“Travelling Stockholm from Underneath
– a Journey of Light”

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Fig. 1 The green colour shows the stretch of the possible biking tunnel route from Fatbursparken to Tomteboda.

Fig. 2-4. Street views from central Stockholm.
“Travelling Stockholm from Underneath – a Journey of Light”

Abstract

The report Stockholm city's regional biking plan presents information of a continuously rising numbers of cyclists in central Stockholm. However, the central parts of Stockholm have not now, or in the near future, the capacity or structure to provide a functional as well as safe traffic situation, especially for cyclists. The increasing demand from traffic of the commuter street network in central Stockholm make the 6 km long underground maintenance tunnel along the newly build Citybanan commuter train tracks a possible and interesting alternative for safe, fast and easy bicycle travelling underneath Stockholm. The tunnel stretches from Fatbursparken to Tomteboda, with exits/entrances along the route in central parts of Stockholm [Fig 1.]

There are several examples in the world where former car, train and maintenance tunnels are used as biking tunnels. The longest existing example is the Croix Rousse tunnel in Lyon, France (2013). A 1.3 km long tunnel with separate lanes for cyclists, pedestrians and commuter busses, which also functions as an evacuation tunnel to the parallel car tunnel. Another example is the Lugaritz-Morland bicycle tunnel in the city of San Sebastian, Spain (2009), which is a former railway tunnel (850 metres) that connects two neighbourhoods in the city.

The specific conditions a tunnel have with no daylight and limited access, give the lighting designer the important task to shape the space using light. Light is the factor that makes us see the world, our visual ability is depending on the light. Light has the ability to reveal and transform the character of a space and influence how the observer experiences the situation, both physically (by vision) and psychologically (emotional experiences as comfort and feeling of safety). Therefore a good visual condition in public space, traffic as well as enclosed spaces like tunnels, are very important and a basic need for humans in the city.

The aim with this thesis was to develop a lighting strategy and proposal for the maintenance tunnel of Citybanan in Stockholm, based on literature and case studies research, a full-scale light observation by a reference group in a tunnel context as well as research by questionnaires. The primary purpose of the full-scale light study was to confirm literature research hypotheses about the importance of light distribution and experienced spatial atmosphere in relation to psychological effects, as well as the importance of light giving information. Findings confirm and shows that light distribution have a great impact on how the observers experience the space visually, as well as emotionally. Findings also show that light can influence people’s behaviour to intuitively slow down or be alert. Further this thesis results show that giving a space it’s own identity by collaboration between light, colour and architectural elements have a great impact on the psychological experiences of a space regarding safety, comfort and social interaction, crucial factors in a tunnel environment for cyclists.

The thesis results in a concept presented in the Proposal chapter, based on design principles and a lighting strategy where a combination of light typologies is used to create a human centred and comfortable environment. Light is used as guiding element and for spatial understanding to create comfort and support social interaction. In addition the concept includes a theme used as inspiration in the lighting strategy to create a connection on a human scale between the cyclist and the space. The theme is based on a common preference of the reference group, as well as my personal, for the ideal dream biking environment; In the nature. Experiencing for example the variation of light filtered through the leaves, the sunset and the absence of traffic.

The aim with the proposal is to transform the tunnel to an attractive bicycle route for daily cyclists in Stockholm, as well as being an interesting tourist attraction.

- A large underground landmark and art piece stretching under the city of Stockholm.
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1. Introduction

The Swedish transport administration (Trafikverket) has in their investigation “Stockholm regional bicycle plan” (2012) found strong indication of a steady increasing numbers of inhabitants using the bike as their daily transportation from home to work through central Stockholm. Today almost 25 000 cyclists/day pass Slussen a week day in May and the tunnel could be useful for at least half of them, depending on the destination. One of the strategic future goals of the “city plan of Stockholm” is to improve the bicycle lanes as well as increase the numbers of daily cyclists in the city. From several studies among Stockholm’s citizens the highest valued factors for choosing the route are traffic security and how fast and easy that route take them from A to B. The traffic situation through central part of Stockholm has not today the capacity or structure to provide a functional as well as safe traffic situation especially for cyclists.

The increasing demand from traffic of the commuter street network in central Stockholm make this tunnel an interesting alternative route for cyclists in central Stockholm. A first stage report of the tunnel, its potential as bicycle route and a general lighting strategy has been done by Tyréns in Stockholm assigned by Trafikverket. They made an investigation of the possibilities and suitability of using the tunnel for bicycle traffic. In their analysis for example the entrance/exit tunnel in south, at Fatbursparken have a inclination and turning that could become and effort for the cyclists especially leaving the tunnel at this position. Further the entrances need to be adjusted to the existing traffic situation so the passage are safe and the entrances are visible from a long distance for easy orientation. Regarding the usage of the tunnel, factors, as orientation, visibility, safety and identity need to form the base of the concept for the tunnel.

I am a daily cyclist my self and I share the common feeling of frustration caused by the intense traffic in the centre of Stockholm, sharing the space with cars, pedestrians, roadwork and large renovation of the Slussen area. The travelling situation for cyclists in central Stockholm contain safety and access problems, a situation that need to be improved to fulfil Stockholm city strategy of traffic and accessibility where the goal is to increase the numbers of travelling done by public transport, walking and biking. The investigation presents the intervention with motor traffic as one of the major safety problems for cyclists in central Stockholm, further the different weather conditions of the seasonal change is another factor that influence the cyclists travelling experience and comfort. Extending the independent travelling within the city give positive social benefits as well as physiological. Light has the ability to reveal and transform the character of a space that can influence how the user are experience the situation both physically (by vision) and psychologically (comfort, feeling of safety etc). Providing solutions that serve the user is one of the most important assignments for lighting designers. Together with the lighting technology light can really make a difference.

1.1 Aim with the Thesis

This thesis has the aim of providing a proposal of how this tunnel can become an alternative to the dense bicycle route through the city, that would give both a faster, safer and “weather proof” alternative to the citizen of Stockholm. Further it could increase the numbers “healthy citizens” choosing the bike as transportation from home to work. It has as well the potential of becoming a “large underground landmark and art piece” stretching under the city that can both give an alternative bicycle route as well as an interesting experience a tourist attraction in Stockholm. Giving the tunnel its own artistic quality and identity would link it to the “longest art exhibition in the world” along the different lines of Stockholm subway network, totally stretching 110 km, with art from 1950 to today [visitstockholm.com].
2. Methodology

The work includes a theoretical part as well as a practical part. In literature and paper review I gathered knowledge about human perception, human basic needs as well as psychological aspects. The relation light and space, space perception of public space, regulations for public space, light and speed and reference projects of existing bicycle tunnels as well as car tunnels is also researched. Further I looked to other situation that can wider the knowledge to use in the tunnel situation, such as space perception in room scale and behaviour effects of the use of patterns in traffic situation and using light as information.

The practical part consists of two Field Studies with volunteer subjects that are familiar with the environment for cyclists in Stockholm. Field Study 1 was conducted as a focus group study with 8 volunteers, 4 men, 4 women in the age from 25 – 60 years. The meeting took place 5th of March in the evening at a meeting room at Tyréns in Stockholm. The meeting was arranged by Tyréns to add data to their own investigation of cyclists and their opinions. I contributed with a questionnaire with the aim to understand what the cyclists on the streets of Stockholm think, collect information about preferences for tunnel light design, opinions of tunnel layout and the experienced perception of safety and emotional aspects.

The study included verbally presented open answer questions (Part A) and a questionnaire presented with 8 projected large-scale photos of tunnel situations (Part B). In part B volunteers were asked to Grade their feeling of safety. Grading scale: 1-5. 1 represented ‘non existing’, 3 representing ‘good’, 4 representing ‘high’, 5 ‘very high’. The volunteers were also asked to comment and motivate their choices/grading for each picture in a verbal discussion after all pictures has been shown. The result was translated into graphs to get an overview of average as well as differences and similarities among the volunteers. Additionally their verbally expressed opinions where written down. The selection of pictures was made for the variety of tunnel typology and light setting that would give the reference group the chance to express their opinion of diverse situations, giving information of what will work or not.

The volunteers signed up at an open call on the social platform Facebook for attending the meeting. On the question why they wanted to attend this meeting the majority explained that they as devoted cyclists in Stockholm and wanted to make their voice heard about the biking situation in Stockholm.

It is believed that studies in a reality situation give more reliable results. To gain deeper knowledge and to test hypotheses in a real tunnel situation, Field Study 2 was conducted as a full-scale light study in a tunnel environment evaluated by volunteers. Evaluating visual as well as emotional experiences in an architectural context, being in the space, is very important to be able to evaluate the parameters properly. The following hypotheses was tested, regarding visual perception, experienced safety and functionality from a biking perspective, based on background research and Field Study 1 results.

1. Light can give visual information
2. Light can increase the feeling of safety in public environment.

Additionally parameters investigated and explored in the study:

1. ‘Light as an information voice’.
2. Confirming the result from previous Field Study 1, which indicate that the direction of light as well as composition, relation and contrast affect the users feeling of safety as well as functional security.
3. Investigate if it is the perception of light around you rather than lux levels on the floor that make you feel comfortable?
4. How can light give intuitive information to slow down the cyclist?
5. Can colour and light together form a strong informative indicator?
6. How can dynamic light affect speed of a cyclist?
7. How can light lead the way?
The volunteer group consist of 9 persons, 3 Women and 6 Men with the age from 28 - 65 years. The study took place on the 7th of June at 9:30 pm, at dawn, to avoid as much "bright endings" in the tunnel as possible to influence the visual condition in the study. The tunnel space used is the Karlbergs tunnel in Stockholm, a pedestrian/biking underpass tunnel at Karlberg train station. It is approximately 60 meters long and has equivalent width and height dimensions, as well as surface material, as the evacuation tunnel investigated in this thesis. Because of no access to the actual tunnel site, the field study could not be made there.

The study was evaluated in a questionnaire including open answer questions (part A) and grading questions (part B). The grading question scale: from 1 – 4. 1 represent: I do not agree at all, 2: Agree at some level, 3: agree, 4. Agree totally. The volunteers were asked to make a circle around the number representing their opinion best, additionally they could write a personal comment, or answer; I do not know.

The grading questions were answered evaluating 7 different light scenarios presented one at the time with approximately 10 minutes evaluation time at each scenario. The volunteers were asked to evaluate standing still as well as biking through the tunnel space. The result was translated into graphs to get an overview of average as well as differences and similarities among the volunteers. Additionally the results of the open answer question (part A) as well as written answers of questions in part B was merged down to common opinions and conclusions.

The results of the field studies presents valuable information to evaluate and combine with literature research and previous knowledge as lighting designer to end up in a user-orientated proposal based on collected research and knowledge. There has been made many and much larger user evaluations in general for public space, but not with focus on pedestrian/biking tunnels. The aim with the studies is to add new knowledge regarding cyclist and their preferences and experiences, valuable for the resulting Proposal in this thesis, as well as reference within the field of modern lighting design. The findings and results are presented in the Thesis chapter Field Study 1 & 2 and form the base for a lighting proposal, presented in the Thesis Proposal chapter, for the maintenance/evacuation tunnel to Citybanan.

2.1 Research Questions

QUESTION: How can light become a tool to create a functional and aesthetical environment that provides a safe and comfortable experience for the users of this bicycle tunnel?

Aspects of importance:
> Physical and psychological issues of perception in a tunnel space
> Light and speed
> Light and visual perception
> Light as information
3. Background – Existing knowledge

The thesis and research topic - lighting design for a tunnel space used by cyclists, include aspects connected to light, enclosed space and us as human beings.

3.1 Light & Perception

Without light we cannot see. Without light there is darkness. With the sunrise the daylight opens up the door to a new day for us to explore with all our senses. To experience the light we also need darkness. The electrical light and development of technology give us access to live, work and transport ourselves regardless of the time of the day. Our visual perception is connected to our emotions and our experiences form the base for our actions. How the light reveal the space with contrast, direction, in relation to surrounding darkness and intensity create the full experience and understanding of a space.

Light reveals the surrounding and reality for us to experience with our senses; vision, emotions, physically and intuitively. The evolution of nature depends on light and our adaptation to nature; the existing situation and surviving are developed in relation to daylight/darkness, season and time. The natural daylight change constantly and transform and interact with material, surface, space and topography.

William Lam, lighting designer, point out the complexity of our basic biological information needs together with a social aspect of activity needs. - Information needs of location, time, enclosure and the presence of other living things (Lam, William, 1999). Further the needs of territory, opportunities and place of refuge. An example of activity need is defining ones territory where the activity is to understand/set its boundaries and make the space personally. Lam explain the social aspect as follows; If the information we seek is clearly visible and confirms our desires and expectations without background distraction, we are comfortable and free to focus our attention on what we need to see (Lam, William, 1999). I believe that these activity needs are even stronger today in modern society where the reality and virtual reality are present parallel to each other where the virtual world embodies fantasy worlds and personal development. The new technology and its possibilities also enhance the development of identity, uniqueness and invention. This development has pushed the usage of light as tool of identity as well as 24-hour access to public space and social interaction. Architectural lighting design has to, in my opinion, relate to these basic biological inherited relations to light as well as social needs to fulfil its purpose and serve its needs in refinement.

3.1.1 Visual perception - Spatial Perception

Our visual perception is dependent on contrast in light levels and colour. Our brain translates the visual perception electric impulses collected by the rods and cones in our eyes by the optic nerves. Our eyes automatically attracts and adjust to the brightest area in the close visual surrounding, demonstrating the importance of light distribution (Liljefors A, 1999). For our peripheral vision, conversely, the central vision (fovea vision) functions better in a uniform light, therefore norms and recommendations, for example the European Committee for Standardizations (CEN) and the International Commission of Illumination (CIE) are based on uniform lighting (task light/reading light) and quantitative research of light level, light colour and vision acuity has been in focus. Visual evaluation regarding spatial experiences and light distribution is less researched, but highly important to create a complete understanding of our visual perception and what lighting quality is. For orientation in urban space we use the peripheral vision (alt. retinal or side vision). The fact that the two types of vision, central vision (corresponding to 2 degrees of the viewing field) and peripheral vision (170 degrees of the viewing field) function in different ways and in different light situations is of great importance to light planners/designers. The primary task of the peripheral vision is spatial understanding aided by surrounding visible contrasts therefore, light at vertical surfaces as well as larger brightness contrasts – and not uniformity – is useful for our spatial experience and orientation ability (Liljefors A, 1999).
“For our visual experience of brightness in a normal visual condition there is no direct correlation between the surface lightness and its luminance” (Liljefors A, 1999, p. 27). This explains by the fact that it is the condition of contrast in the visual field as well as the present adaptation level that create the visual impression.

A good visual situation is depending on the specific situation of contrast and balance in lightness of surfaces in the visual field. A visual object, that is by contrast clearly defined as lighter than other surfaces in the visual field, attract the eye and support the visual understanding of a space. A situation with too big contrast creates the opposite condition, with visual discomfort and glare, for example a dark room with one window with bright daylight. A soft transition within the visual field is the foundation for a good spatial perception. A balanced and activity based light planning is of great importance to assure the best lighting for each situation including factors as emotional experiences, visual ability and acuity as well as spatial experience and economy. Anders Liljefors ”7 parameters” - light level, light distribution, shadows, reflections, glare, light colour temperature and colour rendering point out the most important factors in light planning based on the complexity of the human visual perception. (Liljefors A, 1999, p.13 ) The ”7 parameters” are connected to the physical parameters of the space; its dimensions, material and surface characteristics and their relation to the visual experience. The parameters defining the experienced light level are the reflectance of the surfaces in the space, the light level, the light distribution and light colour temperature. “The experienced light level is determined mainly by the reflectance characteristics of the surfaces in the space than the actual measurable light level” (Liljefors A, 1999 p. 32). Comparing a even/monotonous light distribution and a varied light distribution, the even light distribution is experienced as a lower light level but measured it is the same. A room can be experienced as too dark because of low reflectance of the surfaces in the space, in this situation a higher light level is not the most effective solution. To rise the reflectance ability of the space surfaces will create an experienced higher light level and provide a better solution. Further there is not a direct correlation between a doubled light level and an experience two times higher light level.

The light distribution is determined by the relation between the light sources placement and typology and its relation to the reflectance characteristics of the space. Shadows are important in our visual understanding of the world with its ability to reveal shapes and texture of the visual surrounding. Our perception of the world is based on the natural daylight variation that create shadows with very different characteristics. Further Liljefors refer to a study [Liljefors A, 1999, p. 35] made by S. Hesselgren (Hesselgren S, 1967), in the publication Language of Architecture, where the results indicates that the best light setting that depict a human face is a combination of angled light from in front and from above together with a diffused light [Figure.1]. Reflections are created by light direction, surface and the position of the eye. Reflections provide within the luminare an effective light distribution to the space where reflections on surfaces can give visual experiences of sparkling light effects, shimmer and light play, that is often connected to positive emotional associations. Negative effects can occur by wrong direction or position of luminaire or strong sun/daylight beams. Glare occurs when the contrast situation is to big in relation to visual adaptation abilities and in general it is the most important factor to avoid in light planning. The perception of light colour temperature is determined by the light temperature in Kelvin degrees, light level and light distribution. The experience of the colour temperature of the light is strongly connected to emotional state and associations rather than perceived colours. An incandescent light bulb has a “warm” light temperature but is not often experienced as giving a warm atmosphere hanging barely in a string with out a lampshade, instead perceived as glary and uncomfortable. Colour rendering defines the ability of the light source to show object colours realistically or naturally compared to a familiar reference source, either incandescent light or daylight where the CRI index 100 represent the maximum value (Liljefors A, 1999).

Figure 1. Light distribution effects on face appearance.
In Jan Ejheds publication “Ljus och Rum” (Ejhed Jan, 1992) the possibility of creating a “grammar” for describing the correlation between light and spatial perception of a space is studied. The luminance values was registered by a light measuring tool with max/min/average lux (lx) values and 145 volunteers evaluated 4 different rooms, grey or white walls and with 3 different light principles. No 1. Illuminated ceiling No 2. Wall mounted luminaires with upward direction giving indirect light, No 3. Recessed narrow spotlights directed downwards from ceiling along the walls, giving high contrasts.

Result in the study presented some clear common preferences of lighting principles, independent of the room layout. No 1. Was evaluated as the most functional and useful room associated with public environments as reception and museum. No 2. Was associated with waiting rooms and was perceived as the brightest but at the same time by spatial experience the most unstable. No 3. Was perceived as the most pleasant and beautiful room, yet darker in relation to the others and with the highest contrast between light source and ceiling (1/1300), the ceiling was not evaluated as the prominent feature in the room. Further this light principle was associated with private activities and spaces as bedroom, living room and restaurant. The rooms with white walls was perceived as more useful and peaceful, comparing to the dark grey wall colour where the spotlight principle in the dark grey room was evaluated in majority as the calmest, most relaxing room, spite the great contrast in light levels/shadow – highlights.

Jan made the conclusion of this study that it speak for that there is no general simple correlation between photometric data and visual spatial perception.

Figure 2. Pictures showing variation evaluated in the study by Lind W Ulrika.

Figure 3. Photo from study by Lind W Ulrika.
With the Phd Thesis “Light Shapes Spaces Experiences of Distribution of Light and Visual Spatial Boundaries” Ulrika Wänström Lindh (Lindh, W. Ulrika, 2012) presented research with the aim to increase the understanding of lighting quality and relation between light distribution and experienced spatial atmosphere, adding research knowledge to the most used working method for architects and lighting designers; visual analysis.

The assumption that illuminated (visible) walls enhance spatial enclosure and that lack of wall illumination makes a room alienating and poorly defined, was a point of departure for the two papers presented below, included in Ulrika Wänström Linds Phd thesis (Lindh, W. Ulrika, 2012). Results from both studies (Wänström L Ulrika, Paper A/paper B) supported this assumption but also several exceptions contradicting the assumption were found.

The paper “ Distribution of light and spatial enclosure – a scale model study” (Lindh W Ulrika, Paper A) present findings of the study where she evaluated and compared twelve different luminaire positions in two scale models with the aim to find relationships between the distribution of light and the perception of a space’s shape, size and whether illuminated walls contribute to the experience of a space being enclosed. When the observations were preformed, the rooms were studied in relation to the questions below:

- Which rooms are experienced as warm/cold? Why?
- Which rooms are experienced as hard/soft? Why?
- What is the importance of lit walls and corners for the spatial experience? Why? How?
- How are complexity, plainness and spatial enclosedness experienced?
- Does the illumination co-operate or counteract with the room shape?
- Does the illuminated room give any associations to ordinary functions and room-types?

Spatiality is discussed by examining light zones created by contrasts of light and shadows, and the light zones’ relationship to the physical space.

The findings show several examples of how the distribution of light influences the perception of the shape of a space: both compound and separated light zones can increase depth or width, depending on how these patterns of light are read together in the spatial context. Spatial enclosure was also found created in other ways, such as by darkness and contrasts [Figure.2]

In the paper “ Distribution of light in spatial complexity: appearance of five lighting scenarios in an auditorium” (Wänström L Ulrika, Paper B) Ulrika W. L. aim was to gain a deeper understanding of the complex relationship that exists between distribution of light and spatial experience. The relationship between the experienced light zone and the built space and how the perceived size, shape and experienced atmosphere. The study was conducted in an auditorium with five light scenarios. 21 informants answered a questionnaire and drew sketches, followed by in-depth interviews.

The result indicates a relation between indirect up-light giving a open, airy, high impression. Focused light impact the attention. Wall emphasis gave a wider but lower impression. Picture below [Figure.3] showing the Auditory scenario' with illuminated walls and indirect light reflected in ceiling that was perceived as the most open and airy scenario confirming the hypothesis that up-light combined with wall lighting, reinforce height and openness. Further the light crown and focused light zone in the ceiling gave an impression of a vaulted ceiling. The scenario also was perceived as “democratic” and inviting in the context of an auditorium. Lux levels in scenario; min; 28 lx, max 83 lx [Figure.3]
3.1.2 Visual Comfort & Recognition

Vertical illuminance is important to support visual recognition and identification of an approaching person, exemplified in a study made by Boyce and Rea (1990) (Boyce R. Peter, 2014, p. 448-449) The results presents findings where a minimum vertical illuminance of a human face to ensure confident identification need to be 33 lx at 17 m and 0.8 lx at 4 m. examined people’s ability to detect someone walking towards them and additionally recognize them from a selection of four black and white photographs. The results showed that the probability of detecting someone approaching reached 90% at a vertical illuminance on the person of 4–10 lx, where the lower illuminance level was enough when the person was approaching along a known path, while the higher illuminance was needed when a person could come from anywhere ahead of the observer. Higher illuminances are needed to approach 100% detection.

Further Boyce refer to a study made by Davoudian and Raynham (2012) in Human Factors (Boyce R. Peter,2014, p.427) that show the importance of a clear visual surrounding. The participating people in the study was wearing an eye-tracking device walking around in London after dark and the result showed that the pedestrians spent about 40%–50% of the time looking at the pavement ahead and the rest of the time, 50– 60%, looking at objects that attracted attention, such as people approaching, objects of personal interest, signs and vehicles driving nearby.

Boyce conclude `The study confirm that pedestrians want to be able to move safely over the ground, to see where they are, and to appreciate their surroundings. The desire to be able to see where you are is a very basic desire. Further there is a desire to avoid visual discomfort. All forms of lighting can cause discomfort through glare, particularly where low mounting heights are used. Discomfort can also appear by bad colour rendering where other people skin tone or objects / spaces are perceived “unnatural”.

Visual comfort is important to create a good visual situation as Boyce point out in the publication Human Factors (Boyce R. Peter, 2014, p.455) when it comes to creating lighting that is visually comfortable and attractive, meeting simple recommendations of horizontal illuminance is not enough. Attention has to be paid to the CCT, colour rendering and scotopic/photopic ratio of the light source used. Further, the luminaires have to be chosen and positioned so as to avoid disability and discomfort glare and to provide a light distribution that is even enough to be safe but diverse enough to be interesting. There is still some way to go before lighting recommendations for pedestrians can approach this ideal’. (Boyce R. Peter, 2014, p.458) ‘The situation for pedestrian security is a complex and difficult matter because the perception of security is a psychological phenomenon and people will differ over how they interpret the environment around them. Some who are confident about being outside at night may not bother about seeing at a distance, while those who are nervous might want to be able to see well all around. This means that light distribution is likely to be important for ensuring security’. 
3.1.3 Light in Relation to Colour

With the publication Färg & Ljus Karin Fridell and Ulf Klarén [Fridell, Karin, Klarén, Ulf, 2014] want to merge the knowledge of light - colour and space and give an overview and extended knowledge of how these field of practice should and can correlate. Light and colour together create and shape the visual experiences we perceive of the world we live in, despite this correlation and relation, light knowledge are separate from colour knowledge and practice. With the development of technology and LED the field of light has expand and with that the relation light and colour perception. The measured light in lumen/lx can be perceived as very different amount of light and colour tones and the measured value never correspond to a specific visual perception. The wavelengths of the light, the angle, the intensity and distribution together with specific property of the surface the light hit and reflects on, effect our perception of the world. Properties of surface - reflectance/ absorption, material and colour. The absence of light can also give a perception of colour, for example looking into a dark tunnel we perceive “blackness”. Seen as visual phenomena, shadows are darker colour fields in our visual field, in that meaning also visual objects. The perception of light is always connected to shadow, and the perception of light and shadow are always connected to space.

Light and colour it self does not give any spatial information. Colour has the only property of relate to other colours (contrast, saturation, hue etc) as well as light need to follow the structure of the space.

The perception of colour is created by a correlation between the colour and the light waves/ray. Further your colour visions adapts to the present situation and by that perceive a colour different in different light conditions [http://ljuskultur.se/files/2013/05/Visuella-f%C3%B6rh%C3%A5llanden.pdf, ljus & rum, p.27]

![Fig.4](image)

Fig.4 Contrast relation between grey tones and black.

Our perception of space is always characterized with some degree of emotional or intuitive understanding based on our cultural heritage, knowledge and values. These cultural understandings’ can change over time and are defined by location and area. Nevertheless this intuitive heritage together with the direct perception of a situation form the over all perception of space and create an important information for lighting designers and architects in their work creating functional as well as emotional understandable environments. Further research has developed the expression non – visual effects’ of the light, meaning the biological effects light has on our bodies, for example the awakening effect daylight has and how coloured light/surfaces can have a stimulating or calming effect. Effects important to be aware of when creating spaces with only access to artificial light.

Pictures below show example where white colour reflect the light coming from openings and create a sufficient light level in this transition zone in the subway [Fig 5]. In the picture to the right [Fig6] coloured green light exaggerate the green nature and create a mystical fairytale visual impression.

![Fig. 5](image) ![Fig 6](image)
3.1.4 Light as information

Except from visually reveal the spatial surrounding environment light can also be a tool for information. The most common information by light all over the world is the traffic lights [Figure 7.], coordinating the traffic with the green – “go”, orange and red light – “stop”, a clear optical signal system giving information we have learned the meaning of. Further light is used in traffic to give information about roadwork, accidents and signs of direction [Figure 8.]. The signals are given by light directed towards the viewpoint to attract the eye effectively and stand out in contrast to the surrounding. Often the light also has a dynamic feature of a pulse to give information of attention, for example at a roadwork where the traffic needs to go by an alternative route. This information can be seen as mainly learned but in some degree intuitive, where the strong pulse off light trigger our biological instinct for survival.

Light can also give information of borders and directional changes, marking for example the exit of a multi-storey car park or where a tunnel starts and ends [Figure 9.], this kind of information is connected to the specific space and situation, connected to the architecture. The information is not as clear as the optical signal system of traffic lights that we have learned the meaning of, but the collaboration with architecture and space we read and understand the message of the light intuitively where it gives information about the visual image in front of you and you read and understand it by biological knowledge together with your own previous experiences and cultural settings.

In the research paper “Investigation of Lighting signals as distance warning in traffic “ the author Anders Fransson (Fransson A, 2012) got results that confirms the believe that light signals can help car drivers keep a safe distance to the car in front. The result gave indication that the majority of the participants felt supported in the traffic situation by the light signal indicating a too short distance to the car in front. The signal was lit up in three stages and turned off one by one when the driver increased the distance to the other vehicle. The result also gave indications that participants felt relived by the supporting help and calmer in general in the traffic.

In Deike Ladwigs Master thesis in Architectural Lighting design “Information by intuition” (Ladwig D, 2006) she wanted to investigate the light as a spatial medium for expressing information that can be understand by intuition. “When light is truly integrated in the architecture light as a medium disappears and intuition can unfold as she express it in her thesis. This integration Deike L. believes can rise the living and working qualities in cities where the visual impression put a high demand on our information processing, sorting them out. In her full-scale lighting study she wanted to explore if a dynamic light could “move people”, to intuitively influence their behaviour. The experimental setting was conducted in a staircase indoor with integrated linear light on both sides along the walls. The result indicates that light can influence the behaviour and movement of a person.

Translating this to the bicycle tunnel situation I find it interesting to investigat if a dynamic light can help giving the cyclist information of an upcoming exit/entrance with other cyclists coming.
3.1.5 Light & Speed

There are differences between car and biking tunnels but also similarities, supporting the relevance of including it in the thesis research. Generally speaking, the car tunnel dimensions and length is larger, speed and perception of speed and distance is different and the fact that you sit inside a vehicle. The similarities are the effect an enclosed tunnel space has on the subject emotional experiences of safety and comfort, further in both tunnel situation the distance recognition and visual orientation is important to transport your self on bike or in the car.

**Example 1.** In the paper “Interior tunnel design and traffic safety aspects” (Patten Christopher, 2013) Christopher Patten investigated in a driving simulator experiment if lighting design can have effect on the drivers performance and road safety. Further the participants subjective opinion was rated and explored in a questionnaire. The study was conducted as an investigation for the design of the 18 km long Stockholm Bypass tunnel that are build to extend the road network around Stockholm. The length of the tunnel is expected to affect the drivers experiences of drowsiness, distraction, arousal and safety. The study was conducted in the VTI driving simulator no.III in Linköping. 24 participants drove 2 versions of the tunnel, one with light strings along the ceiling [Figure 10 a] and one without. Additionally artistic lighting features were presented situated at exits/entrances of the tunnel [Figure 10 b]. The aim of the study was based on the hypothesis that visual variation created by light design can have an emotional as well as perception effect that raise the comfort and driving performance. The result show that 58 % of the participants preferred the tunnel with string light design, further the result showed a statistically significant preference for the string lighting design regarding ”visually stimulating/arousal”. Based on the over all results of the study, the effect of the string lighting design was considered as more beneficial from a traffic safety point of view as well as breaking the monotony of the tunnel experience.

**Example 2.** In the report “The influence of lighting, wall colour and inattention of traffic safety in tunnels, a simulator study” by Katja Kircher Sven-Olof Lundkvist (Kircher ,Lundkvist 2011) the author concluded from the participants respond “that everything that makes a tunnel simplier also makes a tunnel safer”; Bright walls, bright illumination, wide shoulders, no oncoming traffic and no entry or exit ramps. Most participants also consider activation in the form of colours or art as unfavorable to safety. Bright walls and higher illumination was preferred, with a preference to the bright walls over additional illumination, as long as the illumination does not fall below a “minimum level”. The study was conducted in the Simulator III at VTI where 24 participants took part in the experiments. Illumination was varied on three levels, the tunnel wall colour and driver attention were varied on two levels each. Driving data, eye tracking data and subjective data were collected by a questionnaire. During the study participants had identified other factors that influenced their perception that was not altered and a part of the study, for example the tunnel length, the height of the roof, or the brightness of the road surface. This additional information could help when designing new tunnels, to make them appear as shorter, spacious or bright as possible. The author also point out the important fact that generally, when investigating traffic safety and driver comfort in tunnels it has to be kept in mind that the overall effect is often more than a sum of the tested variables, as there can be interactions and accumulating effects that will not be noted if only a single factor is varied. Also, safety indicators do not necessarily change linearly. The study indicate, for example, that there seems to be a level

![Figure 10 a & b](from left) Pictures from the study of Example 1. by Christopher Patten
for “enough light”, and a higher illumination is not followed by a greater benefit. (Figure 11 a& b.)

**Example 3.** In a study made by Manser and Hancock "The influence of perceptual speed regulation on speed perception, choice, and control: Tunnel wall characteristics and influences. Accident Analysis & Prevention" (Manser, Hancock, 2006) results indicate that drivers gradually decreased speed when exposed to the decreasing width visual pattern and increased speed with the increasing width visual pattern. The presence of texture served to attenuate overall driving speed. Results suggest that “the drivers’ perception of speed and their subsequent response to such perceptions were modified by the visual pattern and texture expressed on the tunnel wall.” The study was conducted in a driving simulator with a tunnel wall design in 2 variations; 1. wide stripes that gradually became thinner, 2. thin stripes that gradually became wider, 3. thin stripes throughout and 4. no stripes at all [Figure 12, 13]. For half of the participants the walls carried an additional texture, while it was smooth for the other half of the participants. The main findings were that was, in fact, possible to influence driving speed via tunnel wall design, with the participants slowing down when stripe width decreased and speeding up with increasing stripe width.

**Example 4.** In the article "Drivers’ perception of long tunnels" by Marianne Flø and Gunnar D. Jenssen (Flø, M. & Jenssen, G. D, 2007) the authors investigate in a study the potential of how art and artistic lighting design in tunnels can reduce the road users’ anxiety and the monotony in long tunnels as a pree-study for the building of the 24, 5 km long Laerdal tunnel between Oslo and Bergen. The experiment was conducted in the SINTEF driving simulator with 16 subjects that was studied when driving through four virtual tunnel alternatives; Three different alternative lighting designs and one with no lighting design (Basic) [Figure 14]. Objective measures such as speed, lateral position, overtaking, stops and turning maneuvers was logged continuously as well as verbal expression such as comments, sighs or outcries. Further subjective measures were gathered by a questionnaire filled in after each alternative. The study present experimental results that point out that the artistic design in a tunnel must be thought through very carefully regarding for example, colours and what is associated with them. The combination of red, orange and yellow made the subjects suddenly brake, reactions based on frightening feelings, relating to a tunnel fire. The results from the simulator trials show a variation in the experienced level of comfort/ discomfort and monotony where the difference between alternative 1 (Basic) and 3 (Rock crystals) is statistical significant. Basic gives discomfort to the users because the lack of colours and a cold expression as well being experienced as monotonous. Rock Crystal with “nice colours, being esthetical and pretty” as well as provide a varied visual experience. The author states “that there is no doubt that lighting design is a positive initiative.
in long road tunnels. Compared to Basic (no artistic light) all alternatives with lighting design got a significantly higher score. The alternative Rock Crystals got the highest score next to Outdoor. These findings formed the basis for the final tunnel design where four rock caverns with separate lighting design divide the tunnel in sections, example in figure 15.

Figure 14. Screen shots of the different tunnel designs tested in the study.

Alternative 1: "Basic"

Alternative 2: "Water"

Alternative 3: "Rock Crystals"

Alternative 4. "Outdoor experiences"

Figure 2: The Laerdal design alternatives

Figure 15. Photo example of the final tunnel design in reality, Laerdal tunnel between Oslo and Bergen.
3.2 Lighting in Public Space

Biking tunnels are a part of the public space but often not prioritized in the economy of public lighting resulting in a light setting with the simplest and cheapest alternatives, often not supporting the specific architecture of the space as well as the users emotional experience of the space. The tunnel situation in this thesis can be regarded as a public space with a constant darkness because of the lack of daylight. Providing a comfortable and functional space is crucial to become a space that is used by the citizens.

The public lighting and street lighting have had the single aim to illuminate the space enough to visually perceive the space, nothing more. Focusing on the function of the activity, not the experience of the space. During the 90- ties the role and usage of the city during dark hours was put in focus where the aesthetic role of light was added as a values to the city’s beauty and identity.

Today master light plans are integrated in both regional and city planning as a very important factor. Electrical lighting gives access to public space after dark for the citizen, by revealing the outlines of buildings, paths, streets, parks, different surfaces and directions. Light also act as a very important factor regarding the citizens feeling of safety as Boyce discuss in his publication Human Factors in Lighting. (Boyce Peter R, 2014).

Lighting in public space should follow the principle of providing readability of the space. The most important factors are where and how not the level of light (Nattens ljus, 2005). This include ability of seeing a meeting persons face expression as well the readability of the surrounding: that means illuminate key features of the environment as trees, bushes, niches or characteristic elements in the space, such as texture of a brick wall or other architectural elements that give identity to the space. A good planning of the light also point out landmarks and directions in the cityscape[Figure 16]. Figure 17 depict a unsatisfying light setting creating an uncomforting situation with glare for the observer. The lighting need to be planned after material and existing surfaces to be successful and efficient. A light and smooth surface reflect much more light than a dark textured one. In the Huddinge municipality masterplan of safety in public environments “Handbok för tryggare stadsmiljöer”(Huddinge kommun) the important factor of balance between light and natural darkness with smooth transitions between light levels. Further the parameter “taken care of” are discussed to enhance the perceived feeling of safety as well as equality between gender in Anna Karin Fridh project for Alingsås Municipality [Figure 18 a & b] (Fridh, Anna Karin) as well as in Kajsa Sperlings article (Sperling Kajsa, 2014) A space with suitable lighting for the specific location visualize the structure of the space including spatial environment as trees or dark corners [Figure 18 b]. Positioned in the centre of the space you have good overview and can early recognize for example another person. The space is taken care of in the sense of visual perception and feeling of safety. Analyses also show that “taken care of” spaces often also are spared from vandalism.
Figure 16. A good lighting example

Figure 17. An unsatisfying lighting example

Figure 18 a (top) & b. Existing light setting to the left and Anna Karin Fridh suggested lighting to the bottom right, creating a visual situation that promote safety and comfort.
3.2.1 Lighting methodology

Deike Ladwig and Clara Fraenkel have developed a lighting method that put the human being in centre for the light planning. The modern lighting technology give opportunities to work with the light in several “layers” where different lighting typologies create a site specific light design that increase the value of energy efficiency as well as comfort. Today this is common believe among lighting designers but they put forward in an article in Tidskriften PLAN (Fraenkel, Clara, Ladwig, Deike, 2013) that there is still a gap between traditional methods and the deeper understanding for the potential of lighting developing the city.

The traditional concept of functional lighting/ effect lighting and general light/accent light can limit the total overview of lighting planning where several different solutions are added to each other that both give inefficient lighting and unnecessary/wrong lighting. They point out that the main reason are the hierarchy within these terms that divide the lighting in necessary and additional lighting, where the additional easy can be neglected. The concept functional lighting define a function but not what kind of function and can create an unconscious decision that light not covered by the concept functional lighting have no important function. As mentioned before, when the aesthetic values of public lighting in the city was discussed in the early 90-ties the effect/accent lighting was added as additional lighting to the necessary functional lighting.

Their strategy is based on the three concepts: Spatial lighting, social lighting and identity lighting where the interaction and combination between these three create a deeper and more complex base for lighting design in public space. The Spatial lighting has the function of creating, recreate or redefine the spatial experience. For example illuminated vertical surfaces frame the space and small light spots can give direction and create a focus point or rhythm. The social lighting put the human being in centre. To experience feeling of safety a social orientation need to have the same value as spatial orientation, supporting human interaction as well as depicting the surrounding on a human scale with details and tactile qualities showing material and nature, a human environment. Identity lighting reveal, depict or create the soul of the space. Revealing the special and unique character of the space or creating a new identity, connection to the people using the space by positive associations. The feeling of community and belonging to a place are the fundamental parameters giving the space an experience of being safe. These added values of identity are precious in the modern world of uniformity.

Ljusarkitektur lighting concept for Axeltorv, Helsingör [Figure 19.] show a successful collaboration between those concepts where the result reveal the unique identity of this space as well as giving a good spatial perception on a human scale. The “milky way” over the ground give direction as well as a flow of movement also when empty of people.

![Image](Figure 19. Ljusarkitektur lighting concept for Axeltorv, Helsingör)
3.2.2 Regulation & Standards for Lighting

The tunnel space is a part of the public city and therefore need to follow regulations. The Swedish Transport Administration defines lighting regulations in the document; “Vägars och gators utformning” (VGU, 2012) and VGU Swedish transport administration directory for street lighting (VGU 2, 2012).

In the VGU regulation documents there is requirements and reference values to follow to ensure a good standard. The requirements values help to ensure a safety environment both regarding dimensions, material, curve radius, angle of inclination as well as lighting standards.

(VGU, 2012) In a traffic situation safety defines the condition of how the street, pavement, surface structure, traffic lights interact with the pedestrians, cars and cyclists to create as good and functional situation as possible to not cause any danger or accidents. In this situation light is mainly planned from a functional perspective based on regulated values in light level and distribution (VGU, 2004). The raised awareness of how light can effect the users of public spaces and bicycle/walking paths (VGU, 2004,p.6) psychologically there has been added directive where the terminology ‘lighting concept’ should be used instead of ‘street and road lighting’ because it better describe the complex work of illuminating the different situation in a city’s public space.

VGU (VGU 2, 2012) presents following categorization of the purpose and role of illumination/lighting concept in public space: Visibility – Spatial perception – atmosphere. To illuminate the function, the spatial surrounding and to create an atmosphere perceived as safe.

This change of directive influenced the lighting design in public space and today light has a given role in the development of both accessibility and visual comfort in the city and public spaces. Modern lighting technology gives the opportunity to to a very energy efficient way, with suitable light sources, outline the city during the dark hours and create accessibility, visibility and identity to public spaces.

3.2.3 Lighting in tunnels - Adaptation

There are several parameters to control creating a good perceptual condition in tunnels. The situation during daytime and night-time are very different. At daytime the tunnel space provide a much lower light level than the daylight outside the tunnel and opposite during night-time, where the tunnel space have a higher light level. Our visual system needs adaptation time to adjust to the existing condition. This is especially important when driving a car or a bike where the speed will put you in a position far into the tunnel in a shorter time than the eyes adapt. There is a developed method for calculating and plan the best light situation in a car tunnel with one way direction, based on exterior light level and tunnel length (VGU, 2012 p. 226-233). The tunnel is divided in five zones called the access zone, threshold zone, transition zone, interior zone and exit zone. Figure 20. shows an illustration of the relation of the 4 first zones. At daytime as well as night time the light levels in all the zones need to adapt to the existing light condition outside providing a “adaptation illuminance condition” where the light level following a curve connected to adaptation and specific speed resulting in values of luminance (cd/m2) and length (m) of each zone.

![Figure 20. Adaptation zones (VGU, 2012, p. 226)](image-url)
3.2.4 Regulations for bicycle

The regulations (VGU, 2004) does not provide any detailed information about the correlation of visual adaptation and pedestrian/cyclists in tunnel situations. The values for pedestrian/biking paths are defined in lux (lx) levels for horizontal plane where values for car traffic are in cd/m².

VGU directive - Architectural parameters
To be able to comfortable stop on the bike in a speed of 30 km/h with 2 seconds reaction time, the visual condition need to be clear of 35 meters to regard it as a good and safe situation (VGU grundvärden för gående och cyklister p.5).

Further the minimum curve radius are 40 meters and angle of inclinations with a maximum of 2 % as good standard, higher inclination can be accepted shorter distances.

The tunnel space I am investigating in this thesis fulfils in general the requirement values of VGU regarding dimensions for a 2-lane bicycle path.

VGU directive - Light levels in biking tunnels (longer than 150 meter)
VGU (VGU, 2012) requirements define requirements for pedestrian/biking tunnels in a few lines;

At daytime the average light level should be at horizontal level 100 lx and vertical on walls from 1,2 meter and up: 250 lx.

At night-time the horizontal lux level should be minimum 10 lx or higher, depending on the minimum level requirements for the exterior street/path connecting to the tunnel space.

Biking paths
Further VGU define following light levels for horizontal surfaces at pedestrian/biking paths with a smooth asphalt surface; 7, 5 – 15 lx (class p 3 – 1) and for vertical surfaces where identification of a person is important to prevent crime 10- 50 lx (class EV 3 -1). Further the requirements point out that the lighting needs to be very good at crossings and where the path change directions.

Lighting at pedestrian crossing
The complementary directory to VGU “vägbeslynsningshandboken” (VGU 2, 2012) point out the importance of a higher light level at pedestrian crossings to rise the awareness of an eventual crossing person to the car drivers. If the environment is bright and contain a mixed situation with different light zones it is most efficient to create a negative contrast situation between the person and the background in the area of the crossing instead of rising the vertical and horizontal light level just at the pedestrian crossing. This is exemplified by rising the horizontal light level to approximately to the double at a area of 50 meters before and after the crossing where a person entering this area will be perceived by contrast to the brighter background [Figure 21.].

Figure 21. illustration from VGU “vägbeslynsningshandboken”, 2012
4. Case Studies - Lighting strategy in bicycle tunnels

4.1 Bicycle Tunnels in the world

There are several interesting examples where tunnels have been transformed into commuter bicycle tunnels to become a part of the bicycle net in the city.

Example 1. [Figure 1] The Lugaritz-Morland bicycle tunnel in the city of San Sebastian, Spain (2009) is a former railway tunnel on the Bilbao-San Sebastian route with the distance of 850 metres long that connects two neighbourhoods in the city, giving the citizen possibilities to independently transport themselves by bike between this two city areas, enhancing both the individual independence in the society as well as the opportunity for exercise. The tunnel space is totally covered in white industrial fabric, asphalt ground and a central positioned line of down light in the ceiling.

Example 2. [Figure 2] The Somerset railway, the longest cycling tunnel in the UK, stretching 1,700-metres between Bath and the village of Midford. The track includes two vast viaducts and a tunnel (2013). The space material is stone bricks on the walls with asphalt ground, illuminated by two lines, one on each side of the tunnel giving down light on the ground as well as the walls.

Example 3. [Figure 3] The Brunkebergstunnel in Stockholm, Sweden is 230 meter long and function as a shortcut for cyclists as well as pedestrians (1886). The space has a mix of material and surfaces with mirror walls at the entrances and yellow coloured walls in the tunnel. Recessed lighting from the walls following the curved ceiling gives a reflected spatial light in the whole space.

Example 4. [Figure 4] The longest example is the CROIX ROUSSE in Lyon (2013) a 1.3 km long tunnel with separate lanes for cyclists, pedestrians and commuter busses. The tunnel also function as an evacuation tunnel to the parallel new build car tunnel with connections every 150 meters. The interior has a curved shape with a flat white surface where large-scale light projections are directed. Additional vertical spotlights are giving light on the ground.
Analyse from a lighting design perspective

The analyse is based on the 4 pictures of the examples using the Spatial lighting, social lighting and identity lighting strategy and the 7 parameters concept by Anders Liljefors, evaluating the visual perception in relation to space.

Example 1. [Figure 1] The Lugaritz-Morland bicycle tunnel is experienced as a quite narrow space because of the white surface and the narrowing shape of the ceiling. The same direction and layout of lighting and street marking give a clear direction but monotonous environment where the walls are perceived as “coming closer” by the slight inclination. The light distribution is even and the light level provide a functional light but there is lack of visual references for distance recognition because of no variation or contrast in the light. In a situation biking alone, the feeling of being trapped and exposed by being the only “actor” in this bright space are likely, giving negative emotional experiences regarding safety. There is no clear identity/design to the space and by that not contributing to the concept of identity lighting and social lighting, not providing human scale or emotional comfort.

Example 2. [Figure 2] The Somerset railway light typology create contrast that are to big, creating a non functional visual condition where the eyes are adapting to the bright spots giving the spatial perception of a dark space with glary bright spots. The light pattern dominates the visual field and provides a kind character/identity to the space, giving direction and outline of the space. Further the dark areas create possible hiding positions for perpetrators, one of the strongest factors for discomfort feelings as well as anxiety, not supporting the social lighting strategy. Adding additional ceiling light could form the basis for a better light situation.

Example 3. [Figure 3] The Brunkebergs tunnel has a strong identity with a bright and welcoming colourful impression and good visual overview linking to the aim with the identity and social lighting concepts. But the mirror interior can be questioned if it is not visually disturbing viewed from different angles and the space seems to be little narrow for comfortable passage for both cyclists and pedestrians. The reflected lighting in the ceiling provide a soft spatial lighting and outline the borders of the space in an interesting way where the material and textures are visible, providing a contrasting visual impression that supporting the understanding of the space borders as well as direction.

Example 4. [Figure 4] The Croix Rousse tunnel has a complex light situation dominated by the light projections giving a varying light scenario depending on the motive and contribute to a strong identity of the space but also the possibilities of glare and too big contrasts or lack of functional light on the ground. The additional spotlights on the ground are creating a visual guiding pattern but does not providing enough light to support the bright projections creating a visual condition where the ground is perceived as dark because of contrast. Bicycling there for a while I can imagine that you get tired of visual stimuli and you can question if the amount of “entertainment” can act as a distraction and jeopardize traffic security. The light projection on the other hand can support the social lighting concept by acting as “company” in the space also providing a reference to scale.
4.2 Pedestrian/ bicycle underpass tunnels

Example 1. [Figures 5 & 6] The pilot study “Ljusdesign I offentliga Miljöer, pilotprojektet Skogås-Trångsund” (Skogås-Trångsund, Huddinge kommun) was conducted to form guidelines in public lighting relating to social aspects for Huddinge municipality. Through a quantitative questionnaire sent out by mail to the local inhabitants where 220 of 1000 answered, information was collected regarding feeling of safety on public places in the area. The result show that more than 60% avoid specific places during darkness and that the main reason for feeling unsecure are inadequate lighting (38%), that the space are used by other people experienced as frightening (24%) and dense vegetation (16%). The majority feeling unsafe do it walking (68%) and (16%) on bike. The volunteers also had the possibility to mark on a map, unsafe places. Paths crossing areas that have much activity during daytime, as a school, but not at night-time was indicated as unsafe because of the dark windows with no one looking after you. Because of the activity at daytime the space are perceived as extra lonely and empty. Inadequate lighting was here the main reason for feeling unsafe. The pedestrian tunnels as well as underpasses was perceived as most unsafe because of lack of visibility both inside and at the entrance and end with “total darkness” visual situation.

An underpass tunnel close to a football field and youth activities in Nytorps mosse that was experienced as most unsafe by the locals was chosen to realize a lighting concept in. Together with 13 youths from the football club Skogås-Trångsunds FF a lighting concept was produced and realized in the spring 2015. The lighting concept consist of blue and green coloured light in a linear pattern as well as added white light at the entrances. Further the space was coloured white and a zebra pattern was painted on the ground to connect the tunnel space to the path, becoming a part of the path, not being a separate uncomfortable unit. The locals experience the result as very positive rising the emotional state of comfort and giving the space its own identity created by local children, a social factor adding a human scale and connection to the place by the children. (Picture taken by Emelie Roupe at Huddinge municipality.)

Example 2. [Figure 7] There are several tunnels in Gothenburg suburbs that are perceived as unsafe by the locals, especially children. A project called Ljuskonst initiated by the city developed different solutions for each tunnel. The picture present the result from a collaboration between the artist Peter Ojstersek, lighting designer Kajsa Sperling and children on the local school in Tynnered. The aim of the design is to make the tunnel perceived as shorter and give an easy overview.

Example 3. [Figure 8] Picture from Ljussättning av broar och tunnlar, 2009, Arkus förlag, p. 169

This underpass tunnel in Härnösand connects two streets passing under the train station. The walls are covered in wood that is illuminated with recessed linear light fixtures reflecting the light to the surrounding. The continuous light outside the tunnel entrances provide a god adaptive visual condition.

Example 4. [Figure 9]

In connection to Kungsbacka train station this underpass tunnel are located. Upward directed light are illuminating the walls and ceiling and recessed spotlights in the walls are directed to illuminate the ground inside as well as outside the tunnel space.

Example 5. [Figure 10]

The pictures show examples of two variations in light setting in two similar tunnel spaces in Lyon, France, giving very different light distribution and perception of space. The vertical light emphasise the walls and pathway, the illuminated ceiling enlarge the impression of space.
4.2.1 Analyse from a lighting design perspective

The analyse is based on the 5 pictures of the examples using the Spatial lighting, social lighting and identity lighting strategy [Deike L, Clara F] and the 7 parameters concept by Anders Liljefors, evaluating the visual perception in relation to space.

Example 1. [Figures 5 & 6] The tunnel project in Nytorps mosse present an example of how a tunnel can be transformed by colour and light. The space has a clear identity created by the linear light, as well providing a distant recognition. There is a risk of too big contrast between the light lines and the surface but probably in the reality the light levels are balanced. The white surface reflect the light and create a much more spacious impression of the space than the former situation. Created together with local children a strong social aspect as well as a human scale is added linking to the social lighting as well as identity lighting.

Example 2. [Figures 7] This tunnel situated in Tynnered, Gothenburg present a good example of how light and colour in a relative simple way, can give information of borders, distance and position of entrance/exit. The contrast of the dark asphalt and the colour white give a strong visual picture and identity to the space. The white ceiling provides an airy feeling, where a dark ceiling likely would give the impression of an enclosed space. Further the white round shapes on the ground reflect the light and create visual guidance and distant recognition. The white borders outline the path in a clear manner creating a safe traffic situation and guidance. The vertical section lines “measure” the space and define the length very good, emphasized by the added downward directed spotlights. All together creating an impression of a bright and welcoming space. From a social lighting perspective the white round surfaces help to visualize another person entering as well as the distance to that person connecting to the human scale perspective as well as a "taken care of" space.

Example 3. [Figures 8] The underpass tunnel in Härnösand show a working example of a situation where the spatial lighting are created mainly by vertical light reflected on the walls as well as ground (snow). The reflected light on the wooden walls give a warm and welcoming atmosphere and by continuing on both sides of the tunnel space giving a clear direction and visual overview of the surrounding creating a safe and comfortable situation. Further the vertical lighting create a

Example 4. [Figures 9] This underpass tunnel has a lighting that supports the architectural layout and materials and by that also exemplifies an effective light setting both visually and economically. The reflected light is giving a light and spacious visual impression creating a luminous ceiling surface that is supported by the spotlights on the ground. The quite uneven light distribution in the ceiling could be disturbing but is working together with the rhythm of the pattern of the spotlight mounted on the vertical walls, perceived as a conscious light setting.

Example 5. [Figures 10] Exemplify the influence light has on space, transforming the visual experience in two very different ways. The vertical light example outlines the walls of the space and the ground, creating a visual focus on the path and road and the activity of the space, further this light setting create a visual connection to the surrounding outside the tunnel where the light are continuing in a vertical visual position. There is a gap in light level at the very exits of the tunnel, creating a contrast situation that is too big influencing the impression of the tunnel to be unsafe by the lack of visual overview of the space on the other side of the tunnel, not supporting the social lighting aspects. The other version with reflected ceiling light is perceived as brighter and with a more even light distribution providing a good spatial lighting as well as on the ground. The ceiling is perceived as the brightest surface enlarging the perception of space. In this example the light level on the ground outside the tunnel is higher than inside the tunnel, providing a good overview of the surrounding after the tunnel creating a safe emotional experience.
5. Field study 1

5.1 Focus Group Study with cyclists in Stockholm

The purpose of the study was to understand how the actual user of the streets of Stockholm by bike think and collect knowledge and opinions from them.

Method
Focus group study with volunteers where the information was collected by open answer questions (Part A) and a questionnaire (Part B) presented with 8 projected large-scale photos of tunnel situations where no information of the tunnel was presented to not influence their grading. (Part B).
The volunteers were asked to Grade their feeling of safety.
Grading scale: 1-5. 1 represented ‘non existing, 3 representing ´good´, 4 representing ‘high’, 5 ‘very high’. The result was translated into graphs to get an overview of average as well as differences and similarities among the volunteers. In the questionnaire the volunteers was also asked to give personal comments.
The meeting took place 5th of March in the evening at a meeting room at Tyréns. Stockholm.
Attendance: 8 volunteers, 4 men, 4 women. Age: from 25 – 60 years.

5.2 Results
Part A. Volunteers were given verbally open answer questions to discuss around presented below:
>Are there any existing problems for cyclists in central Stockholm?
Subjects answers: Where to park your bike in a safe (and dry place)
They all live outside central Stockholm and experience that ‘the bicycle route are smooth until they reach central Stockholm, foe example Götgatan by Slussen. The main problems are road works, pedestrians on the biking path, too many cyclists, cars and red light interrupting the “flow”.

>The most important factor for you to choose the biking tunnel?
Subjects answers: Time saving (does not matter if the distance is little longer). Stretching along the main bicycle route through central Stockholm where there is a mess would be very appreciated.
Don’t want to get off the bike (cyclist shoes), want straight and easy access’.
Entering and exit the tunnel need to be practical and have good visual orientation.
The tunnel should be integrated in the bicycle network plan – connections to and from the street route and tunnel route, a connection with “flow”, no interruption in the travelling to take the tunnel.
Part B. As a second step the attending volunteers was given a questionnaire connected to 8 pictures shown projected on the wall with results presented below:

The questions, repeated on each picture: Grade your feeling of safety
Grading scale: 1-5.
1 representing ’non existing, 2 representing ‘acceptable, 3 representing ‘good’, 4 representing ‘high’, 5 ‘very high’.

Part B. Sum up of questionnaire results [Figure: 1 - 8]
The average grading was at lowest 1,5, representing ’non existing and highest at 4 ‘high’ shown in the graphs. The volunteers were also asked to comment and motivate their choices/grading for each picture in a discussion after all pictures has been shown.

[Figure 1.] Pictures of the tunnel space investigated in this thesis; Citybanan, got the average grading of 2,4, representing a grading between “acceptable/good” regarding feeling of safety. Further it got comments of being spacious and that the width is good to be able to meet other cyclists with a very comfortable distance, a luxury not so common in general on biking paths in the central city. But it was also perceived as dark and need of lighting, as expected because of the present condition of a working site.

[Figure 2.] The Citybanan tunnel section under water got the average grading of 2, 8 and by women 3,3. The tunnel got the comments of being very boring but the light is functional.

[Figure 3.] The San Sebastian tunnel got average grading of 3,1 and by women 3,5. The tunnel got comments of being too bright and the white surface of the whole space make it perceived as little boring, would be nice to have something to “entertain” you along the way. The straight feature give an easy overview ahead, the cold light temperature is contributing to the bright “whiteness” of the light.

[Figure 4.] The Heineenood bike tunnel got the highest grade from both men and women; 4,1. Grading 4,3 by women. The tunnel got the comments of having “good view and being spacious”, here you can go fast!” It was also perceived as safe. The yellow lighting got the comments of making the space ugly.

[Figure 5.] The Croix Rousse tunnel got the average grading; 4,0, By women 4,3. The tunnel got comments of being a “messy environment” ”Need better division of walking people and cyclists are needed. The light projections are fun as well as disturbing and too much.”

[Figure 6.] The former railway between Bath and Midford in UK got the lowest grade in total 1, 5, by men and by average 2,3. The tunnel got several correlating comments of that the contrast was too big between light and dark zones creating a unsafe feeling. It was difficult reading the spaces boundaries as well as eventual obstacles on the path. The regular pattern gave a kind of direction and outline of the space.

[Figure 7] The Nai tunnel/underpass got the average grading 2,3. The tunnel got comments of being hard to read and that the architectural structure of vertical elements gave opportunities for collision with other people. Further it was perceived as dark and uncomfortable. The colours did not contribute to the experience of safety, maybe to some degree of artistic value.

[Figure 8] The Brunkebergs tunnel got the average grading 2,9 and 3,0 by woman. The tunnel got comments of being little narrow but the lighting made it more spacious visually. It is positive to see the exit from the entrance. The floor material is questioned to be functional from traffic security point of view.
Figure: 1-4. Photos and Graphs from the questionnaire, question 1. (Part B) results:

1. Citybanans evacuation tunnel, the thesis site

2. Citybanans evacuation tunnel, the thesis site (under water section)

3. San Sebastian, Spain

4. Heineoord bike tunnel, Netherlands
[Figure: 5-8] Photos and Graphs from the questionnaire, question 1. (Part B) results:

5. Croix Rousse, Lyon

6. The Bath & Midford tunnel, UK

7. NAI TUNNEL/KORRIDOR, Rotterdam Holland

8. Brunkebergs tunnel, Stockholm

Graph showing result of question 1, feeling of safety
6. Field Study 2

6.1 Full-Scale Light Study in Karlbergs tunnel

The purpose of the study is to test the following hypotheses, based on background research and results of Field Study 1:

1. Light can give visual information
2. Light can increase the feeling of safety in public environment.

Additionally parameters investigated and explored in the study:

1. ‘Light as an information voice’.
2. Confirming the result from previous Field Study 1, which indicate that the direction of light as well as composition, relation and contrast affect the users feeling of safety as well as functional security.
3. Investigate if it is the perception of light around you rather than lux levels on the floor that make you feel comfortable?
4. How can light give intuitive information to slow down the cyclist?
5. Can colour and light together form a strong informative indicator?
6. Can dynamic light affect speed of a cyclist?
7. How can light lead the way?

Method

A full-scale light study conducted in Karlbergs tunnel [Figure 10.], a pedestrian/biking underpass tunnel at Karlberg station in Stockholm, approximately 60 meters long. The tunnel is selected based on the similar width and height dimensions, as well as providing a space with textured surfaces and white ceiling, factors important to the study to link to the actual tunnel site [Figure 11].

Date: 7th of June, 9:30 pm.

The study was evaluated in a questionnaire including open answer questions (part A) and grading questions (part B). The grading question scale: from 1 – 4. 1 represent: I do not agree at all, 2: Agree at some level, 3: agree, 4. Agree totally. The volunteers were asked to make a circle around the number representing their opinion best, additionally they could write a personal comment, or answer; I do not know.

The grading questions were answered evaluating 7 different light scenarios presented one at the time with approximately 10 minutes evaluation time at each scenario. The volunteers were asked to evaluate standing still as well as biking through the tunnel space [Figure 9].

The questions were in Swedish translated afterwards.

(Part A) Open answer questions

How often do you bike and how fare?
For what distance would you be comfortable to bike in a tunnel space with security as well as comfort issues taken care of?
How does the lighting affect your perception of safety when biking?
I often feel unsafe at tunnel entrances/exits
I perceive tunnels in general as unsafe
In your dreams, how does your biking route to work look like?
(Part B) Grading questions

Scenarios: 7
The grading question scale: from 1 – 4.
1 represent: I do not agree at all, 2: Agree at some level, 3: agree, 4. Agree totally.
In scenario 1-3 the different light settings presented light typologies evaluated with focus on feeling of safety and spaciousness.
In scenario 4-6 the different light settings are design to test the hypothesis "Light can give visual information”.

In scenario 1-3 the question asked was:
a.) I perceive other persons faces good
b.) I perceive this as a good environment from a safety perspective (please motivate with your own words)
c.) I experience this environment as functional for biking
d.) I perceive the ceiling, ground and walls of the tunnel space, mark the area on the picture that you perceive is most illuminated.

Additional open answer question in each scenario:
1.) The light on the walls/ ceiling/ both make me perceive the space larger/ wider/ other
2.) Describe with own words how your perception of the space change from the previous scenario

In scenario 4-7 the question asked was:
a.) The coloured illuminated vertical surfaces define the outlines of the opening of the tunnel
b.) The coloured light affected my perception of safety
c.) The coloured light catch my attention
d.) The light scenario/coloured light facilitate my perception of distance recognition.
(underline the word describing your reaction best)
d.) The coloured light make me want to slow down/being alert

Additional open answer question for scenario 4-7:
1.) What does the coloured light "say" to you?
2.) Do you associate this scenario to another traffic situation?
3.) Describe with own words how your perception of the space change from the previous scenario
4.) Do you experience this light scenario adding anything to the over all experience?

The scenarios included different light settings based on the hypothesis arranged inside the Karlbergs tunnel. Positions explained in plan [Figure 9] and as typology illustrations in the right corner for each scenario in figures 12 – 19. The light sources used in the study where borrowed by the following lighting companies: Stockholm Lighting, Fergin and Rebel Light.
Figure 9. PLAN
Schematic illustration of tunnel space, luminaire position, evaluation positions and luminaire definition
Site: Karlbergstunneln, Stockholm

Lux values measured at site on ground level:
position Lux 1.
Scenario 1. 30 - 50 lux
Scenario 2. 30 - 40
Scenario 3. 80 lux, Vertical at wall: 1 m from ground: 300 lux, 2, 5 m : 150 lux

Position of luminaires at scenario 1, 2, 3
White painted ceiling

Skala 1: 100 cm

Participants viewing directions and start /end position Scenario 1-5

Rörstrandsgatan

Skala 1: 300 cm

Karlbergs slott

Participant viewing directions and start /end position Scenario 6-7

Scenario 1-3
Luminaire 1: Linear LED tube
Brand/name: Erfurt/Norka
4000 K, Ra 84
Length: 125 cm
Beam: 100/100°
Power: 29 w, 330 lumen
Position: ca 3 m from ground

Scenario 4
Luminaire 4: LED, blue
Brand/name: Meyle/Superlite
Nano 2
Beam: 30°
Power: 4 x 1,5 w
Position: Along the wall, washing the stone walls

Scenario 5
Luminaire 3: Metal halide
Brand: Meyer
Beam: medium °, symmetrical
Power: 70 w
Position: at the entrance of tunnel on a hight of ca 6 m, angled down on ground with green plastic.

Scenario 6
Luminaire 5: Linear LED
Brand/name: Lumencove
Length: 120 cm
Beam: 120/120°
Power: 9 w
Position: Vertical

Scenario 7
Luminaire 6: LED, RGB
Brand/Name. ACDC, Artemis
Beam: 18°
Power: 7, 7 w
Position: along the wall
6.2 Results

(Part A) Open answer questions - Results
The participants are more or less daily cyclists where 5 out of 9 bike every day to work. From 4 - 20 km/day 3 out of 9 bike ones a week or not regularly. On the question how lighting are effecting the persons perception of safety motivated with own words the most frequent comments was: ”To see the ground clear is very important factor”(5 out of 9)”To be able to visualize other people”(3 out of 9) ” A balanced surrounding in light and darkness/shadow to give a clear overview”(4 out of 9). A balanced light in contrast between light and darker areas was the strongest factor pointed out by the majority regarding the feeling of safety at tunnel entrances/exits(5 out of 9). The result of the answers indicate that daily cyclists in Stockholm do reflect over the lighting and light conditions in the public environment. Further the results confirm the importance of lighting in bicycle/pedestrian tunnels and the relations between light and shadow. On the question of how they imagine their favourite way to work on bike, 8 out of 9 answered ”In the nature” where greenery, sunshine, birds singing and no cars, is a part of the dream scenario.
(Part B) Grading questions – Sum up of results [figures 12 – 19]

Scenario 1-3: Figures: 12-14
The personal opinions where in general very coherent and pointing in the same direction of perception and belief where the scenario 3 got the best ratings as well as personal opinions:
"The space feel little more airy, The face recognition is good but the linear light on the ground is little glary, The perception of depth and space are very good as well as functional, Little too much light, The combination of 1 & 2 here in 3 are the best, make the space alive and reveal its material and structure"
(3 persons opinion).
Further scenario 3 also was rated as the scenario perceived as most safe (question b.)
Scenario 1 got personal opinions of being "Boring but functional, Not beautiful but safe, Sterile that I perceive as unsafe, Flat, The contrast in light level is too big between vertical wall and ceiling, Calm".
Comparing to the Scenario 2 with illuminated walls where the opinions were: "More interesting and comfortable and I think it is a better light setting to bike in for a long time, The structure of the walls is revealed in a nice way, More atmosphere, depth and nice feeling, Too little light on the ground and maybe too big contrast in relation to the whole space, Nice and safe, Dramatic atmosphere.

Scenario 4-7: Figures: 15-19
Comparing the results of the questions:
On the open question "what does the coloured light "say" to you? "(information by light) the majority perceived the added light as an alert/information about that there is something happening further ahead, stop, be alert!
Questioning if the light scenario effected their perception of safety. Scenario 4 was not rated as supporting the feeling of safety in a high degree but scenario 5-6 was rated as supporting the feeling of safety.
In scenario 4 and 5 on the question if the coloured illuminated areas define the outlines of the opening of the tunnel, the rating indicate that the light setting help to define the opening of the tunnel; vertical light "stripes" on the walls of the tunnel/ coloured illuminated surface on the ground by the opening.
On the question if the light scenario/coloured light facilitate my perception of distance recognition, in scenarios 4 to 6, the result show that the majority of participants have the opinion that scenario 6 b. with vertical dynamic light lines best help distant recognition, but all the scenarios got rated as passed.
On question a.) In scenario 6; if the light gave information about the direction the path take, scenario 6 b, with the dynamic light scene, got the highest rating with motivation with associations to roadwork lighting for example changing lane. The information already exists in the common mind.
Figure 12. Results of grading questions presented in graph and text (part B)

SCENARIO 1.

a.) I perceive other persons faces good 1 2 3 4
b.) I perceive this as a good environment from a safety perspective (please motivate with your own words) 1 2 3 4
c.) I experience this environment as functional for biking 1 2 3 4
d.) I perceive the ceiling, ground and walls of the tunnel space, mark the area on the picture that you perceive is most illuminated. All the participants had the opinion that the ceiling was illuminated (pink circle)
e.) The light in the ceiling make me perceive the tunnel “airy” 1 2 3 4 (if there is a better word describing your experience please write it down)

“ I perceive the spatiality (rumslighet) of the tunnel”

Personal opinions of the subjects:
“Boring but functional, Not beatiful but safe, Steril that I perceive as unsafe, Flat, Create dark eye areas on face, The contrast in light level is too big between vertical wall and ceiling, Calm”.

Light level on ground: 30 - 50 lux
light temperature: 4000 K

Graph: Answers of grading questions
Picture from light study scenario
Figure 13. Results of grading questions presented in graph and text (part B)

**SCENARIO 2.**

a.) I perceive other persons faces good 1 2 3 4

d.) I perceive the ceiling, ground and walls of the tunnel space (mark the area on the picture that you perceive is most illuminated)

All the participants had the opinion that the walls was illuminated (marked with pink circles in illustration)

e.) The light in the ceiling make me perceive the tunnel “wider” 1 2 3 4

“interesting, a feeling of speed, limit the space and pronounce the tunnel shape”

1. Describe with own words how your perception of the space change from the previous scenario

 “More interesting and comfortable and I think it is a better light setting to bike in for a long time, The structure of the walls is revealed in a nice way, More atmosphere, depth and nice feeling, Too little light on the ground and maybe too big contrast in relation to the whole space, Nice and safe, Dramatic atmosphere

Light level on ground: 30 - 40 lux
light temperature: 3000 k vertical

Graph: Answers of grading questions
Picture from light study scenario
SCENARIO 3.

a.) I perceive other persons faces good 1 2 3 4
b.) I perceive this as a good environment from a safety perspective (please motivate with your own words) 1 2 3 4
   "I see the ground and people good."

c.) I experience this environment as functional for biking 1 2 3 4
d.) I perceive the ceiling, ground and walls of the tunnel space, mark the area on the picture that you perceive is most illuminated.
   Ceiling: 2, walls and ceiling 4
e.) The light in the ceiling make me perceive the tunnel "volume"
   1 2 3 4
   (if there is a better word describing your experience please write it down)
   "Spacious"

1. Describe with own words how your perception of the space change from the previous scenario. The space feel little more airy, The face recognition are good but the ground up light is glary. The perception of depth and space are very good as well as functional, Little too much light, The combination of 1 & 2 here in 3 are the best, make the space alive and reveal its material and structure" (3)

Personal opinions of the subjects: A good transition between tunnel environment and outdoor environment”.

Light level on ground: ca 70 - 80 lux
Light level vertical:
1m from ground: 300 lux, 2, 5 m : 150lux
Light temperature: 3000 k vertical, 4000 k up light

Graph: Answers of grading questions
Picture from light study scenario
SCENARIO 4.

1. What does the coloured light "say" to you?
   "That there is something happening further ahead" (5)
   "A change, the light creating a portal/frame of the opening!" (2)

a.) The coloured illuminated vertical surfaces define the outlines of the opening of the tunnel 1 2 3 4
   (If there is a better word describing your experience please write it down)

b.) The coloured light affected my perception of safety 1 2 3 4

c.) The coloured light catch my attention 1 2 3 4

d.) The light scenario/coloured light facilitate my perception of distance recognition 1 2 3 4

Personal opinions of the subjects: "As exit, little disturbing, it is important that the light are not too strong so it makes it harder to see what is outside"

Light level on ground: ca 70 - 80 lux
Light temperature: 3000 k vertical, 4000 k up light

Graph: Answers of grading questions
Picture from light study scenario
SCENARIO 5.

1. what does the coloured light "say" to you?
   "Something is happening further ahead" was an answer by the majority of the people. Be alert, Warning, stop, Start/Mål (2)

  a.) The coloured illuminated area define the outlines of the opening of the tunnel 1 2 3 4
      (if there is a better word describing your experience please write it down)
      "I think this type of signal/alert represent something important like a sudden curve or narrowing path, just for marking the end of a tunnel is more disturbing"

  b.) The coloured light affected my perception of safety 1 2 3 4
  c.) The light scenario/coloured light facilitate my perception of distance recognition. 1 2 3 4
  d.) The coloured illuminated surface support my perception of another person earlier 1 2 3 4

Personal opinions of the subjects: The scenario make me feel safe because I perceive that someone have put care and effort in this place.

Light leve on ground: ca 70 - 80 lux
Light temperature: 3000 k vertical, 4000 k up light

Graph: Answers of grading questions
Pictures from light study scenario
SCENARIO 6 a. Static light

1. what does the coloured light “say” to you?
   “Stop! something is happening, Warning. The path is turning “turn”
   “Party 2
   “light art 2

a.) The light give information about the direction the path take
   1 2 3 4
   “Arrows would be better”

b.) The coloured light affected my perception of safety
   1 2 3 4

d.) The light scenario/coloured light facilitate my perception of distance recognition.
   1 2 3 4

d.) The coloured light make me want to slow down/being alert. Slow down: 3, Become alert: 3
(underline the word describing your reaction best)

Light level on ground: 20 lux
Light temperature: unknown, light from existing luminaires

Graph: Answers of grading questions
Picture from light study scenario
Figure 18. Results of grading questions presented in graph and text (part B)

SCENARIO 6 b. Pulsating light

1. what does the coloured pulsating light “say” to you?
   “Stopp, new direction, 2
   Attention 4, something is happening 2”

a.) The light give information about the direction the path take 1 2 3 4
b.) The coloured pulsating light affected my perception of safety 1 2 3 4
c.) The coloured pulsating light facilitate my perception of distance recognition. 1 2 3 4
d.) The coloured light make me want to slow down/being alert.
   Slow down: 3 Become alert; 4 (underline the word describing your reaction best)

1. Describe how your experience change comparing to earlier scenario 6 a. with static light.
   “Now I know why I should have attention, the meaning of the light, allertness of something is changing. (4)
   The dynamic light arouse my attention more (2)

2. Do you associate this scenario to another traffic situation?
   “Roadwork 7, change of driving lane,
   Light signal for a sharp curve of a road
   The pink colour take away the direct relation to roadwork, which is good.”

Light level on ground: 20 lux

Graph: Answers of grading questions
Pictures from light study scenario
Figure 19. Results of grading questions presented in graph and text (part B)

SCENARIO 7.

a.) The coloured light catch my attention 1 2 3 4
b.) The light scenario affect my emotional state 1 2 3 4
   (describe with own words how)
   "make me exciting, safe, calm and welcoming, happy, playful,
   the light beams I perceive a little harsh to the material on the wall, wash it away

1. Describe how your experience change comparing to earlier scenario
   "The tunnel get its own identity, give it a nice atmosphere
   "Make the space I want to be in rather than just go through"
   Less anonymous, more comfort;

2. Do you associate this scenario to another traffic situation?
   "Södra länken and Norra länken
   A rainbow, a painting made by children, stage lighting

3. Do you experience that this light scenario add anything to the overall experience?
   "Nice atmosphere, In a long tunnel I think this type of light scenario can help you stay focused and "entertain you" and give distance recognition (2)

Light level on ground: 20 lux
Light temperature: unknown, light from existing luminaires

Graph: Answers of grading questions
Picture from light study scenario
7. Site Analysis of the Tunnel space

7.1 The tunnel space

There are several aspects to critically to be aware of and evaluate regarding the space. From a larger point of view such as the few entrance/exits in relation to distance, that rise the importance of security and difficulty of creating a space giving a safe experience for the users. Issues not researched in this thesis [Figure 3]. The positive value the tunnel could provide, in relation to the dense city streets, is a car and pedestrian free transportation environment for the increasing daily cyclists in Stockholm. This would increase the traffic security by reducing occasions for eventual accidents and confrontations. The architecture of the space provide a spacious environment for a two-way bicycle lane and also improve the environmental factors of weather that can cause trouble regarding visibility and accessibility by rain, snow and ice [Figure 6]. Further the tunnel could attract more citizens as well as tourists to choose the bike as transportation vehicle. Through discussion with people taking part in my studies and friends, the fact that many of them feel stressed biking in the city [Figure 1] has come to my knowledge and some of them feel forced to choose public transport instead because of lack of security in the city street traffic.

The tunnel space differentiates very much from the cityscape it connects to and stretches under. Architectural wise it has an enclosed shape with ground, walls and ceiling in contrast to the varying city architectural structure with an open sky and connecting transportation routes. Further there is no natural daylight and no sound from the activity of the city with car traffic, public transport and people in large numbers or nature inside the tunnel space. The space is not visual perceptible with out added electric light. In that sense the space are like a blank canvas that can be transformed into “anything”. The absence of sound is also a very important factor to take in consideration. Leaving a noisy busy street and entering a total quiet long space can be a too big contrast and be perceived as uncomfortable and deserting. Here I believe it is important to work with the transition from noisy to quiet, to coordinate the sound with light. Further it is also a great opportunity to create a unique environment for all our perceptual senses. Tunnels have a very specific architectural nature, creating a frame around the path going through, this create a trapped situation with limited escape opportunities, challenging our natural biological behaviour. The main issue in this situation are the lack of light before and after the entrance/exits to the tunnel, creating a black wall in contrast to an enclosed exposed situation in the lit tunnel space. To create a comfortable situation for the citizens the tunnel space need to be connected with the surrounding by the architectural design as well as connecting with the light; to – through – and out, of the tunnel.

For longer tunnels, such as the one investigated in this thesis, there are additional parameters to consider as orientation, distance recognition, spatial experience and social/psychological aspects. This will be the focus point of my thesis and reference point in my proposal.

Picture below [Figure 1 & 2]: A normal morning at Götgatan where pedestrians and cyclists have a difficult situation additionally with demanding car traffic.
7.1.1 Architectural Analyse

The tunnel space has a complex architectural typology of dimensions, surface as well as borders and structure [Figure 6, photos from site]. The height and width dimensions are larger than regular pedestrian/bike tunnels in Stockholm. It has dimensions closer to a one way car tunnel for the purpose of evacuation from Citybanan [Figure 5]. The tunnel space has the total length of 6000 meters with 5 access/exit with the longest internal distance of ca 2000 meters and shortest 500 meters. The access points are located at (from south): Fatbursparken, Söder mälarstrand, Bangårdstunneln, Torsgata and Tomteboda [Figure 3]. The general dimension of the tunnel space is approximately 4.9 meters high and 4.6 meters wide. The tunnel space has a “dynamic” feature with variation in inclination with down/up hills and turning direction [Figure 6]. In general the inclination are maximum 2-4 % providing a situation fulfilling “good standard” (VGU definition).

Variation of the tunnel space: There are 21 connecting tunnels along the route, creating alcoves in the tunnel space, with an internal distance of approximately 300 meters for evacuation purpose [Figure 4, blue colour]. At these connecting points the width of the tunnel increase as well as the height to provide space for vehicle parking or/and ventilation/technical facilities. Here the width increase to 7 - 8.1 meter and a height of 5.6 meters. These alcoves provide a break in the monotonous long tunnel space with opportunities for creating visual variation with light presented in the Proposal chapter. The tunnel space fulfils VGU requirements for a two lane biking track with extra space for overtaking in the same lane within the definition of “good standard” (4.4-3.25 m). In general the inclination are maximum 2-4 % providing a situation fulfilling “good standard” (VGU, 2012).

The access tunnels (marked with red colour in figure 3 & 4) connects the city with the tunnel at 5 different sites in the city centre. The dimensions range from 3,9 – 7,5 meters in width and fulfil “very good standard” where 4 cyclists can meet in width, providing a safer situation [Figure 5]. The inclination range from 2-17 % giving a quite heavy down/up hill situation at some distances but still fulfil the minimum requirements for VGU (VGU 2012).

The length of the access tunnels is between 80 – 270 meters with a varying layout of straight and turning direction and different inclination. The layout give a quite challenge to the cyclist at the uphill sections but on the other hand provide some rest going the other way [Figure 3 & 4, red colour].

The physical parameters of rough textured and uneven concrete surface of the walls and medium mate grey as the surface colour give the impression of being under ground relating to tunnels in general. The ground has a surface of asphalt and together these dark and unreflective material and surfaces give little opportunity for light reflection. There are also objects within the space that create hidden dark corners that decrease the visual overview and control [Figure 6, light blue & green arrow].
In figure 3 & 4: Red colour: access tunnels, Green colour: the tunnel space, Blue colour: the alcoves position.

Figure 3.

Figure 4.

Figure 5. The variation of dimensions of the tunnel space, technical drawings. Measurements in millimetre.
Figure 6. Photo collage from the tunnel space.

Tunnel section under water
7.1.2 Analyse of space from a visual impression and experience

[Figure 6.] From my personal visual impression as a lighting designer, the overall visual impression of the tunnel space is dark, and it has strong associations with underground caves and tunnels because of the rough texture. The rough texture of the walls can add unexpected shadow effects and create an unstructured visual situation as well as being experienced as an unsafe place. On the other hand, the structured wall surface can add a pleasant variety and "alive" surrounding creating a subtle visual reference surface, naturally leading your vision forward searching for the next "visual variety".

The dimensions are perceived as quite large but the ceiling height and layout are not visually clear where lighting can reveal the structure to add clarity to the overall visual picture of the space. Further at some areas [Figure 6. red arrow] the ceiling height and layout are not visually clear. The flat asphalt surface gives a functional and traffic-safe environmental experience.

The variation in dimensions in height and width add visual reference and make the space not perceived as monotonous, an issue that is common in tunnels in general. Further the variation in inclination and direction create associations to the normal street variation in the city and make the visual as well as physical experience diverse demanding a focus on the activity of biking.

The tunnel space alcoves can create dark [Figure 6. blue arrow] areas within the space if not illuminated and will likely be perceived as unsafe elements with a potential perpetrator hiding inside. On the other hand, the alcoves break up the long tunnel space and give variation as well as a rhythm in the architecture.

Analysing the space using the "7 parameters evaluation light level, light distribution, shadows, reflections, glare, light colour temperature and colour rendering" (Liljefors, A, 1999) vertical light can depict the wall structure giving a clear visual impression of the vertical border of the space as well as the texture and materiality of the space, creating a contrast variation of shadows and variation in light distribution that contribute to in a natural way reveal the identity of the space. Regarding light distribution, the existing light (Figure 6. top left picture) creates a non-functional contrast situation where the light areas are perceived as glary and the space between dark and unpleasant (Figure 6. yellow arrows). The pattern on the ground is disturbing the functional visual condition by not providing a long-distance view and by that create an uncomfortable biking experience. The solution would be to provide a spatial light with a more even light distribution for an easy overview. The different objects in the tunnel space create shadows and dark areas that need to be visualized not being experienced as threatening (green arrow). Warmer colour temperature is also important to use, not emphasizing the "cave" association where a colder light, exemplified in left top picture, gives an unwelcoming emotional impression.

The tunnel section under water [Figure 6. Photo collage, picture on bottom right] differentiate very much from the rest of the tunnel with flat white walls and ceiling. The existing light creates a visual rhythm that give distance recognition but the light temperature is perceived as anonymous and the "light all over" situation could give an emotional experience of being exposed.

Analysing the space with the strategy; spatial, social and identity lighting strategy (Fraenkel C, Ladwig D, 2013) a light distribution based on different light zones wit an internal hierarchy would support the social lighting aspect and human scale principle that contribute to an comfortable emotional experience. Further the extended spaces, alcoves, within the tunnel space have a great potential for identity lighting adding "personality" on a human scale to the biking route as well as contributing to the architectural rhythm and distance recognition, linking to the spatial lighting aspect.

7.1.3 Conclusion of analysis

To have as background to the lighting strategy in the proposal

Architectural parameters
Dark and unreflective material
Unstructured and textured surfaces
Enclosed space with variety in dimensions, alcoves, creating "hiding places"
Long distances to entrance/exits
8. Discussion

8.1 Field Study 1

The fact that the study was conducted with a very small reference group (8 persons) the result cannot be representative for a large group of people and general assumption but the result give a reference point regarding tunnels and cyclists and their specific opinion as public space users. In literature as well as digital research it has not been found any specific studies from cyclist perspective, so this study can form an important starting reference. The result shows interesting as well as expected “common” believes about public space and emotional state of safety and comfort of the user. Public space in a city as parks, squares as well as streets. The result in questionnaire showed that the Somerset railway between Bath and the village of Midford was experienced as the most unsafe [chapter, 5.2, Figure 6] by the reference group. It has a very dark appearance with repetitive light zones creating a great visual contrast situation, not supporting the spatial vision, confirming the common belief that dark places with no overview of the surrounding, is experienced as unsafe by the user. The Heinenoord tunnel was graded as most safe, having the opposite composition [chapter, 5.2, Figure 4] with a white surface on ceiling and walls, an even light distribution created by ceiling mounted linear down lights, giving a reflected general light on the whole space. The emotional impression of safety was graded very high but also seen as boring, but very functional, where functionality was rated as most important by the focus group. These results confirm the opinion that light distribution is of great importance to support the emotional state of safety. Further the participants where concerned about the visual conditions of the ground, to ensure a low risk of injury because of obstacle on the ground. The results also indicate that a tunnel would be a welcomed alternative if it provides a faster and safer route. The participants had in common not being ”anxious” or afraid of enclosed spaces, representing one type of cyclist/personality. The majority of the participants perceived the Croix Rousse tunnel as disturbing by the light projections [chapter, 5.2, Figure 5], indicating that light has a strong visual impact where large light projections can cause glare and uncomfortable contrast and need to be used consciously and not creating unwanted effects.

8.2 Field Study 2

The result of scenario 1-3 confirms [chapter 6.2 Figure 11-14] the hypothesis that light can influence the human experience of a space by direction, position and distribution, as well as perception of safety and comfort, correlating with space perception studies by Ulrika W. Lindh [Lind, W. Ulrika, 2012]. Further it confirms the function of a lighting strategy based on the combination of several light sources as well as direction and internal hierarchy (Fraenkel C, Ladwig D, 2013). The over all result confirm the lights ability to influence our spatial perception and impression of space. In scenario 1 - 3 the aim with the study was also to evaluate if experienced light settings correlate with light levels measured in lux (lx). The result from scenario 1 and 2 [chapter 6.2, Figure 12-13] indicates that the direction of light influence the perception of light level where the measured lux levels on ground was the same but scenario 2 was experienced as less light on the ground because of the illuminated walls and the contrast relation the dark surrounding, confirming the importance of a balanced light distribution where otherwise the possibilities of creating the opposite effect is likely, for example glare or decreased visual performance. Further the results indicates the influence light temperature has on the perception of space, where the colder light temperature of 4000 k in scenario 1, directed on the ceiling, gave the perception of a sterile and unsafe space. In scenario 2 the linear wall wash with 3000 k gave the space a more welcoming impression and by its position illuminating the texture of the walls, the character of the space, it was experienced as safer and more comfortable. The ground light level of scenario 6-7 was approximately 20 lx, perceived by a few as little low, but in general was experienced as enough. The light in these scenarios was distributed in a larger area and the conclusion can be drawn, that the dimensions of the illuminated surface has an impact of the perceived brightness. Light temperature and CRI (colour rendering index) is important factors in light planning to create an situation where skin tone and surrounding look natural, supporting the psychological
factors of safety [Nattens ljus, p. 3]. The results also confirm the relation between light temperature and light level/direction [Liljefors A, 1999, p. 39] where a directed and varied light, here scattered by the uneven surface of the stone wall, scenario 2 & 3, [chapter 6.2, Figure 13-14], support the visual impression of the light temperature that is also strongly connected to emotional experiences. A warmer light temperature (2000 – 3000 k) is in general associated with fire, home, safety.

The result in scenario 4-7 [chapter 6.2, Figure 15-19] support the hypothesis that defined coloured light zones/objects can support the perception of distant recognition, where in scenarios 4 and 6 the light are visually in vertical position, giving the best distant recognition perceived from a the standpoint of evaluation as well as evaluated going on the bike. Naturally scenario 5 are perceived better closer up because of the horizontal ground position, yet perceived on a distance. Further the comments on the question “what does the coloured light “say” to you?” The answers shows that colour have a strong visual effect. One participant commented that the coloured illuminated surface in scenario 5, was giving a too strong impression in relation to the purpose of “only marking the entrance” to the tunnel. The person explained that the strong colour was indicating that something unknown could happen at the entrance, a serious alert.

The result show (scenario 4-6) [chapter 6.2, Figure 15-18] that the coloured light where perceived very clearly and confirmed the hypothesis that light can be used as a strong communication/informative tool and that it needs to be used carefully and with a defined purpose to not create situations for example indicating ”danger” or create an unsafe feeling where there is no risk of danger or other interventions. On the other hand it can be connected strongly to culture where road marking and visual language in traffic can look different in countries as well as how colour is used as symbol in religion.

Further scenario 6 a/b [chapter 6.2, Figure 17-18] confirms the association to common knowledge of light as information in car traffic situations where the dynamic light (scenario 6 b) was associated with guidance of direction that was also connected to the feeling of safety.

In scenario 7 [chapter 6.2, Figure 19] on the question b.) if the light scenario affect their emotional state, the result gave a strong indication that coloured light, colour and ligh, light pattern, can influence the perception of space and make connection to the human emotions and personal references or memories. These emotional connections are strong factors forming the base of the identity of a space as well as social factors, connecting to the strategy of Deike Ladwig and Clara Fraenkel (Fraenkel C, Ladwig D, 2013).

8.3 Research and Field Studies results and findings merged together

The context for this master thesis is from a cyclist’s perspective, where the aim is to investigate and explore the parameters of how the lighting and design of a tunnel can be perceived, and function, as a safe and comfortable biking transportation route under ground. The user is defined as a “pedestrian in public space” sitting on a bike with the same preferences regarding feeling of safety as well as visual perception and needs. This specific tunnel situation is unique in the parameters of the length and dimensions in relation to regular underpasses/tunnels for pedestrian/cyclist, providing an interesting and challenging job for a lighting designer. The tunnel space has a 2-way direction - forward or backwards, that needs to take in consideration for the light planning, being experiences from two directions. The tunnel space characteristics are the medium grey mate concrete walls with an uneven surface creating a variation of highlighted surfaces and shadow, a curved ceiling and variation in width, height and alcoves, and an asphalt ground. The space dimension is constructed as an evacuation/service tunnel with space for vehicles. These large volumes provide a situation where volume and spaciousness can support the impression of not being underground in a tunnel space, supporting the users feeling of safety and comfort. The access to the space is limited by the entrance/exits. How these are conducted and illuminated has a great impact on the perception of the tunnel space and the immediate surrounding, as well as function and safe usage.
The tunnel space has great possibilities to provide an alternative biking route that is faster, safer and “weather proof” from a traffic security point of view. Further from a lighting planning perspective the space has a unique feature regarding dimensions and the fact of no present daylight. Working with light in different levels and typologies, the space can be transformed and shaped to an interesting, safe and functional biking tunnel. The different parameters to take in consideration are discussed further in this chapter. Additionally there are of course important and demanding aspects of user security in this very special environment, but that is to be investigated by specialists in that area.

### 8.3.1 Light distribution in relation to space

Being under ground, as well as the situation of an enclosed space as a tunnel, is not a natural environment for us human beings adding aspects of psychological effects. (Appleton, 1975) In the “Evolution-based theory ‘prospect- refuge theory” by Appelton he propose that the safest environment is one with enough prospects to see the surrounding but not so many that a possible refuge is eliminated. Translating this to light distribution, the light situation should give a good overview of the whole space but not put the subject in focus to be able to escape. This theory correlate with study results of this thesis, case studies as well as Ulrika W Lindh findings in her research, presented earlier in the thesis.

A balanced and activity based light planning is of great importance to assure the best lighting for each situation including factors as emotional experiences, shown in the study “Example 1” (chapter 4.2 Case Studies- Pedestrian/bicycle tunnels) where the lack of light and contrast of bright light/darkness is the factor creating great discomfort for the subjects. This relation between discomfort and contrast in light/darkness was confirmed in the thesis Full – scale light study results of “Scenario 1” [Figure 4], where the contrast of cold reflected ceiling light and dark walls gave an unsafe and unwelcoming experience.

Further Ulrika W L. report conclusions from the Scale Model Study that - light beams can likewise provide own rooms within the room, either separately or in connection to other light beams. These can be experience as enclosing or excluding, as the observer has an opportunity to step into the light or stand outside. When light falls on the floor it may also fall on people within the light beam. A feeling of being inside or outside is then easy to visualize. - What we regard as a space may shift between the light zone, the experienced space and the physical space (Wänström Lindh Ulrika, p. 61,2012) This phrase I believe frame the complex context of lighting design in public space very much. The relation between the human and physical surrounding can vary in proportion, be undefined and at the same time a single strong street light that decrease the psychological space and visual perception to a very small space within the large space.

Further the result from the thesis Field Study 1 & 2, point out the complexity of what is experienced as a safe environment by the influence of personal preferences as well as confirming research about visual perception in relation to space and light distribution. In the Focus group study where the subjects where presented photos of tunnels the main opinion of the strongest factor regarding feeling safe was light everywhere, that contradict to the previous mentioned theory (Appelton, 1975) and findings in research of Ulrika W L, mentioned earlier in this text as well as other studies presented. The focus group gave the reason that they prioritised traffic security and not emotional experiences where the opportunity to bike in high speed, not caring much about the atmosphere, then was available, representing a type of cyclist using their bike as vehicle to and from work, where speed and distance are in focus. Result from the Full – scale light study present opinions from a more varied group of cyclists, representing more likely the average citizen and potential user of the tunnel space, where the light distribution of the tunnel space influenced in a high degree the emotional state of safety as well as functionality (Field Study 2, scenario 2- 3).

The findings are further supported by the well known and used lighting strategy of Anders Liljefors where spatial experience and visual ability and acuity is depending on light distribution created by contrast, light levels and position of light source (Liljefors, A, 1999, p. 8,9,42).

Illumination of vertical surfaces as a part of the lighting strategy is of great importance to support the impression as well as experience of an enclosed space. Depending on the light typology the space can be perceived as enlarged, airy or decreased in size, presented in Ulrika W. L. studies [Lindh, W. Ulrika Paper A/Paper B.] as well as confirmed in the Full scale light study scenario 1 – 3 (Field Study 2), as well exemplified in the Case Study - pedestrian/biking underpass tunnel chapter 4.2, Example 4. Here the light
distribution is mainly created by vertical illuminated wooden walls where a warm soft light are reflected to the surrounding as well as supported by the architecture provide a good visual direction and space perception and depict the unique character of this space. Another example, Figure 3 a &b next page, where vertical lighting totally transform a space from a unsafe dark space to a functional and comfortable public environment is Anna Karin Fridh’s [Fridh, Anna Karin] suggested lighting of an entrance underpass where the aim was to promote safety and comfort by light (Chapter 3.2 Lighting in public space).

Further Ulrika W Lindh’s both studies were conducted with the aim of supporting the hypothesis that non-calculative effects of light influence our spatial experience in a high degree and therefore a human centred lighting design should be based on visual evaluation and not measured light standards. A professional opinion Jan Ejhed also supports with his study “Ljus och Rum” (Ejhed Jan, 1992) presented in chapter 3.1.1 where the measured light levels did not correlate with the visual evaluations.

In the thesis Full-Scale Light Study, scenario 1. [Figure 4] the participants associations connects/ correlate with the hypothesis and presented findings in above mentioned study by Jan Ejhed, where the scenario with only strong up-light was perceived as the brightest but at the same time by spatial experience the most unstable. In my study cold (4000 k) up light into the ceiling gave the spatial experience of a sterile, flat and unsafe atmosphere with too big contrasts.
Using a lighting strategy based on a combination of lighting typologies is exemplified in Ulrika W. L results of her Auditory Study (Lindh W, Ulrika, Paper B) [Figure 1.] correlate with the result from the thesis (Field Study 2) Full scale Light study scenario 3 [Figure 2.] regarding the perception of that illuminated walls and ceiling give the impression of a greater volume and larger experienced space than the physical space are. Further the illuminated walls increased the perception of space, of depth as well as giving the space an atmosphere that can be translated as identity by revealing the texture of the wall or the structure of the ceiling decoration, experience of space. Additionally results indicates that there is a relation in feeling of safety and the perception of the space both visually and atmospheric, presented in the picture below [Figure 2.] scenario 3, where both walls and ceiling are illuminated and evaluated as most safe, best face recognition, functional and atmospheric.

Ulrika W. L. formulate a distinction between the words; perception of space and experience of space in her Phd (Lindh, W, Ulrika 2012) that I find very useful and clarifying. Spatial perception is used to address how we perceive and understand the direction, size, shape and colour of the space; how we get an overview of the room, orientate and see connections to other spaces, for example functions as exits/entrances as well as daylight openings. Spatial experience refers to what makes a room atmosphere to seem warm, enclosed and how intense the light contrast is and if the light-patterns seem to be active or calm. The lighting strategy SPATIAL LIGHTING, IDENTITY LIGHTING, SOCIAL LIGHTING (Fraenkel C, Ladwig D, 2013) is framing the complexity of lighting and what powerful tool it is to create and shape our surrounding and perception of it, where SPATIAL LIGHTING connecting the two definitions; spatial experience and spatial perception. Further the strategy connects the spatial experience to the SOCIAL LIGHTING aspects as well as IDENTITY LIGHTING. Aspects investigated in the thesis studies where results exemplify the connections between experience of safety (social aspects) and light supporting the features of the space (identity) in the (Field Study 2) Full Scale Light Study scenario 4, 5 & 7 [chapter 6. Figures 15,16 & 19] where the combination of colour and light was reported to both support the perception of safety as well as giving the space identity and visual direction. This strategy exist in many variations over the world but for me they have taken it to higher level where the simple form create complex and long lasting lighting solutions. Planned with an internal hierarchy of light level and visual impression, using the whole spectrum from “loud” to “whispering” light typologies it is a powerful tool of an successful lighting design, therefore this strategy will be used in the development of the lighting strategy proposal in this thesis.

Placing this strategy (SPATIAL LIGHTING, IDENTITY LIGHTING, SOCIAL LIGHTING) in a tunnel context the spatial lighting are the foundation of the lighting design because of the enclosed space where no other light influence the space, from traffic, buildings etc. Further the SOCIAL LIGHTING and IDENTITY LIGHTING aspects are very important to reassure an environment experienced as emotional safe and comfortable. A challenging assignment, because of the nature of the tunnel, an enclosed long space with limited exits that naturally trigger our experience of an unsafe situation. IDENTITY LIGHTING connects to the spatial experience of the space articulating the atmosphere of the space adding lighting solutions visualizing the specific character of the space or adding a new identity to the space.
8.3.2 The Lights ability to transform a space and support human interaction

The research and findings present result that show the ability of using the light to transform, reveal and create an atmosphere of a space. How this is done has a great impact on how we read, interpret and experience the space. Further, this impacts the emotional factors of safety, comfort and identity. Defining together if the space is functional from a user perspective.

In car tunnels light has been used for a long time giving also providing identity and guidance of the different exits for example. In a bicycle tunnel I believe light can be used in the same way, but in conducted research for this thesis no really good example has been found. In fact tunnels for bike traffic as well as pedestrians the lighting are even more important, supporting the perception of safety and comfort. In a car you are protected in your own sphere by the vehicle but on a bike the protected sphere are mostly the ability to escape by speed on the bike.

In the chapter 3.1.4 example 4, Marianne Flø and Gunnar D. Jenssen investigate in the study the potential of how art and artistic lighting design in tunnels can reduce the road users’ anxiety and the monotony in long tunnels. A pree-study for the 24.5 km long Laerdal tunnel between Oslo and Bergen. In the study the subjects experienced discomfort “driving” the “Basic” alternative with no added artistic lighting. Comparing to the “Rock crystal” alternative with the highest grading, presenting an artistic lighting with a variation of coloured light placed in rock caverns along the route, also providing distance recognition along the driving route. This findings correlate with the result of the Full Scale Light study, scenario 7 (Field Study 2) where a
“rainbow” of colours was experienced as adding a positive emotional impression to the space [chapter 6.2 Results of Full-Scale Light Study, Figure 19].

Example 1 in the same Chapter 3.1.4 (Patten, Christopher, 2013) the author present statically significant preference (58 %) for a string lighting design regarding ” visually stimulating/arousal” based on the hypothesis that visual variation created by light design can have an emotional as well as perception effect that raise the comfort and driving performance. Connecting to Example 3. In the same chapter (Manser and Hancock, 2007) there is an interesting conclusion to be made regarding how pattern speak to us humans on an informative level, based on common knowledge. In the later example the study indicate the influence a linear pattern can have on speed regulation where a decreasing linear pattern make the subject slow down. Further the research and field studies present correlating facts where light and colour can create a strong visual as well as emotional impression of the user.

Example 2 [Figure 5], in the chapter 4.2 Case studies - Pedestrian/ bicycle underpass tunnels, exemplify the visual strong correlation between light and surface/colour that can be used, as a simple but effective tool together with light, to create defined borders and distance recognition of entrances/ exits. The round white circles visualise the entrances as well as divide the tunnel space to sections, defining the borders. This correlation between light and colour and the visual effect is confirmed in the Full-scale light study results of scenario 4 and 5, chapter 6.2 Results of Full-Scale Light Study [Figure 6 & 7]. The participant experienced the coloured surface on the ground as a strong visual indicator of that something is happening ahead, something important to be aware of, a warning, further it was experienced to some degree support their perception of distance as well as feeling of safety [Figure 6]. In scenario 4 coloured light beams on the vertical walls by the exit/ entrance was perceived as catching their attention in a high degree [Figure 7].

Lighting in public environments use light as information in different ways that has in some degree developed to a common knowledge. Especially in traffic situations light are used as communicating tool to guide, lead and control where the traffic light (green, orange, red) are the dominating information by light in the public environment. The information is very clear, direct and strong with the striking colours directed towards the eye. The same typology are used in lighting warning for road work/ change of line at motorway’s where the cars move with a very high speed and to have the time to react and slow down/ change position the information need to be perceived on a fare distance. In these scenarios the light speak with very loud “voice” to reach its purpose in every situation. This common knowledge was confirmed in the Full Scale Light study, scenario 4-6 (Field Study 2) where the added light and colour was understood as information in different ways [Figure 6 & 7], for example the reaction of being alert or read a dynamic light pulsating as a change of direction. Light giving information can be design as a powerful tool also in the shape of “a whisper” where the light is very subtle and integrated in the environment, exemplified in Deike Ladwig’s master thesis study ‘Information by intuition’ (Ladwig, D. 2006) where the result indicates that light can influence the behaviour and movement of a person.

A common example and variation of the “whisper” is directed light spots on the stairs of a staircase in a park or in an escalator in a shopping mall. The small light beams attract the eye and focus the attention on the activity ahead and define each surface supporting the safety of the action. In this situation if the light design are correct, you don’t pay attention to the light itself, you just experience a functional environment where you feel comfortable and safe [Figure 8].
8.3.3 Formulating the lighting strategy

Defining the appropriate light levels for the tunnel space include different parameters and need to be investigated in detail in relation to the specific site to assure the right composition. Presented here is a proposal based on researched and conducted studies made within the limitation of this thesis. The VGU regulations define that at a pedestrian/biking tunnel the interior horizontal light level at daytime should be 100 lx and horizontal from 1.2 meter and up: 250 lx. Comparing this to the measured light levels at the Full Scale Light Study (Field Study 2), the measured light levels at scenario 3 present levels approximately fulfilling the regulations. The VGU (VUG 2012) further state a recommendation for vertical surfaces where identification of a person is important to prevent crime to 10-50 lx in public space (class EV 3 -1). These situations of course contain other light sources in the visual surrounding creating a higher general light level, but still the vertical surface values differentiate very much, defined by the same directory. Comparing this to the study made by Boyce and Rea (Boyce R. Peter, 2014, p. 448-449) where the result indicates that to provide a visual condition for confident face recognition at 17 m 33 lx is needed and 0.8 lx at 4 m. This measured levels is based on results evaluated by walking persons where you move much slower than on bike, so comparing with the levels of the VGU and conducted field study the conclusion can be made that the vertical light level presented in the VGU directory of 250 lx can be questioned as unnecessary high but the study made by Boyce do not work as reference for a situation with the speed of a bike. It is also important to question and suggest a revision of the pore lighting regulations in the VGU for pedestrian/biking environments where the few lines indicates the low priority where in fact lighting for public space has a great importance in a city.

A horizontal light level of approximately 40 lx was perceived as functional in the Full Scale Light study scenario 1, [Figure 4] but perceived as little low in scenario 2 where the light was created only by vertical light. At scenario 3 the measured horizontal light level (on ground) was 80 lx (vertically average 200 lx) with the approximately relation 1 to 3, that are quite close to the regulation value of the VGU daytime horizontal level: 100 lx, was perceived as bright and too bright by a few.

This 1 to 3 relation in light level and distribution can also be found in the study made by Ulrika W L [Lindh Wänström Ulrika, Paper B] Figure 1. In this chapter, where the measured light levels were: Minimum 28 lx/ max 83 lx, also perceived as the most democratic and comfortable light setting/level. These results indicate the importance of a balanced light distribution and that this light level relation, 1 to 3, can be used as a base for a lighting strategy of enclosed spaces like tunnels or in room scale.

The VGU (VGU 2012) regulation light level at night-time is specified to be at a minimum of 10 lx, or as the exterior classification light level are determined (up to 50 lx).

Comparing to the Full-Scale Light study where 40 lx was perceive as ok or little low, the VGU value (10 lx) can be questioned to be underestimated but based on the above presented results, the daytime level 100 lx can also be questioned as high.

Formulating a foundation of the light levels in the tunnel based on the above presented results, the guiding factor should be the relation in light levels: 1 to 3 of walls and ground, where the walls are the brightest. Trying to formulate some reference values (lx) based on the discussion above, the ground light level could be between 30-70 lx and 90 - 210 lx on vertical surfaces where the relation 1 (walls) to 3 (ground) is used. Further, the colour of the ceiling should be white or in a bright colour to reflect the lighting in an effective way as well as contributing to defining the space borders.

Further above mentioned results confirm the complexity of light planning where the light distribution, position, angle and space surfaces play a big role of the perceived light level where recommendations and regulations for pedestrian environment should be based on luminance levels (cd/m2), the experienced light and not only horizontal/vertical luminance (lx) levels.

This complexity Boyce conclude as follows: [Boyce R Peter, 2014, p.455] ‘when it comes to creating lighting that is visually comfortable and attractive, meeting simple recommendations of horizontal illuminance is not enough. Attention has to be paid to the CCT, colour rendering and scotopic/photopic ratio of the light source used.’

Also confirmed in Jan Ejheds study “Ljus och Rum” (Ejhed Jan,1992) where he made the conclusion that there is no general simple correlation between photometric data and visual spatial perception.
8.3.4 Conclusion of lighting strategy for spatial lighting

Based on the research and findings the strongest factors when planning the light for the tunnel space is light distribution and light in relation to the space and its surface characteristics. The surface of the tunnel space is dark and unreflective where the use of white colour on selected surfaces would improve the perceived light as well as measured, by the reflectance properties of a white colour. The visual perception of a white/bright coloured surface and how it effects the space lightness are exemplified in the Full Scale Light Study, scenario 3 [Figure 2], as well as Case study examples of pedestrian/bicycle tunnels, Example 1, as well as confirmed in the car simulator study example 2. Chapter 3.1.4, where the subjects rated white coloured walls as more important than a higher light level, to rise the perception of safety. The selected surface to be coloured white is the ceiling based on the result of the Full Scale Light study as well as Ulrika W L studies where a white and illuminated ceiling was experienced as creating a airy and inviting atmosphere, aspects important in a narrow tunnel space.

Further the general light in the tunnel space is created by a combination of light typologies, exemplified in Scenario 3 [Figure 2], where both walls and ceiling are illuminated to provide a situation supporting experience of safety, best face recognition, functional and atmospheric, based on result presented earlier. To emphasize the white ceiling and provide a varied light distribution by both light temperature and light levels the ceiling light has the highest light level and a colder colour temperature (4000 k) to link to the sky above as well as distribute a diffused reflected light over the whole tunnel space. The vertical light, washing the wall, revealing the texture and characteristics of the space as well as supporting the face recognition of the cyclists has a warmer light temperature (3000 k) to give a natural face appearance and a warm welcoming emotional association.

8.3.5 Using light as information at Entrances & Crossings

The VGU requirements (VGU 2, 2012) point out that the lighting need to be very good at crossings and where the path change directions. Requirements supported by the research findings of the lights ability to give visual information and raise awareness by contrast in light level/ light distribution. The light level is suggested to be double or more to be visually perceived by the user in the tunnel space, based on the VGU recommendation for pedestrian crosswalks recommendations. It is relevant to rise the light level at a distance, VGU recommends 50 meters, before the crossings and in the centre of the crossing where a directed spotlight could rise the awareness another level. At this limited area the light level should be in a clear visual contrast of estimated 4-5 times higher than the general horizontal light level.

Further light is used together with coloured surfaces and ground pattern to clearly define the change of situation for the cyclists, rising the awareness, to provide a traffic safe environment. At the very entrance of the access tunnels narrow coloured vertical light beams are used to articulate the visual impression of the entrance, based on the findings from Full Scale Light Study scenario 4, further a linear pattern is painted on the ground based on the research findings as well as result of Full Scale Light Study scenario 5 where colour together with a directed spot light was perceived as a strong visual information [Figure 6].

8.3.6 Light as identity supporting the social aspects and human scale

Based on the findings light will be used in different visual levels to give the tunnel its unique identity supporting the orientation, distance recognition and emotional state of safety as well as “entertainment” by dividing the tunnel space in sections with different themes. The identity lighting will have the highest visual hierarchy at the access tunnels entrances, crossings inside the tunnels as well as in the alcoves along the tunnel space. Identified zones where identity is important and light can be used as an effective tool. The large scale light projections in the Croix Rousse [Figure 9.] bicycle tunnel in Lyon is an example of the “loudest” visual light level of the identity lighting concept of the proposal. On a steppless grading scale down to a “whisper” where the “milky way” in the lighting concept for Axeltorv by Ljusarkitektur is an example [Figure 10].
8.3.7 Sum up of important lighting strategy parameters:

- Support distance recognition of space by creating visual key points
- Divide and clarify different surfaces and specific materiality in the space
- Use a variation of light zones and light levels to create a light distribution contributing to a good spatial visual condition.
- Work with colour temperature to add to a human scale and welcoming emotional experience
- Add light colour/material to reflect light
- When defining light levels for this specific tunnel, it need to be based on real lighting tests at site and evaluated by visual impression as well as light measurements.
- Having the relation 1 to 3 as a base for the light distribution, where vertical walls and ceiling has the highest light level.

8.3.8 Adaptation lighting strategy

It is relevant to use the adaptation lighting strategy presented in Chapter 3.2.2 in the bicycle tunnel entrances and access tunnels, to assure a good visual transition between interior and exterior conditions supporting the visual ability as well as emotional state of safety and comfort. The strategy is illustrated below where the light levels need to be defined by site-specific measurements, not included in this thesis.

From a biking perspective it can be reasonable to compare values developed for car traffic but the difficult parameter is the speed (where the minimum speed in the tables are 40 km/h for car traffic in tunnels.) Translating and adjusting the adaptation method to a tunnel for cyclists the parameters are likely to be considered the same but calculated on a lower speed (15-30 km/h) and by that shorter distances of each zone. Prior realization further research and knowledge need to be established to get valid values for this specific biking tunnel.

In VGU there is a table with examples for car traffic tunnels [VGU 2004 table 8.5-4, page 23.] estimating zone distances based on daylight conditions at the entrance of the tunnel. Taking an example; A medium daylight condition with 35 % visual sky, the length of the threshold zone with a speed off 40 km/h are defined as 26 meter based on a reaction time of 1 second for car traffic. Translating this to a biking speed of 20 km/h the threshold zone length would be 13m and the speed of 30 km/h ca 20 m. VGU estimate the reaction time of a cyclist to 2 seconds, where a speed of 30 km/h the visual condition need to be clear of 35 meters to regard it as a good and safe situation (VGU,2004, p.5). Taking all this parameters in consideration the medial length of the threshold zone I suggest could be approx. 25 – 30 meters. Visualized in illustrations, Figure 11-12.
The schematic illustration [Figure 11] depict the visual adaptation zones based on car tunnel lighting principle. There is an internal relation between the zones based on the CIE curve with stopping distance and speed as parameters giving values for illuminance and distance for each zone. Entering the tunnel at daytime, the light level in the threshold zone and transition zone is adjusted in relation to daylight illuminance level at the access zone, to prevent an uncomfortable visual condition with "blindness" in the darker space inside the tunnel. The threshold zone and transition zone need to be longer during daytime comparing to night time because of the situation from bright to darker our visual adaptation are slower than from dark to brighter light level. When leaving the tunnel the adaptation goes fast and it is not that demanding for the vision because of lower contrast, comparing to night-time situation.

Entering the tunnel at night-time or from a dark exterior condition, the adaptation goes faster than leaving the tunnel, therefore the adaptation zoning need to follow that scenario. Entering the tunnel the threshold zone and transition zone will have lower light level comparing to daylight scenario corresponding to the outdoor light situation [Figure 12].

Leaving the tunnel there is a lower light level outside the tunnel comparing to the interior that can cause a condition of some seconds of "blindness". Here the Access/Exit zone should be positioned and created by the street lighting in the area outside the tunnel opening, support the adaptation from the threshold zone.
9. Proposal
“Travelling Stockholm from Underneath
– a Journey of Light”
9.1 Light Strategy of Proposal

Being under ground as well as the situation of an enclosed space is not a natural environment for us human beings adding aspects of psychological effects regarding feeling of safety, relation to tunnel scale as well as visual condition. The design and lighting strategy are the important tools to create an attractive, functional and usable tunnel space.

9.1.1 Background

Through a human centred and diverse visual surrounding the human behaviour and experience of the tunnel can become comfortable and experience as safe. Anders Liljefors (Liljefors A. 1999) define the complexity of the human visual sensitivity of spatial perception where light level, light distribution, shadows, reflections, glare, light colour temperature, colour rendering, are parameters influencing our visual perception of space “the 7 parameters”. This is exemplified in the result of the pilot study “Ljusdesign i offentliga Miljöer, pilotprojektet Skogås-Trångsund” that presented unsatisfying lighting strategy where big contrasts, lack of light and difficult face recognition as the reason for the participants/users state of unsafeness and anxiety in pedestrian tunnels, making them choosing another way or transport them selves with a great emotional discomfort. The perception of borders, material, face recognition as well as a clear overview of the closest surrounding is the strongest factors for a safe and comfortable emotional experience created by the light distribution of the space.

This sensitivity of variation in our spatial perception Ulrika Wänström Lindh explored in her Phd scale model study and auditorium study (Lindh W. Ulrika, 2012) where results confirmed the importance of light distribution. Her result indicates that a illuminated ceiling visually “expand” the impression of the ceiling creating a “airy” experience. Illuminated vertical surfaces and light zones can expand, divide and emphasise the visual impression of a space. Further the light composition can create a visual experience of being included or excluded in the space.

Jan Ejhed (Ejhed Jan, 1992) found correlating results in his study where a preference for illuminated ceiling gave the participants the most welcoming experience as well as comfortable and calming. Further his research indicates that measured light level and light impression not correlate.

In the full-scale light study at Karlbergstunneln the result confirm that the participants experienced the space as most comfortable as well as functional, from a biking perspective, with the combination of vertical light and illuminated ceiling.

These results point out the importance of light distribution and light typology, creating light zones and hierarchy within the light distribution forming the visual impression of a space, depicting its own character, materiality and borders. Parameters that are the base for creating a human centred lighting where visual as well as emotional comfort are present.

- Very important factors in a lighting strategy for tunnels, being one of the design goals of the concept.

Deike Ladwig and Clara Fraenkels human centred lighting strategy (Fraenkel C, Ladwig D, 2013) based on the interaction and combinations of the three concepts: – SPATIAL LIGHTING, SOCIAL LIGHTING and IDENTITY LIGHTING I believe describe a very good working method to create a human centred lighting that I also take on board in the concept.

The Spatial lighting has the function of creating, recreate or redefine the spatial experience. The social lighting put the human being in centre. Identity lighting reveal, depict or create the soul of the space. A concept I believe frame the complexity of a successful lighting strategy.

Light distribution is very important. An even illuminated space can be perceived as dark at the same time measuring high light levels. Strong light beams from above create unnatural face expressions, giving emotional discomfort as well as placing the person in an exposed position. Using light to give the space a unique identity is exemplified in many of the case studies in the research chapter as well as confirmed in the Field Study 2, scenario 7, to be an important and effective solution to attract the user as well as support the experience of safety and comfort.
Research show that light can add visual guidance and influence the human behaviour by light direction, light zones and in collaboration with colour and pattern form a visual language, for example inform the cyclist of a change in situation and intuitively make the person slow down or being alert. Stating as an example the study “The influence of perceptual speed regulation on speed perception, choice and control” [Manser and Hancock], indicates that a linear pattern with increasing width and internal distance can influence the speed of the driver to slowing down. Using colour and road marking pattern to give information about borders and upcoming change of situation, for example in a crossing, create a strong contrasting visual picture that attracts the human vision and mind. Result from my light study in Karlbergs tunnels correlate with the fact that light and colour have a great visual impact and giving association to a change of situation and being alert.

9.1.2 Architectural parameters influencing the cyclist’s experience

Biking through Stockholm is an adventure it self. Passing the shopping streets, different architecture, experience dense traffic and beautiful nature, tough hills and fast down hills, rain and sun. - A normal day to work if you are a daily cyclist in Stockholm.

Choosing going in a tunnel instead need to be motivated. In this case the tunnel can provide a space with no weather change, only biking traffic and by that a fast lane under the most dense parts of central Stockholm.

The tunnel space architecture contrast very much from the streets being in an enclosed long space with limited access/exits.

Further in the context of biking tunnels in general this tunnel have very long distances to entrances/exits demanding. The tunnel is used in both directions so the tunnel layout and lighting strategy need to take that in consideration, creating a space with the same visual condition regardless of direction.

The architectural parameters of the space need to be modulated to collaborate with the lighting strategy. The physical parameters of the underground tunnel space are variation in width, height, inclination and direction. This variation can create associations to the normal street variation in the city and make the visual as well as physical experience diverse. There are alcoves, creating “dark corners” along the tunnel route that likely can be perceived as threatening by the user and have by that a high priority in the lighting concept.

The interior has a medium grey unreflective and textured surface of concrete and flat asphalt on the ground. Surfaces that do not reflect much light and demand a light typology created by several light sources and from different directions to both give light to the space as well as a pleasant natural light on the users.
9.2 Design Principles of Concept

The proposal has the aim to transform this tunnel space to a welcoming and functional alternative route to the increasing number of daily cyclists in Stockholm. The tunnel space is a transportation route where the cyclist’s speed and interaction with each other demand a clear and defined orientation strategy.

9.2.1 Interior Principles

To create an energy efficient environment as well as efficient light distribution the surface need treatment of white coloured paint to reflect the light in the space. Colour has the ability to reflect as well as intensify the impression of light where white have the strongest ability to become a visually light emitting surface. Painting the ceiling in white are the best solution for both visual condition as well as for the perception of space by giving a maximum reflected spatial light from above creating an “expanded” and “airy” visual experience of the ceiling, based on research findings presented. Together with vertical lighting the space is transformed to a functional as well as attractive space by a lighting strategy built up by light zones revealing the texture of the surfaces as well as defining the borders and dimensions relating to the human scale where the surrounding are visually understandable. - Very important aspects to control in a tunnel situation where the narrow long space it self create an emotional as well as physical state of being enclosed.

To support orientation in the tunnel space colour and road-marking pattern together with light, will give information about borders and upcoming change of situation where the important locations is crossings and entrance/exits. This solution will provide a strong contrasting visual picture that attracts the human vision and attention.

Further the space need to be divided in sections to support orientation within the tunnel space as well as in relation to the city above. A combination of signs and theme lighting at identified key points will define the sections. The identified key points are: Entrances, crossings, alcoves and general tunnel where aspects of emotional safety, orientation, traffic security and identity are important.

9.2.2 Lighting Principles

Regarding light levels, colour temperature and light quality it is very important to work from a site-specific perspective as well as user orientated lighting strategy based on Deike Ladwig and Clara Fraenkel SPATIAL LIGHTING, SOCIAL LIGHTING and IDENTITY LIGHTING strategy. The most important factors are where and how, not measured light levels. Therefore it is not possible to create a good generalized light plan without having the specific place and its specific situation clear. Where and how the lighting are placed effect the visual impression as well as measured light level.

Additionally, to provide a functional visual situation entering and leaving the tunnel, in relation to exterior daylight, the principle of adaptation-zoning should be used in a section of the access tunnels. The principle are based on “adaptation luminance conditions ” for car traffic tunnels where the light level following a curve connected to adaptation and specific speed resulting in values of luminance (cd/m2) and length (m) of each zone of the lighting. Specific light levels and dimensions of each zone are not presented in the proposal because of the dependence of real site-specific measurements.

9.2.2.1 Light levels and distribution

Directing the light on several surfaces of the interior/borders of the space give a good visual understanding of the space as well as providing a soft reflected light where the human face look natural supporting the social lighting aspect. There should be a balance between the illuminated surfaces of a space where the function as well as the human needs define the internal hierarchy of light zones. In this specific tunnel situation the emotional effects of the users is the main parameter. The light zones are:

1. The borders; ceiling and vertical surfaces of the space, having the highest position in the hierarchy of light zones providing a clear visual impression of the character of the space as well as the direction and distance.
2. The ground surfaces where the lighting should provide a clear overview of the surface.
The colour temperature of the light has a great impact on the visual impression as well as experiences of a space that is to some degree a personal preference. In general colder light temperature (5000 - 4000 k) are experienced as making the space public or impersonal, but also giving associations to daylight. A warmer colour temperature (3000 - 2500 k) in general link to the human scale by associate with a home feeling of warmth and comfort. A combination of light temperatures in a space give the space a dynamic light impression perceived as natural, based on the natural constant variation of the daylight over day and season. Giving associations to the outdoor environment the ceiling have the colder light temperature and highest light level, followed by the vertical walls with a warmer light temperature, accentuate the structure and materiality of the walls as well as supporting a natural face appearance by adding vertical light to the reflected colder ceiling light. This light setting provides a soft and in general even light distribution on the ground.

When defining light levels for this specific tunnel, it needs to be based on real lighting tests at site and be evaluated by visual impression as well as light measurements. The light level should be based on the relation 1 to 3 where the highest light level is measured on the vertical/ceiling plane. The bright “daylight” visual experience is created mainly by the white surface with reflected light distributed in the whole space, supported by illuminated walls. Based on research and regulations the suggested basic light level in the tunnel space is minimum 30 lx on a horizontal ground plane and vertical 90 lx. Further at crossings and access tunnels the light level should be higher. In crossings the light level is doubled or tripled to use the light as visual information for the user, rising the alertness to be prepared for a change of situation. At the entrances in the access tunnels the light level should follow the below presented concept of adaptation light zoning.

9.2.2.2 Light giving identity

Light will be used in different visual levels to give the tunnel its unique identity supporting the orientation, distance recognition and emotional state of safety as well as “entertainment” by dividing the tunnel space in sections with different themes. The identity lighting will have the highest visual hierarchy at the access tunnels entrances, crossings inside the tunnels as well as in the alcoves along the tunnel space. Identified zones where identity is important and light can be used as an effective tool. To give the tunnel its own unique identity and attract the user as well as supporting orientation and emotional aspects, a theme is developed based on results of the Full-Scale Light Study (Field Study 2). On the question of how their dream biking route to work would look like a coherent dream was through nature with birds singing, no cars and beautiful scenery as a view.

Stockholm is a city with a very present nature where trees and water providing a beautiful scenery. Further the unique Nordic variation of daylight with long sunsets and dark winter months, add a dynamic feature to the city. Stockholm at summer time is very appreciated by the citizens as well as tourists. To create a tunnel space associating to this special time of the year gives strong emotional connections to a pleasant environment and wellbeing, providing a human scale to the concept of the tunnel layout.

The theme for the tunnel is Nature, visualized at selected key points in the tunnel; Entrances, crossings, alcoves and along the tunnel route where visual variation is needed.

Sound

Additionally, sound can be used to support the theme experience of forest by all senses as well as connect to the street level above where sound is present everywhere. Entering the tunnel from the busy street with visual as well as strong sound stimuli, could create a too big and sudden contrast of ”silent vacuum“ in relation to the city and create an unsafe experience. The soundscape can be built up by recorded birds singing, wind through leaves and water, situated in the access tunnels and along the tunnel route, supporting the identity lighting and connection to the world above.
9.2.2.3 Design Goals for Concept

> Provide a situation where aspects of orientation, traffic security, identity and experience of safety are provided.

> Create a comfortable biking situation providing an alternative underground biking route that attracts the user.

> Adding a large underground landmark and “art piece” stretching under the city.

From a site specific lighting strategy and architectural design transform the tunnel space to a comfortable, safe and visual interesting underground biking route. By working with a variation of light, the variation of the space as well as different scales and surfaces the space can be perceived as welcoming, taken care of and having its own identity and becoming a positive and unique biking experience under central Stockholm. Working with colour and light typologies from the Theme the tunnel can as well become a large underground art piece, visited not only for transportation but also as a unique experience.
9.3 Concept - Key zones

Identified key zones and areas in the tunnel space where the aspects of emotional safety, orientation, traffic security and identity are important. At each key zone the aspects has different hierarchy of importance reflected in the lighting strategy presented in each zone.

The different key zones are the entrances, crossings, alcoves and general tunnel.
9.4 Concept – Orientation of Theme

The tunnel length need to be divided in sections to give an overview, orientation within the tunnel as well as in the relation to the city above. The theme variations give visual identification of each tunnel section between the entrances and their location in the city. The Forest variation dominates, starting and ending the whole tunnel space connecting to dream scenario of the cyclists. It is important to give the tunnel space its own identity in the cityscape to become a appealing space to the users as well as function as guiding elements in the tunnel space. The theme is based on a dream scenario of my self as well as of participants in the Full-Scale Light Study where an imaginative ideal biking route to work would be through a landscape with nature, flowers, birds and no traffic or other disturbing elements. The theme also connect to the city above where the natural elements that are missing in the tunnel space from the outdoor environment above are represented in the identity lighting transforming the tunnel space to a parallel world with references to the variation of daylight and season of nature experienced biking through the city. The variations of the theme are: Forest, Sky and Sun.
**9.5 Lighting Concept**

With the strategy based on the interaction and combinations of the three concepts: – SPATIAL LIGHTING, SOCIAL LIGHTING, IDENTITY LIGHTING the concept is formulated from a human centred lighting design, providing a functional as well as stimulating comfortable environment based on research as well as conducted field studies.

**SPATIAL LIGHTING**

**Situation:** As the basic light in the whole tunnel space; GENERAL TUNNEL, and with variation and combined with other light principles and theme zones.

Defining the spatial experience applied in the whole tunnel space, having the role of providing the general light as well as outline the space borders, materiality and variation. Connecting to the SOCIAL LIGHTING concept, the light shall give an inviting atmosphere on a human scale by natural colour appearance, good colour rendering, light directed mainly on the interior and creating a varying “natural” visual picture, relating to the natural outdoor environment with the bright sky as ceiling. Revealing the texture and material of the space provides a good spatial experience as well as spatial impression based on research where illuminated ceiling as well as illuminated walls provide a safe and comfortable visual as well as emotional state of the user.

**Lighting principle**

A combination of [Figure 1] illuminated ceiling giving reflected soft ambient light and [Figure 2] vertical lighting giving a visual variation by the play of highlights and shadows on the textured surfaces. In the hierarchy of the illuminated surfaces the ceiling is brightest and the walls having a light level where mainly the surface and texture is illuminated, depicting the borders of the space as well as giving a soft reflected light supporting a natural face appearance connecting to the social lighting aspect. Naturally by the dark grey asphalt the ground create the horizontal foundation of the visual impression, defining the dimensions and visually leading the way. Using different colour temperature of the light another layer of variation are added to the visual impression. Having a colder light temperature, 5000 - 4000 k, in the ceiling and 3000 k on the walls creates a visual impression of daylight where the reflected light on the white surface in the ceiling give the sky light impression with the brightest light coming from above. The vertical light on the walls connect the space to the darker ground, creating a gradient in light level, visually divide and structure the borders of the space [Figure 3]. Additionally the light fixtures internal distance give a variation in light zones under the fixture and in the space between, creating a soft gradient rhythm of light, providing a visual distance recognition as well as leading the eye forward in the direction of the tunnel

**Light Levels**

Using the relation 1 to 3 where the highest light level is on vertical surfaces and on the ceiling.
9.5 Lighting Concept

LIGHT AS INFORMATION

Situation: Entrances/ Crossings

Based on research findings as well as result in the full - scale light study, the light will be used as guiding element as well as visual information of attention, where a contrasting light level/colour can be a communicating element supporting the interior concept of road marking pattern, Chapter [Figure 4 & 5.]. The purpose is to give a clear visual information to rise the cyclists attention of that something is happening - to intuitively slowing down or be alert. By supporting human interaction and orientation this lighting concept link to the SOCIAL LIGHTING aspects as well as supporting the traffic safety in the space.

Lighting principle

[Figure 4.] Light zones created by narrow light beams with a contrasting light level on the ground at the crossings. [Figure 5.] Coloured light creating vertical zones on the wall attracting the eye at the entrances.

IDENTITY LIGHTING

Situation: Entrances, Alcoves, Crossings and at selected situation in the general tunnel.

Within the concept of identity lighting, a thematic lighting is added at the entrances to attract the cyclist as well as giving the tunnel its own identity in the city. The thematic lighting is also added where the architecture change (alcoves, crossings) in the tunnel space to give a varying visual experience as well as supporting the orientation and human interaction in the space.

The added IDENTITY LIGHTING also connect to SOCIAL LIGHTING aspects by giving positive associations by colour of the light, light temperature as well as the projected motives connecting to the nature in the city above as well as the users own experiences and memories. The feeling of community and belonging to a place are the fundamental parameters giving the space an experience of being safe.

Lighting principle

Light temperature and typology connecting to the theme; Coloured light, light projections with motives [Figure 6.] Light zones created by light beams in different scales and intensity, Light pattern [Figure 7].

Situations

AT THE ENTRANCES, situated at the very start of the entrances, on walls and ceiling visual from both the city street and inside the access tunnel space for a limited distance.

IN THE ALCOVES, Along the tunnel route where the architecture differentiate in volume and/or shape natural orientation points are created and the thematic lighting can add an unique identity to each site and expand the visual impression and physical experience for the cyclist. Using the surface as a projection canvas where the light can transform a dark external space to a interesting experience and impression connecting the cyclist emotionally to the space and decreasing an eventual emotional discomfort.

IN THE TUNNEL SPACE UNDER WATER, [Figure 8.] the walls and ceiling are flat and white, providing a good situation for projected coloured light that can transform the whole space to a light experience.
9.6 Interior Concept

The dark concrete surface material needs to be modulated to create a good condition for the design goals. Figure 12 a - c. show pictures of the existing situation where the dark, unreflective concrete do not reflect any light, creating a situation with big contrast between direct illuminated surfaces by the existing light and pitch-dark surfaces next to it. To paint the ceiling surface with a white tone the light can be reflected to the whole space. Leaving the vertical walls unchanged keep the identity of an underground tunnel as well as the opportunity of working with light and darkness contrast variation of the space spatial lighting, illustrated in Figure 9. The white ceiling principle support the visual definition of the space, dimensions as well as visually give the enclosed space an “airy” impression, exemplified in Figure 10. Further the lighting directed on the ceiling creating a luminous surface as well as giving a soft reflected spatial light in the tunnel space and on the ground. The light is also directed along the stone material to reveal the texture and different surfaces in the space. The rhythm of the light beams defines the direction and dimensions of the tunnel space. This light typology direct the focus on the architecture and not the user, but still giving enough light to illuminate the face and body in a natural way, supporting the feeling of safety from a SOCIAL LIGHTING perspective.

Figure 9.

Figure 10. Photo from Kungsbacka Station.

Figure 12 a. Crossing situation in the tunnel  12 b. General tunnel space  12 c. Alcove situation
9.7 Concept - Theme

Description and analyse of lighting characteristics of theme.

**Theme:** Forest - Light characteristics present in the forest [Figures 13]
**Direction of light:** From above, sky light/ A “ceiling” of illuminated tree crowns giving a light with no visual direction.
**Quality of light:** Filtered (through leaves)/ light zones with glimpses of unfiltered light/ diffused, /high contrast mixed with diffused light.
**Colour temperature of light:** from cool skylight to warm sun light beams/ pale coloured in green shades. (2500 - 7000 k)

**Lighting concept applied in tunnel space**
**Situation:** Primary at entrances, in the alcoves and secondary along the general tunnel space.
**Light typology:** Light beams with a variation of light temperature and green colours creating patched light zones inspired by the light through tree crowns on the ground/ With projected photos of trees and forest on a live scale, the tunnel space expands to a imaginative route through a forest.

Visiting the tunnel space, small growing patches of moss was found under luminaries, depicting the power of nature and it’s willingness to expand everywhere it can [round photo].

**Theme:** Sun - Light characteristics of the sunlight [Figures 14]
**Direction of light:** In a range from horizontal to vertical
**Quality of light:** Direct/ filtered/ high contrast between bright sun light/shadow/ shadow projections
**Colour temperature of light:** Variation of warm orange sunset variation (1000-3000k).

**Lighting concept applied in tunnel space**
**Situation:** Primary at entrances, in the alcoves and secondary along the general tunnel space.
**Light typology:** A variation of warmer light temperature. Shadow projections with warm light temperature /projected photos of sunrise/sunset in the morning/evening give the sense of time change over the day also inside the tunnel.

*The under water tunnel section:* the present elements of nature; sun and water, interacts by creating a scenery of rainbows, combining the natural elements and in a subtle way indicate the position under water, not only under ground. **Light typology:** A neutral general even light with additional vertical coloured light beams creating “rainbows”/ projected pictures of rainbows on the walls and ceiling.

**Theme:** Sky [Figures 15]
**Direction of light:** From above/ “everywhere”, sky light
**Quality of light:** Bright/ filtered (through clouds)/ diffused/ high contrast mixed with diffused light.
**Colour temperature of light:** bright cool skylight variations. (4000 - 7000 k)

**Lighting concept applied in tunnel space**
**Situation:** Primary at entrances, in the alcoves and secondary along the general tunnel space
**Light typology:** Variations of cooler light temperature in directed spotlights/ dynamic video projections of blue summer sky with fluffy white clouds moving over the ceiling as well as creating a dynamic light scenery on the ground giving a sensation of being outside.
**Architectural change:** Both ceiling and walls are painted white in the alcoves and at entrance situation. Additional build modules are added to create “openings” where the sky light comes from. Light reflections are created with mirrors.
**Aim with Theme**

During the darker period of the year when the sunrise and sunset often appear during the working hours spent inside, the daylight level is experienced as not enough and the nature is present by bare branches and no colour, the tunnel space with variation of light temperature and projected images can provide emotional light treatment. During the dark season of winter or a rainy day, the tunnel experience can remember the cyclist of the summer ahead, the beauty of the nature and the rich variation of colours and light. - A journey of light.

**9.7.1 Inspiration Pictures to the variations of Theme**

Figures 13 top row, Figures 14, middle, Figures 15, bottom row

**Theme: Forest**

![Forest Theme Images](image1)

**Theme: Sun**

![Sun Theme Images](image2)

**Theme: Sky**

![Sky Theme Images](image3)
9.8 Lighting Proposal at Key zones

The key zones with defined lighting strategy at each location based on function, need and physical parameters.

- Access/Exit tunnels
- Crossing
- General tunnel
- Alcoves
### 9.8.1 Lighting Proposal - Key zone Access tunnel

**Light strategy:** Spatial lighting, light as information, identity lighting  
**Function:** Traffic security, orientation, identity

Entering the tunnel from the street level by bike the entrance visible from a distance by the green stripe pattern on the ground [Figure 17], by the coloured vertical light [Figure 16.1] as well as theme light projections on the interior walls of the tunnel entrance supported by reflected ceiling light [Figure 16.2]. The light function as guiding element as well as visual information of attention supporting the architectural concept of road marking pattern. The purpose of giving an clear visual information to rise the cyclists attention of that something is happening - to intuitively slowing down or be alert is very important in a city traffic situation where cars, pedestrians and cyclists interacts. The combined lighting strategy supports together the social lighting aspects, providing a light situation on the human scale.

Inside the tunnel focus is directed to the action of biking again where the spatial lighting typology are giving light [Figure 16.3] to the tunnel space by reflected ceiling light and vertical light on the walls.

Beginning at the entrances and for a specific distance into the tunnel the light should be adjusted in relation to exterior daylight level to create an “adaptation illuminance condition” following a CIE adaptation curve the first zone, the threshold zone would approximately be 25 – 30 meters at an average daylight condition.  
[Further information in chapter Regulation and Standards]
9.8.2 Lighting Proposal Key zone Crossing

**Light strategy**: Spatial lighting, light as information, identity lighting

**Function**: Traffic security, orientation

At the crossings inside the tunnel space the light are raised to a visually contrasting level to contributing to gained awareness [Figure 18.1 & 2]. In a 10 meters area at approximately 20 meters from the crossing the reflected ceiling light level are raised [Figure 18.1]. At the crossing a strong light beam is directed on the green ground surface to visually create a contrasting “luminous” surface [Figure 18.2]. Identity lighting based on the theme are situated on the vertical facing wall coming from the Access tunnel to further contribute to the visual information of change in situation [Figure 18.3]. Visualised in Figure 30.

Figure 18.
PLAN
Illustration of graphic road marking pattern at the crossing inside the tunnel.

Scale: 1: 200 cm
9.8.3 Lighting Proposal - Key zone General tunnel

**Light strategy:** Spatial lighting

**Function:** Orientation, emotional safety

A combination of up light and vertical light; Light directed on the white painted ceiling creating a [Figure 19. 1a] luminous ceiling surface that give reflected soft ambient light in the whole space. [Figure 19. 1b] Vertical lighting on the walls create a visual variation by the play of highlights and shadows on the textured surfaces as well as giving supporting light for a natural face appearance connecting to the social lighting aspect presented in the Lighting Concept.

In the hierarchy of the illuminated surfaces the ceiling is brightest and the walls having a light level gracing the surface revealing the texture as well as visually perceived as the borders of the space, but not as the focus point. Using different colour temperature of the up/vertical lighting another layer of variation is added to the visual impression. Having a colder light temperature, 5000 - 4000 k, in the ceiling and 3000 k on the walls, the visual impression create an experience linked to the outdoor condition and visually divide and structure the borders of the space. Further the vertical light can create visual variation and give information about change of direction by alternative light typology with narrow strong light beams directed on the wall, creating a visual contrast. [Figure 20.] CRI: 100.

![Figure 19. SECTION](image1.png)

![Figure 20. SECTION](image2.png)
Lighting Proposal - Key zone: General tunnel

**Light strategy:** Spatial lighting

**Function:** Orientation, emotional safety

The spatial lighting has the role as the basic lighting throughout the tunnel. At defined areas it is combined with the Theme lighting. For example in the area of the alcoves with Theme lighting typology, only downward directed vertical light [Figure 21.1a] is giving light on the ground. The additional Theme lighting is providing reflected light [21.3] that is supporting the vertical light [Figure 21.1a].

Inspiration pictures:

Figure 22. (top) Picture showing the principle of a combination of vertical light and reflected light on a white ceiling at the light study in Karlbergs tunnel.

Figure 23. Picture showing the principle of how a pattern of focused light beams can both provide spatial light as well as giving the place an identity.
9.8.4 Lighting Proposal - Key zone  Alcoves Variation in general tunnel

**Light strategy:** Social lighting/ Identity lighting - Theme  
**Function:** Orientation, emotional safety, comfort

In the area of the alcoves with Theme lighting typology only downward directed vertical light is giving light on the ground [Figure 24.3]. The additional Theme lighting provide reflected light that supports the vertical light in the general tunnel space and spreading out from the alcove to the ceiling/walls in the general tunnel space, visual from a distance [Figure 24.2]. [Figure 24.1] As an alternative variation of the Spatial lighting typology the Theme lighting can act in smaller areas as guiding elements and visual key points on the ground, as well as on the walls by contrasting light pattern or colour. Figure 25, show an example of light pattern for the Forest Theme variation.

Inspiration pictures:  
Figure 25.(top) Inspiration picture of light pattern created when filtered through the leaves for the Forest theme.  
Figure 26. Picture showing the principle of detailed motive light projection and how the scale of the motive strengthen the visual impression.  
Figure 27. (bottom) Picture showing how large areas with light projections can transform a space as well as giving identity and atmosphere.
9.8.5 Lighting Proposal - Key zone Alcoves

Section illustrations of lighting principles of thematic identity lighting - Theme Forest

In the area of the alcoves with Theme lighting typology only downward directed vertical light [Figure 28/29.1] is giving light on the ground. The additional Theme lighting is providing reflected light [28.2] that is supporting the vertical light.

[28.2] The Theme Lighting consist of projections with photograph motives with gobo and coloured / white light (LED - RGB) combined with light pattern on the ceiling/walls/ground inspired by the patched light scenery found on the ground in the forest or when looking up on the green “ceiling” of leaves [Figure 25, Theme Forest pictures].

Figure 28.
1. SECTION Alcove
Following a cyclist in Stockholm from home to work through the tunnel a day in September. Starting at the entrance at Fatbursparken, ending in Tomteboda and back again in the evening.
Visualisations - Key zone: Access tunnel/ general tunnel crossing

Visualisations Map position: 1.
Theme zone - Theme Forest

Figure 30.
Lighting typology:
Spatial lighting: Reflected light in the ceiling giving a soft general light in the space and on the ground. Vertical light on the walls brings out the borders and texture of the space. A rised light level is created in the close area of the crossing as well as by a focused light bema on the ground at the crossing supporting the orientation and social lighting aspects.
Identity Lighting based on Theme: Photo projections on wall.

Interior Concept: White painted ceiling, linear pattern on ground, directions written on the wall, sounds from the forest creating a transition between the busy street and silent tunnel route.

.....Busy morning traffic in Stockholm city. Taking the tunnel instead, will take me much faster to work.

.....Still warm outside but the fall is comming. Nice to experience the feeling of spring again in the tunnel. I like the photo projections of forest, reminding me of my great summer holiday in southern Sweden.
Visualisations Key zone Alcove

Visualisations Map position: 2.
Theme zone - Sun

Figure 31.

Lighting typology.
Spatial lighting: Vertical light on the walls in Theme colour/white light.
Identity Lighting based on Theme: Photo projections on walls and coloured light beams/light pattern on ground and walls in warm colour tones. The light level is lower in the area of the alcove and connecting tunnel section to give a visual impression of a sunset with strong contrasts between the warm light and dark shadows.

Interior Concept: White painted ceiling and walls.

.....Miss the late sunsets....great to experience it again here in the tunnel!
Visualisations - Key zone Alcove

Visualisations Map position: 3.
Theme zone - Sky

Figure 32.

Lighting typology:
Spatial lighting: vertical cool white light on the walls.
Identity Lighting based on Theme: Dynamic video projections on ceiling and walls. Projected coloured light/light pattern on the ground and walls creating an imaginative sensation of being in the sky. The light level is 2-3 times higher than the spatial lighting in the general tunnel space.

Interior Concept: White painted ceiling, walls and ground, integrated built shapes hiding light beams from the sky as well as moving mirrors creating playful light reflections in the space

.....What a light boost!....feels like being a bird in the sky..
Visualisations - Key zone General tunnel

Visualisations Map position: 4.
Spatial Lighting

Figure 33.
**Lighting typology:** Reflected cooler light in the ceiling giving a soft general light in the space and on the ground. Vertical warmer light on the walls brings out the borders and texture of the space as well as illuminating the face/body of the cyclists supporting the social lighting aspect of the Lighting concept.

**Interior Concept:** White painted ceiling, directions written on the wall.

...Almost at work
Visualisations - Key zone General tunnel

Visualisations Map position: 5.
Spatial Lighting with Theme variation

Figure 34. Lighting typology. Reflected light in the ceiling giving a soft general light in the space and on the ground. Vertical light on the walls brings out the borders and texture of the space. Theme lighting “Forest” adding visual keypoints and variation connecting to the world above, created by real growing moss and additional directed spotlights in white and green hues. On the ground and ceiling light pattern add another layer of the forest feeling and identity.

Interior Concept: White painted ceiling, directions written on the wall, real growing moss on the wall.

The forest feeling of the lighting makes me in a really good mood...taking next exit to work.
Visualisations - Key zone General tunnel under water

Theme zone - Sun/rainbow

Figure 35.
Lighting typology:
**Spatial lighting:** Reflected warm white light in the ceiling give a soft general “sunny” light in the space and on the ground. Additionally filtered light pattern on the ground support the presence of the sun.
**Identity Lighting based on Theme:** Vertical coloured light beams on the walls creating “rainbows”/projected photos of rainbows on the walls and ceiling. The vertical repeated rainbows support distance recognition as well as spatial understanding.

**Interior Concept:** Ceiling and walls with white flat surfaces.

...I always make a wish passing the rainbows...They symbolise luck and happiness for me.
Visualisations - Key zone  Access tunnel/ general tunnel crossing

Visualisations Map position: 7.
Theme zone - Forest

Figure 36.

Lighting typology:
Spatial lighting: Reflected cooler light in the ceiling giving a soft general light in the space and on the ground. Vertical warmer light on the walls brings out the borders and texture of the space as well as illuminating the face/body of the cyclists supporting the social lighting aspect of the Lighting Concept.
Identity Lighting based on Theme: Photo projections on walls and light pattern on ground and ceiling created by spotlights giving the experience of biking through the forest with sky light filtered through the leaves, connecting to the nature in reality and by that to the human scale and the cyclists emotions and well being.

Interior Concept: White painted ceiling, pattern on ground, real growing moss on the wall.

Great day at work!
...not that great weather - taking the tunnel is a dry and comfortable alternative.
10. Conclusion

Conducted Proposal, field studies and research strengthen My opinion from a lighting designer perspective that it is possible to create a functional bicycle route experienced as safe in this tunnel space. The large dimensions both put a great demand on the light planning as well as the orientation structure, but not least, providing a unique space for creating light experiences far from the usual, expanding the field of light design in public space.

Results of the Field Studies confirm the opinion that light has the ability to define a space, reveal its identity as well as in a high degree influence the emotional perception of space. The defining parameters are position, light typology and light level in correlation with material, surfaces as well as dimensions.

Regarding the users perception of a space, the field study results are based on very few subjects, but the result can form a basis for feature larger studies of “common” preferences and opinions of cyclists regarding the effect of lighting in relation to experience of safety and other emotional effects, in a tunnel situation. On the other hand, the results confirm larger user studies regarding human experience of safety in public space, and correlate with professional lighting strategies. By that the results are strengthen and the reliability of the results as well as the thesis proposal.

The proposal connects to the existing knowledge of the lights ability to affect the impression of a space emotional as well as physical where a site-specific lighting strategy based on a site analysis as well as a user perspective on a human scale is the key-elements.

The proposal content needs to be tested on site by full-scale light evaluations, to be refined and revised before an eventual future realization. Further light specification as well as light levels need to be revised in collaboration with the City’s light planning.

Additionally, the Swedish Transport Administration has published in media information about the possibilities of opening the tunnel for commuter biking in the future supporting the opinion that this tunnel is a functional biking route.
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