulevard route suffered the most during the one-hundred year storm in 2010. The green space usage in Copenhagen was limited and although there was a desire to create more green space, none had been planned along either route. Based off of their research, either location they picked would add green space to the city.

Both noise and air pollution were identified as key factors that needed to be addressed. To determine the actual impact of both noise and air, mapping was used that demonstrated the different levels around their proposed routes. In both cases the Ågade and Åboulevard route had a significantly greater threat of pollution than the Borups Allé-Rantzausgade. By studying the history of Nørrebro the team was able to learn the history of the canal itself, including the reason why it was piped in the first place, and any previous efforts that were done to daylight it in the past.

The purpose of daylighting the Ladegårdsåen would be not only to reduce the amount of traffic that affects one of Copenhagen's busiest streets, Åboulevard, but also to alleviate flooding during large storms, and increase the amount of green space in the city. Previous project proposals suggested that the tunnel would cost upwards of 10-15 billion kroner, however because the new proposal plans on just digging, rather than boring, the cost is estimated around 4-5 billion kroner instead (Christiansen, 2013).

From the daylighting project we can see several different design suggestions that would properly solve all of the issues. The Åboulevard route was the more affected route and thus the route that they suggested for daylighting.

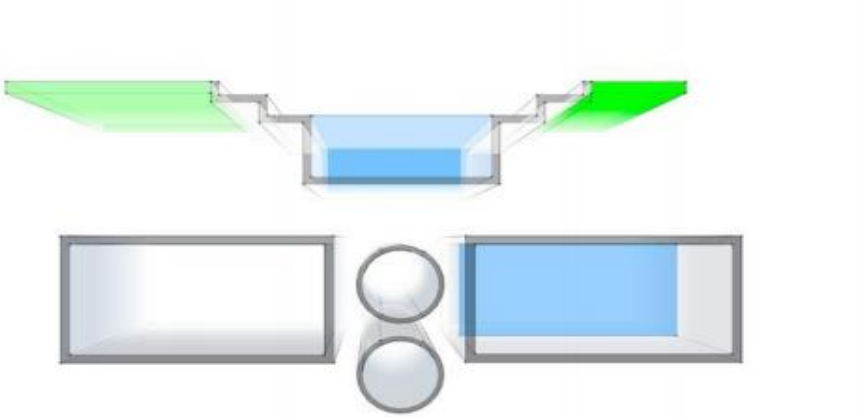

Figure 4 - Vision of Aboulevarden Tunnel courtesy of Flood Prevention and Daylighting of Ladegardsaen IQP

The above figure is the design that was suggested to Miljøpunkt Nørrebro that would run under the canal. The two rectangular tunnels would primarily be used for motor vehicle travel. In the case of massive flooding, the tunnels could act as extra reservoir space and would eventually drain. The tunnel concept comes from the ideas of the Stormwater Management and Road Tunnel (SMART) project that was completed in Malaysia in 2007. The team also provided surface level designs that incorporated green space, foot bridge design and location, and bike path design. Money was set aside in the 2014 city budget to perform a more detailed feasibility study on the possibility of daylighting the Ladegårdsåen (CW, 2013).

Introduction to the Harbour Tunnel

In the early 2000s a collaboration of companies for Sund and Belt Partner proposed an idea of a tunnel design that removed traffic from central Copenhagen and distributed it to an area of the city with less motor vehicle activity ("Harbour Tunnel in Copenhagen,"). Similar to how the Ladegårdsåen tunnel aims to direct traffic down towards the start of the Amager district, the Copenhagen Harbour Tunnel plan takes traffic at the north end of central Copenhagen and directs it south underneath the harbour to the Langbro bridge at the Amager district border. The main assumption is that it would calm inner city traffic ("Copenhagen Harbour Tunnel,").

The twelve kilometer long tunnel has appealing features for much of Copenhagen. The tunnel will utilize the cut and cover method, which entails excavating a trench and putting a roof over it with support measures to handle any activity and structures above it, at the entrances and exits along its

planned route. Several models and visual aids have been put forward to help the public visualize the aesthetics of the tunnel. These include the Extra Land Model, the Spiral Design, and the Circle Design ("Harbour Tunnel in Copenhagen,"). The Extra Land Model and Spiral Design both utilize the space above the tunnel emergence from the harbour by adding harbour parks. As shown in Figure 5, the Extra Land Model consists of a straight-away ramp emerging from the water with the harbour park at an incline above the roof of the tunnel. The Spiral Design utilizes a similar method as shown in Figure 6, except instead of having a sloped rectangular park like the Extra Land Model, it uses the spiral to create a gently sloping landscape enclosing an open air pool. Both designs aim to use exotic plants to create a unique and tropical island feel that cannot be found anywhere else in the city. In addition, the added foliage absorbs rainwater and carbon dioxide to conduct photosynthesis, aiding the city in reaching its goal of being carbon neutral by 2025 ("Harbour Tunnel in Copenhagen,").

Figure 5 - Extra Land Model courtesy of sla.dk

Figure 6 - The Spiral Design courtesy of sla.dk

The Circular Design, also located at the Langbro Bridge, gets its name from the rotary-style entrance and exit system utilized. The goal of this design is to shut down the bridge to all motor vehicle traffic so that it can be used for green space, cyclists, and pedestrians. To accomplish this, the tunnel contains an entrance and exit emerging from the water on each side of the bridge. The exits and entrances create a circle around the bridge with entrances and exits to the city on each entrance to the bridge. This is the most descriptive of the proposed plans because it details not only the exits and entrances to the tunnel but also the roadway plan for the surrounding area.

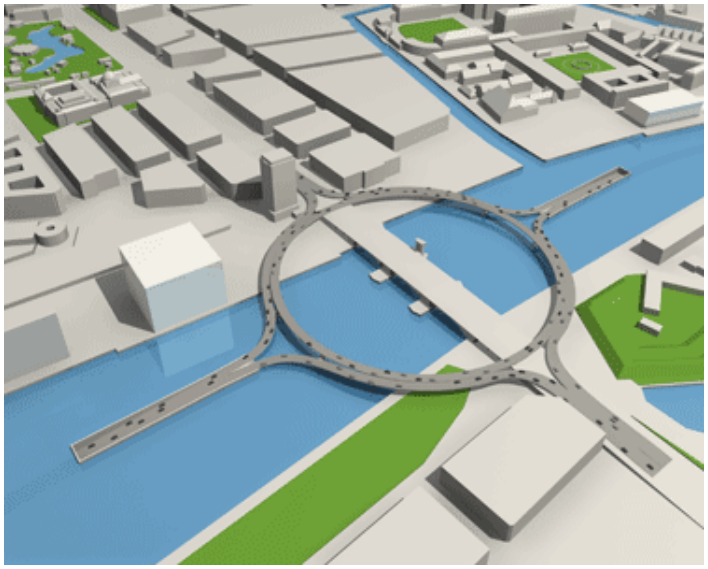

Figure 7 - The Circle Design courtesy of sla.dk

The three proposed plans above all depict the possible transformation of the Langbro Bridge area and have many positives. One of which is added green space, which improves the livability of the city by reducing carbon dioxide levels, absorbing rainfall, and is also aesthetically pleasing. Another is the successful rerouting of traffic from within the city center to a less dense area of the city subject to less motor vehicle traffic. However, with the possibility of the Aboulevarden and Copenhagen Harbour tunnels being built, the amount of traffic being diverted from central Copenhagen to Amager district is more than Amager's infrastructure can withstand. Having the Aboulevarden tunnel in place will remove approximately 700 cars traveling in Norrebro daily according to the Copenhagen Post (CW, 2013). This means 700 additional cars will be traveling in Amager daily. In addition to central Copenhagen traffic being diverted there from the Harbour Tunnel, this will create traffic congestion problems for Amager district that its infrastructure cannot support at the moment.

Primary Problems

Traffic and storm water are the two primary problems with Copenhagen's current urban planning. A proper plan has been set for Copenhagen's expansion and development, but there is minimal work being done to protect the city from congestion and flooding. Dealing with traffic has been simpler than flooding due to the fact that more transportation infrastructure can be made. Storm water is a more difficult issue to handle due to the fact that topography and meteorology take large accounts of the ability to manage it. At current rates in Copenhagen, both traffic congestion and rainfall are expected to increase.

Increasing Traffic Congestion

Copenhagen is experiencing population growth due to increased immigration from other countries ("Denmark Population: Historical Data Graphs per Year,"). As the population continues to grow so does the need for transportation. Since 1988 there has been a 50% increase in traffic, with a similar increase expected for the foreseeable future ("Sustainable Transport- Better Infrastructure," 2008). The transportation sector accounts for nearly 25% of CO_2 emissions, however with the expected traffic increase it is also suspected that emissions will increase ("Sustainable Transport- Better Infrastructure," 2008). In 2008, the EU-27 average for road transport emissions is 1.99 tons, but Denmark contributes 5 tons of CO_2 per capita ("Danish Green Transport Plan to get the Environment Back on Track," 2011). Denmark is attempting to reduce these emissions by enacting

several key actions including, reduced green car taxes, investment in public transportation, intelligent traffic systems, new roads strategy, and funding for public research into green transport technologies ("Danish Green Transport Plan to get the Environment Back on Track," 2011). Roads and transportation are the areas that require action in order to reduce the emissions.

Already Copenhagen has a history of being a cycling and overall green city. Copenhagen has a 100 year history of cycling. Cycling started becoming a major form of transportation in the first half of the twentieth century, but by World War II, cars began taking precedence (Ruby). However, the 1973 Oil Crisis caused a relapse into the use of bicycles, which have had a strong position in transit system of Copenhagen ever since. With the increase in laws that assist cyclists to be more protected and the separated lanes that are devoted specifically to bicycles it has become much easier and more efficient to cycle through Copenhagen (Lindholm). Copenhagen continues to initiate new policies that provide for a faster, safer, and more comfortable cycling experience ("Good, Better, Best: The City of Copenhagen's Bicycle Strategy 2011-2015," 2014).

The Copenhagen Metro, recently completed as of 2007 is one of the most recent projects that the city has done to reduce the amount of traffic affecting the city. The metro system has two lines currently, M1 goes from Vestamager (Amager) to Vanløse (Frederiksberg), while M2 runs from Lufthavnen (Copenhagen Airport) to Vanløse. The metro system in Copenhagen is very reliable with 4 minute intervals between trains, and a punctuality of 98.2% ("Copenhagen Metro,"). The system operates without a driver and was voted the “World's Best Driverless Metro” ("Copenhagen Metro,"). The first line of the metro was completed in 2002 and led to a change in transportation for the city. With the introduction of the Copenhagen Metro, about 26,000 previous bus users started taking the metro by 2003, and approximately 3000-5000 car trips across the harbour switched over to the metro as well (Vuk, 2005).

Figure 8 - Image courtesy of Cityringen-Copenhagen Metro website

Copenhagen hopes to add two more lines (Cityringen) to their metro system that will encompass Nørrebro, Østerbro, and lower parts of Frederiksberg ("Metro,"). The addition of the two newest lines are expected to be completed by 2018 at a cost of approximately 21 billion kroner ("København Cityringen contractors selected," 2010). The addition of these two lines, similar to the first two lines should reduce traffic from Nørrebro & Østerbro. The current Metro system works alongside the S-Tog, the old train system, which has been transporting people since 1934.

Efforts have been made to reduce traffic by implementing a stronger cycling culture and a more reliable metro system. However little has been done to change the actual roads that people travel on. One of the main issues, especially in Copenhagen, is that the streets are narrow due to the fact that it is an old city ("Good, Better, Best: The City of Copenhagen's Bicycle Strategy 2011-2015," 2014). The streets are only two lanes wide with an additional bus lane and a bike path.

The Ladegårdsåen project is an example of how pedestrian and vehicular transportation are both taken into account when designing. Copenhagen has been actively solving their goals, and they continue to solve more and explore new areas in which to reduce traffic and make it transportation cleaner. Smart urban planning will solve transportation issues as well as other problems, such as

storm water.

Flooding due to Storm Water

Another significant problem that Copenhagen is struggling with is flooding due to increased amounts of rainfall. Since the middle of the nineteenth century, annual precipitation has increased by 129 millimetres per year and continues to increase due to a recent shift in climate patterns (Jeppeson, Christensen, & Ladekarl, 2010). At the same time, the rainwater that is falling in the city is not permeating into the ground due to the increase in impermeable building materials like asphalt, cobblestone, brick, and concrete. Combined with the Amager district's flat and low-lying topography, the increased amounts of rainwater have nowhere to flow and remain stagnant in city streets. This inhibits most forms of bicycle and motor vehicle traffic from navigating the streets as well as costing Copenhagen taxpayers billions of kroner in water damage each year (Buley, 2011). In addition to the city infrastructure's inability to cope with storm water, Denmark and its neighboring Baltic Sea countries are being pelted with powerful downpours and winter cyclones at a more frequent pace than previously experienced.

In Denmark there is a type of weather system that also affects areas around the equator and the Baltic Sea, characterized by its fast pace, intense lightning, and powerful downpours. It is called a cloudburst, and since 2005 this type of storm system has been the largest contributor to rainfall totals in Copenhagen (Vestergaard, 2011). The summer of 2007 was the most significant of these months, with three major cloudbursts occurring between the months of July and August. They moved through the city pouring rain at intensities of fifty millimetres per hour, sixty millimetres per hour, and fifty three millimetres in ten minutes (Vestergaard, 2011). This devastating rainfall intensity is difficult for permeable surfaces like natural soil to absorb. Thus, for a city like Copenhagen being made of impermeable and semi-permeable materials, it is impossible for it to be absorbed and is all directed to drainage pipes.

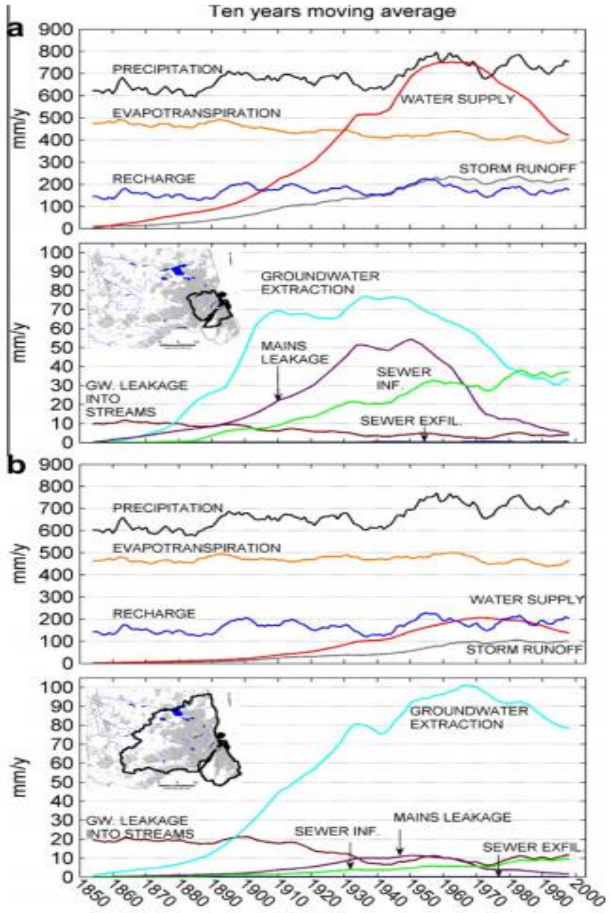

Figure 9 - Storm Water Graphs courtesy of "The Journal of Hydrology"

Then in July 2011, a cloudburst dumped 150 millimetres of rainfall on Copenhagen within three hours (Buley, 2011). The result was flash flooding that crippled the city and left five billion kroner in damage. With the absence of permeable materials throughout most of the city, water was directed to drainage pipes installed by urban planners to drain normal volumes of storm water from the city streets.

Figure 10 – Skybrud 2011 Flooding Image courtesy of (J. S. Nielsen, 2011)

However, two months' worth of rain fell in three hours, caused the drainage pipes to overflow, and pooled up in the streets and buildings. In Amager, the water flowed at such a slow rate towards the Baltic Sea due to its flat topography that it appeared stagnant. The cloudburst, known as "Skybrud 2011", is considered to be the most severe to date to have occurred in Copenhagen (Vestergaard, 2011).

With severe rainstorms hitting Denmark, specifically Copenhagen, at more frequent rates than ever before and costing the city billions of kroner in material damages, the city has decided that the infrastructure needs to adapt. According to the Copenhagen Post, the city has plans to spend over three billion kroner over the next twenty years to improve storm water related infrastructure (Buley, 2011; CW, 2013; Mufti, 2012). Included in this budget outline are the reclamation of green space to aid in absorbing rainfall, and reservoir tunnels to direct storm runoff out of the city and to safe discharge locations. These plans also fall into line with the green space reclamation of the Five Finger Plan, which according to the graphs in Figure 9, has helped with stabilizing the amount of storm runoff that comes as a result of increasing annual rainfall totals. With measures like these being taken, the city of Copenhagen is closer to addressing storm water drainage in the face of more frequent and devastating cloudbursts.

Secondary Problems

Although increasing traffic congestion and storm water levels have become the primary focal points of tunnel design in Amager, there are also secondary problems that can be addressed as a result of building a tunnel. The first problem is air and noise pollution in the city of Copenhagen. When cars travel through the city, they release carbon dioxide and carbon monoxide into the

environment which, in higher concentrations, can be hazardous to human health. Motor vehicle traffic also contributes to noise pollution which decreases the livability of the city and can damage human hearing capabilities. The second problem is the lack of green space in Copenhagen, which the Five Finger Plan has been aiming to improve since 1947. Exploring these two secondary problems in this section provides a clearer understanding of how they harm the city and its goals of reaching carbon neutrality by 2025 (Gerdes, 2013). But with the construction of a tunnel, they will be addressed and the result will ultimately improve the livability of Amager and the city of Copenhagen as a whole.

The Presence of Air and Noise Pollution

On a global scale, air pollution is one of the major issues that affects everyone, especially with concerns of climate change ("Air Pollution: Smog, Smoke and Pollen,"). On a local scale air pollution is still a major issue that affects more than climate change. As discussed earlier, the transportation sector continues to be the largest contributor to emissions in Copenhagen. Air pollution is a mixture of natural and man-made substances in the air we breathe such as fine particles produced by burning fossil fuels (Sciences, 2013).

In any city it can be a problem with high amounts of traffic to have high levels of pollution. Copenhagen struggles with pollution and for the carbon-neutral seeking capitol pollution is not something that can be allowed. Pollution cannot be eliminated entirely, but it can be maintained at a safe level. Currently Copenhagen is above the current threshold value (set in 2010) for emission levels and has been above the specified level of 40 µg/m^3 of NO2 since 1990. Many health risks can be associated with air pollution. Particulate air pollution, including NO_2 is statistically and mechanistically linked to increased cardiovascular disease (Dockery & Stone, 2007). Car traffic can account for 90% of the air pollution in the busiest parts of Copenhagen, such as H.C. Andersens Boulevard (Tørsløv, 2010).

“Noise pollution is the intrusion of unwanted, uncontrollable, and unpredictable sounds, not necessarily loud, into the lives of individuals of reasonable sensitivities” (Bronzaft, 2004). Noise in most cases is measured on the scale of decibels. For the average person exposure to 85 dB or higher for more than five hours daily can cause permanent hearing loss. To give a sense of what the decibel scale is, a ticking watch is about 20 dB, 45 dB is what it takes to wake a sleeping

person, a normal conversation exists at 60 dB, an alarm clock is measured at 80 dB, a lawn mower is at 100 dB, artillery fire is about 140 dB, and an aircraft taking off is at 180 dB ("Decibel Levels of Common Sounds,"). Traffic causes noise pollution as well, but it can vary along a route, and it can also depend on the noise dampening features in the surrounding environment.

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 11 - Table of Traffic in Copenhagen courtesy of "Traffic in Copenhagen 2009"

At 68 dB or higher, 17% of homes in Copenhagen are in the range that is considered a severe nuisance (Tørsløv, 2010). In Copenhagen the most severely impacted areas are those that are next to major roads or highways. Other than hearing loss, noise pollution can lead to poor mental health due to stress and even impaired learning (Bronzaft, 2004). In the figure below, the areas that are darkest have the highest measured (>75 dB) areas of noise pollution.

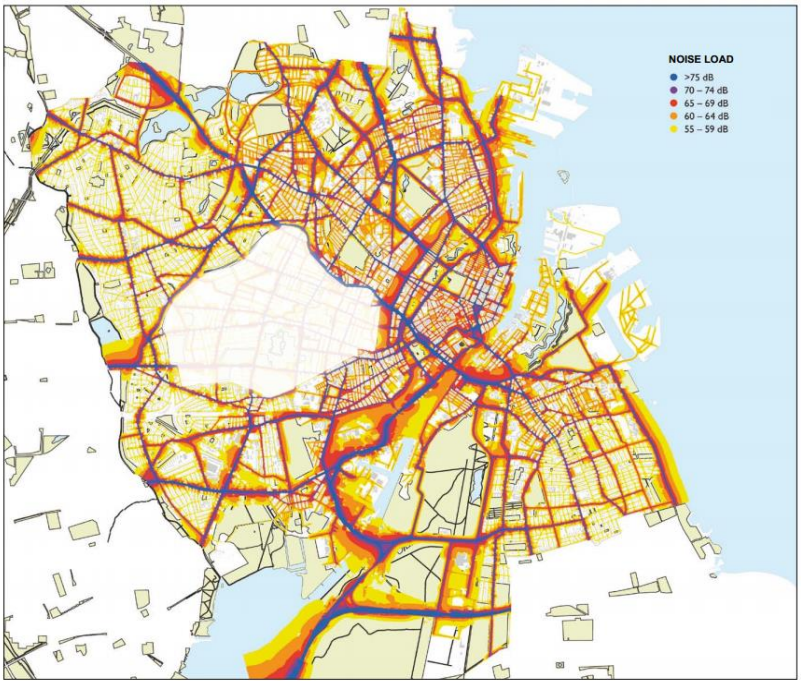

Figure 12 - Map of Traffic in Copenhagen courtesy of "Traffic in Copenhagen 2009"

The above map shows a heat map with levels of noise in Copenhagen. Vehicular traffic can be blamed for major pollution in Copenhagen. Air pollution is the result of greenhouse gas emissions from vehicles, while noise pollution is the sound disturbances caused by vehicles. The reduction of air and noise pollution would increase the livability of the city. An increase in green space would assist in the reduction of both air and noise pollution.

The Lack of Green Space

The lack of green space in Copenhagen became a focal point for not only the transit oriented development plan known as the Five Finger Plan, but also for the storm water and pollution reduction campaigns as well. Adding green space improves the livability of the city in many ways. It adds to the aesthetic appeal of the city by adding color and texture to the environment, improves air quality by absorbing carbon dioxide from the surrounding air to conduct photosynthesis, and absorbs storm runoff and rainfall because it provides permeable surfaces. (De Ridder et al., 2004)

However, the addition of a tunnel in Amager will provide urban planners with an opportunity to reduce the amount of surface roads along its path. Instead, traffic will flow beneath the city and the area where roadway previously lay can be utilized to plant trees, shrubbery, grass, and flowers. The surrounding area can be used by pedestrians and cyclists, and local wildlife will use the new foliage for food and living space. The added green space will provide a place that fosters improved health, community, and a reconnection with nature that cannot be found on a paved street (T. S. Nielsen & Hansen, 2007). By addressing the primary problems facing Amager like storm water and traffic congestion by building a tunnel, Copenhagen can utilize the opportunity to address pollution and the lack of green space as well. The added green space in turn will help absorb storm water runoff and fight flooding, creating an overall healthier and more livable city in every way. ("Danish Green Transport Plan to get the Environment Back on Track," 2011)

Conclusion

Copenhagen has a multitude of problems that can all be settled through smart urban planning. The construction of a tunnel similar to the one proposed in Flood Prevention and Daylighting of Ladegårdsåen would provide a solution to storm water and traffic. The need to divert traffic in Copenhagen is obvious by the desire to explore the two tunnel plans more in depth. Despite the technical advantages of each, there is a lack of public opinion in the research, which will help

assist Miljøpunkt Amager in their proposal of a tunnel that will cut through Amager.

METHODOLOGY

Introduction

We will provide design suggestions for a tunnel that will alleviate traffic congestion and storm water flooding on Amager, an island region to the south of Copenhagen. Our tunnel suggestions will be useful to our sponsor, Miljøpunkt Amager, in the eventual compilation of an alternative design proposal to the existing Harbor Tunnel proposal. To accomplish our goals, we will address the following objectives:

- To gather information and data on current traffic congestion and patterns along HC Andersen Boulevard, Amagerboulevard, and Amagerbrogade.
- To gather information pertaining to flood management during major rainfall events and the current storm water drainage infrastructure.
- To judge the general opinion of local politicians and environmentalists on aspects of the tunnel that affect the livability of Amager.
- To provide possible design suggestions that will attempt to solve traffic and storm water flooding on Amager.
- To provide a summary of a comparison between the Harbor Tunnel and our envisioned tunnel using effects on urban green space, traffic congestion on Amager, and the general livability of the island.

The remainder of the chapter will provide specifics about the methods implemented in order to fulfill our objectives and the proposed timeline for our project. Each goal will be addressed during a predetermined phase.

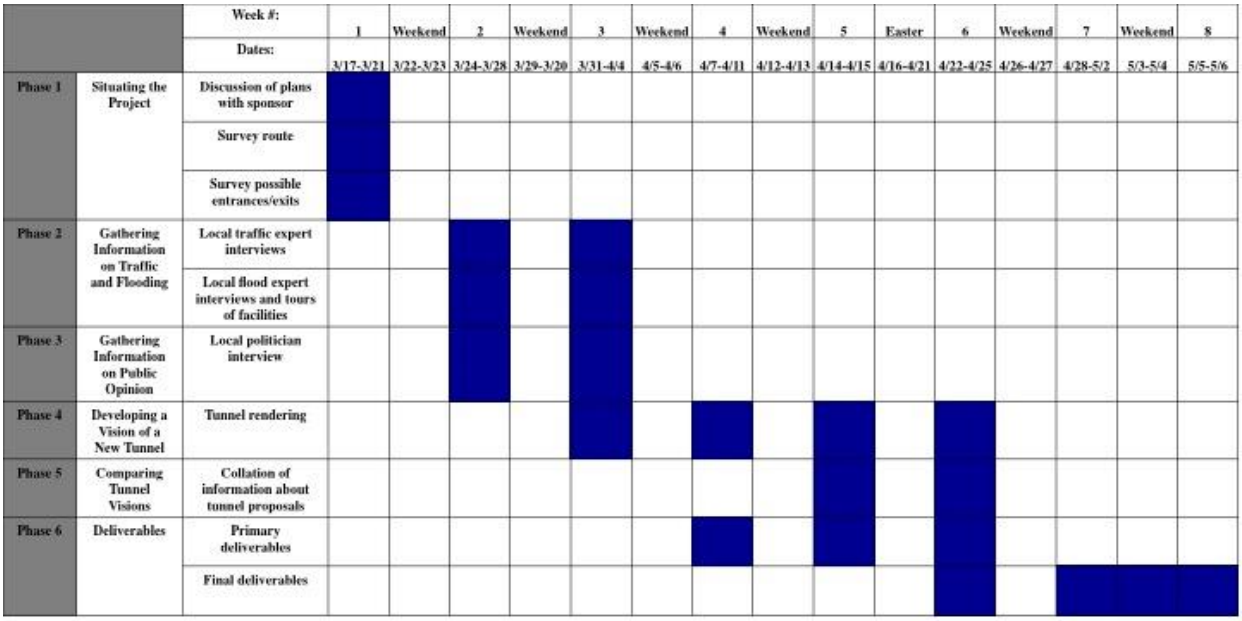

Figure 13 - Gantt Chart of the Proposed Timeline for our Project

Phase 1- Situating the Project

We will begin by gathering general information about the current land development and construction along HC Andersen Boulevard, Amagerboulevard, and Amagerbrogade to develop a complete understanding of the area our project may alter. We will gather images of the road and buildings along the route and select locations that could be used for the generation of new green spaces. Another member of our sponsoring agency will be providing designs for green space development along the selected route.

Phase 2 - Gathering Information on Traffic and Flooding

In order to fully understand the problems that are affecting Amager, we will gather additional data about traffic congestion and flood management on Amager and in Copenhagen through interviews with local experts and by touring water management sites.

We plan to interview employees of the local government for the municipality to garner any valuable information about traffic frequency on HC Andersen Boulevard, Amagerboulevard, and Amagerbrogade the streets we will be altering in our design proposal. Our sponsor has offered to help us get in contact with the appropriate people. Sample interview protocols are included in Appendix A. We would like to have access to more detailed maps and statistics involving the

frequency of traffic congestion along these roads and the effect they have on travel time across the city, as well as the number of vehicles that use this route on an average day. If we cannot get find the appropriate information with the help of our sponsors and local experts, we will need to gather some of our own data through field observations. These will include counting cars that pass through selected intersections on HC Andersen Boulevard and Amager Boulevard during peak traffic hours. Locations for data collection will be determined once we have arrived in Copenhagen and have had the chance to visually survey the selected streets. We will assign two students to each location and gather data at each location three times.

To gain a better understanding of how Copenhagen manages storm water and flooding, we will again reach out to the local municipality (by way of our sponsors) We plan to tour water treatment and collection sites to increase our knowledge of the infrastructure. We have already selected a water treatment plant for visitation at the south end of the Copenhagen harbor. Our sponsors will provide us with the appropriate information needed to set up this tour. We hope to gather most of this information through interviews and audio recordings of all meetings to be archived for reference. Participants or subjects of all interviews conducted during for our project will have the opportunity to deny recording or end their interview at any point. They may also opt out of answering specific questions. Interviews containing information deemed relevant for constructing our design suggestions may be transcribed and included in part or in totality in our final publication.

Phase 3 - Gathering Information on Public Opinion

A crucial step in designing a tunnel plan and producing a vision for the future of Amager and Copenhagen is to evaluate the opinion of the inhabitants in areas that would be affected by the tunnel. Currently, traffic congestion is mainly affecting the residents of Nørrebro and Østerbro and the central city areas. However, if the city decides to implement the Harbor Tunnel plan, then more traffic will be diverted to Amager. The diverted traffic will increase congestion in Amager and will become a nuisance for the local population. The establishment and acceptance of a new tunnel plan likely hinges upon the public opinion of the residents of Amager and what will best suit their needs. To establish the opinions of the citizens, it is necessary to have direct contact with a group of individuals and to evaluate the overall opinion of groups from north of the city down to Amager.

Our IQP team hopes to interview local politicians and environmentalists to gain information about the publics' views on the Harbor Tunnel proposal and their expected level of receptiveness to a new tunnel proposal. Sample interview protocols are included in Appendix A. The questions will focus primarily on the Harbor Tunnel plan versus a new tunnel plan crossing under Amager, as both will have a different impact on traffic within the region. The groups would provide an understanding of how the residents feel about short-term inconvenience versus long-term benefits.

Our group will be working closely with members of Miljøpunkt Nørrebro. They sponsored the Ladegårdsåen daylighting IQP project. They will provide suggestions and guidance to our team and Miljøpunkt Amager about the process of generating a tunnel proposal that includes storm water management in the Copenhagen area.

If our time in Denmark allows, we would like to work on incorporating connections between our tunnel proposal and the Copenhagen Metro or S-Tog systems. We hope that our tunnel design will provide convenient connections between vehicular traffic under the city and pedestrian use of the Metro, so it will be necessary to learn more about the Metro's construction plans and current system. We may choose to interview residents around the current Metro construction sites to gather more information about how the public views major construction projects.

Phase 4 - Developing a Vision of a New Tunnel

The eventual product presented to Miljøpunkt Amager will include a mapped out route of the tunnel as well as a cross sectional design as a suggestion to the sponsor of the tunnel plan that would most benefit the region. Using previous tunnel designs and routes, a map of the region can be produced showing the path for the tunnel vision. The group will use the program SolidWorks to create visual representations of possible tunnel cross sections. The modeling will include information obtained from the previous IQP in Nørrebro to create suggestions for tunnel designs. Storm water drainage infrastructure will be included within the plan as well. Rendering of possible cross-sections can be used as a method of communicating the ideas surrounding this project to stakeholders if our sponsor choses to continue with this tunnel proposal after we leave. With suggestions by the sponsor, further renderings could be performed of the surface structure of the tunnel to model how the submerged roads might affect the area above.

Phase 5 - Comparing Tunnel Visions

We will compare the Harbor Tunnel proposal and our tunnel proposal by combining the findings of our interviews, research, and surveying in the Copenhagen area. The evaluation topics we would like to address are listed below. Evaluation topics that are likely to be beyond the scope of the team's abilities have been noted below. We will gather as much information about these topics from our interviews and from our sponsor where possible. If we cannot gather any information on these aspects of the tunnel proposals, we will include them in suggestions to our sponsor for future work.

Evaluation Criteria

- Length of Tunnel (kilometers)
- North Entrance/Exit Location
- South Entrance/Exit Location
- Number of Exits
- Tunnel Construction Type *Determined with help from Miljøpunkt Nørrebro representative.
- Tunnel Construction Method *Determined with help from Miljøpunkt Nørrebro representative.
- Estimated Cost of Construction *Beyond WPI IQP project scope.
- Possible Effects on Surface Traffic *Beyond WPI IQP project scope.
- Possible Effects on Flood Management
- Soil Type
- Water Basin Inclusion?
- Topography (Slope of Region)
- Possible Effects on Public Transit *Determined with help from Miljøpunkt Amager representative.
- Possible Effects on Cycling *Determined with help from Miljøpunkt Amager representative.

- Possible Effects on Green Space *Determined with help from Miljøpunkt Amager representative.
- Possible Effects on Noise Pollution *Beyond WPI IQP project scope.
- Possible Effects on Air Pollution *Beyond WPI IQP project scope.
- Social Interest (Scale: 1 – 5; 1 = Strongly Against, 2 = Moderately Against, 3 = Neutral, 4 = Moderately Interested 5 = Strongly Interested)

Phase 6 - Deliverables

The final deliverables for this project will consist of cross-sectional views of possible tunnel designs and a presentation containing our design suggestions. The summary of comparisons drawn between the Harbor Tunnel proposal and our tunnel proposal will also be given to our sponsors.

Conclusion

The group will provide Miljøpunkt a complete package vision of an Amager tunnel as a final goal. It will include information on all areas of benefits that the tunnel could provide. The eventual tunnel will work as a solution to traffic and storm water, while providing multiple secondary benefits to the city and affected regions. Noise and air pollution from vehicular traffic will be greatly reduced and Amager will experience lesser side effects than expected from other Harbour tunnel Proposition. The final objective of the project to produce a possible design and route that will complete the vision of an Amager tunnel and allow for greater movement towards the eventual end goal of a tunnel plan that can be submitted for consideration in response to the Harbor Tunnel.

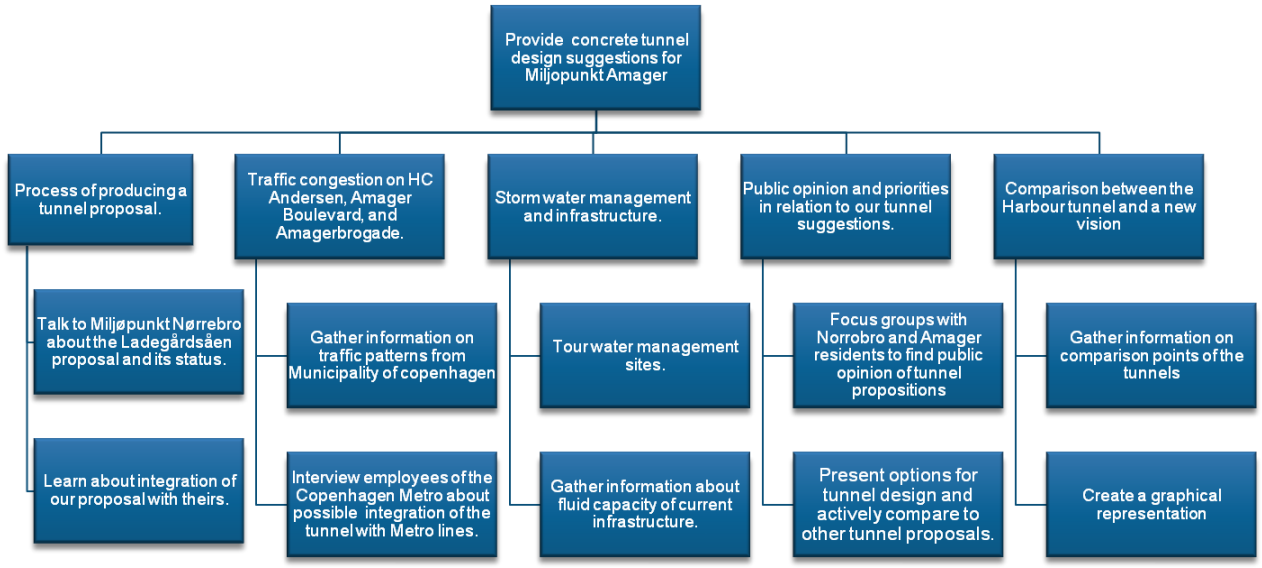

Figure 14 - Proposed Methods Flow Chart

Appendices

Appendix A: Interview with Traffic representative of the Municipality

Introduction of Interviewer and Assistants

This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. Do you give consent to this interview being recorded?

Our topic is Copenhagen's decision to build a tunnel that would connect north Copenhagen to the airport through Amager, and the different possibilities for this plan including the integration of storm water drainage. The results will be used to aid in the construction of a new tunnel plan that would replace the current Harbour Tunnel Plan.

Your were selected because as a representative of the municipality dealing with Traffic, you can provide information pertaining to the motivation for developing a tunnel to alleviate traffic as well as providing information about the current traffic situation.

Opening Question

1. How does traffic currently flow through Copenhagen?
2. Where is congestion in the city the worst?
3. What has Copenhagen done so far to alleviate this traffic excluding the planned building of a tunnel
4. For What reasons has the Harbour tunnel become the primary tunnel plan to alleviate the traffic
5. What has the city done to examine how the traffic would impact Amager
6. What does the Ministry know about Miljøpunkt Amager and the vision for a new tunnel plan?
7. Is the Ministry of Transport interested in storm water drainage and combining the traffic solution with the drainage solution?

Appendix B: Interview with Metro Representative

Introduction of Interviewer and Assistants

This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. Do you give consent to this interview being recorded?

Our topic is Copenhagen's decision to build a tunnel that would connect north Copenhagen to the airport through Amager, and the different possibilities for this plan including the integration of storm water drainage. The results will be used to aid in the construction of a new tunnel plan that would replace the current Harbour Tunnel Plan.

You were selected because as part of the Metro, you can provide information pertaining to how the metro runs, how it deals with storm water, and the correlation between the metro and traffic.

Opening Question

1. What have been the major issue with public opinion and protest during construction of the metro?
2. How does the Metro deal with storm water drainage during heavy rain?

. Is there any information to be obtained on the best possible drainage solutions?

3. What does the Metro know about Miljøpunkt Amager and the vision for a new tunnel plan?

4. Is the Metro connected to plans to develop a tunnel from the north of the city to the airport through Amager
    a. If so, how do the plans interact?
5. Does the Harbour Tunnel plan interact with the Copenhagen metro in anyway?
6. What is the opinion of the metro and the possibility of having underground linkages from the tunnel to the metro and to the street?

Appendix B: Interview with Suzanne LePage: Civil Professor

Introduction of Interviewer and Assistants

This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. Do you give consent to this interview being recorded?

Our topic is Copenhagen's decision to build a tunnel that would connect north Copenhagen to the airport through Amager, and the different possibilities for this plan including the integration of storm water drainage. The results will be used to aid in the construction of a new tunnel plan that would replace the current Harbour Tunnel Plan.

You were selected because as a civil engineering Professor with experience in storm water management, you can provide information pertaining to the development of a tunnel to alleviate traffic and storm water in Copenhagen. We also seek information pertaining to other examples of major tunnel projects meant to alleviate inner city traffic and storm water.

Opening Questions

1. What do you know about the traffic Situation in Copenhagen?
2. What do you know about the Storm water Situation in Copenhagen?
3. What do you know about the Harbour Tunnel Project?
4. What do you know about the previous IQP?

Primary Interview Questions

1. What are primary design options for draining large amounts of Storm water:
2. What kind of slope is needed for drainage
3. Would 15 feet over 5km pose an issue
4. What problems would one encounter when examining Storm water management infrastructure?

5. What are the issues that storm water management poses in conjunction with designing a tunnel
    a. Are these useful projects to combine?

Opinion Question

1. What are the primary problems in developing a vision for a civil based project?
2. What are the primary issues with public opinion and dealing with the public while creating a vision?
3. What are the best methods for contacting officials for information on such projects?
4. Is there a method to generalize traffic patterns in an area and then make estimate possible changes to the traffic pattern

Appendix D: Insurance Company Representative

Introduction of Interviewer and Assistants

This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. Do you give consent to this interview being recorded?

Our topic is Copenhagen's decision to build a tunnel that would connect north Copenhagen to the airport through Amager, and the different possibilities for this plan including the integration of storm water drainage.

The results will be used to aid in the construction of a new tunnel plan that would replace the current Harbour Tunnel Plan.

Your were selected because as an Insurance Representative with experience in the damage Storm water caused to Copenhagen, you can provide information pertaining to the development of a tunnel to best attempt to prevent storm water Damage in the future.

Opening Questions

1. What do you know about the Storm water Situation in Copenhagen?
2. What do you know about the Havne Tunnel Project?
3. What do you know about the Miljøpunkts Vision?

Primary Interview Questions

1. What were the primary problems that extreme flooding caused?
2. Where was the most damage sustained?
3. Is the Insurance Company undertaking any steps to aid in the city preventing damage in the future?
4. Has the Insurance Company undertaken any steps to begin predicting further storms that could affect the area?
5. Have they invested in research, or adjusted flood prone area maps?
6. Would an insurance company be motivated to support a tunnel design that would help to drain storm water?

Appendix E: Interview with Municipality of Copenhagen Environment Representative

Introduction of Interviewer and Assistants

This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. Do you give consent to this interview being recorded? Our topic is Copenhagen's decision to build a tunnel that would connect north Copenhagen to the airport through Amager, and the different possibilities for this plan including the integration of storm water drainage. The results will be used to aid in the construction of a new tunnel plan that would replace the current Harbour Tunnel Plan.

Your were selected because as an Municipality Representative with experience in the storm water management, you can provide information pertaining to the current infrastructure and provide information to aid in the development of a tunnel and further infrastructure as well as a discussion of green space.

Opening Questions

1. What do you know about the Storm water Situation in Copenhagen?
2. What do you know about the Harbour Tunnel Project?
3. What do you know about the Miljøpunkt Amager's Vision?

Primary Interview Questions

1. What is the current infrastructure like in Copenhagen for draining storm water?
2. What were the primary problems that extreme flooding caused?
3. Where was the most damage sustained?

4. What is the city doing to improve the infrastructure?
5. Has the city undertaken any steps to begin predicting further storms that could affect the area?
6. Have they invested in research, or adjusted flood prone area maps?
7. Is their further information on Storm water, including maps?
8. Would the city be motivated to support a tunnel design that would help to drain storm water?
9. How motivated is the city to produce more green space?
10. How much protest is associated with the Harbour Tunnel and its passage through Amager Fælled?

Appendix F: Miljøpunkt Norrobro Representative

Introduction of Interviewer and Assistants

This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. Do you give consent to this interview being recorded?

Our topic is Copenhagen's decision to build a tunnel that would connect north Copenhagen to the airport through Amager, and the different possibilities for this plan including the integration of storm water drainage. The results will be used to aid in the construction of a new tunnel plan that would replace the current Harbour Tunnel Plan.

You were selected because Miljøpunkt Nørrebro representative with experience in the designing of a tunnel vision, you can provide extensive information in how to develop a vision for a tunnel.

Opening Question

1. What do you know about the Miljøpunkt Amager's Vision

Primary Interview Questions

1. What was the summary of the process that the project underwent?
2. How much did storm water play into the acceptance of this tunnel?
3. What was the most difficult aspect of approval for feasibility?
4. What is your opinion of the Harbour Tunnel?
5. Are you planning on having the tunnel possibly link into the Amager vision tunnel?

6. Is there any further information on traffic in the area?
7. Has there been any research done into how the Nørrebro tunnel would impact Amager?
8. What role has public opinion played in developing this tunnel Vision?
9. How has the public reacted?

Appendix G: Survey of Residents

Introduction

1. You are not required to answer any question.
2. You can stop the survey at any time.
3. Your answers will be recorded and may be used in the future.

Survey Questions

1. Are you a resident of Copenhagen
2. What is your satisfaction with the traffic congestion and management in central Copenhagen?
    a. dissatisfied, Somewhat dissatisfied, neutral, satisfied, Very satisfied
3. What is your satisfaction with the route to the Copenhagen Airport?

. dissatisfied, Somewhat dissatisfied, neutral, satisfied, Very satisfied

4. What is your opinion of the harbour tunnel plan?
5. Would a tunnel system with a more direct route from northern copenhagen to the airport improve your travel to the airport?
6. Would a tunnel system with a more direct route through Amager improve your travel situation overall?
7. Do you feel it is necessary to increase drainage systems of stormwater in Amager and Central Copenhagen?
8. What is your opinion of the under construction Metro station and the affect it has had on livability of the city?