THE HIGHWAY, OUR HEALTHY FUTURE LIVING ENVIRONMENT!!!
Exploring the opportunities to build next to a highway and finding solutions for the problems of noise and air pollution caused by the highway.

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Abstract
In different parts of the Netherlands and also in other countries around the world populations are growing. When population grows, urban areas tend to grow as well. Next to the needs for more living space, urban planners have to deal with the demands of mobility and accessibility in and around the cities. Often, cities are built along highway networks. These highway networks create a lot of noise and air pollution which causes health and annoyance problems for both humans and animals within the cities. Therefore, this research paper will study solutions for the problems of noise and air pollution caused by highways.

First, a case study is done in order to map the existing solution typologies regarding the problems of noise and air pollution caused by highways. The case study projects are mainly selected due to their ability of integration within the architecture. Following the case studies, a set of criteria are formulated. These criteria are used as a guideline for a literature study. Secondly, within this study, different kinds of literature such as books, journals, articles, government report, PhD thesis and other academic writing resources are examined. The literature study was mainly focused on the theoretical framework behind the solution typologies which were purposed by the case study projects.

In order to be able to transform and integrate the founded solutions within the architecture, the A12-zone in Utrecht is chosen as a case location. In this part of the city, plans are made to develop this area into a living and working space by 2040. However, these plans are hindered by the A12 highway which is located in the middle of the A12-zone. Based on both the case and literature study, in the last part of this research paper a recommendation is created for the A12 zone where the problems of noise and air pollution caused by the highway are reduced/solved. The results of this study will be described in the following chapters.

Keywords: Noise pollution, air pollution, highway problems, disconnecting barrier effect, urban canyon, noise reflection, noise absorption, contaminated air absorption, filtering.
1.1. Problem Statement
The need for more living space grows in many countries around the world. The Netherlands is no different than all the other countries, especially in cities such as Amsterdam, Utrecht, Rotterdam and The Hague. These cities show the most growth on demand for more living space tremendously. In the past, natural habitats where often changed into new living areas. Nowadays, this solution became unsuitable in the Netherlands, with the conurbation Randstad in particular; there are simply not enough natural areas left in the mid and west of the Netherlands. Next to the growing needs for more living space, cities have to also deal with the problems of accessibility and mobility in and around the cities. Nowadays, city dwellers try to avoid living next to the highways because of health problems caused by noise and air pollution. Automobile industries have been engaged for several years in finding solutions by making motor vehicles cleaner and more fuel efficient. However architects, urban planners and engineers should also be able to find solutions for the problems of noise and air pollution.

In the scope of this study, the A12-zone in Utrecht, which is located in the middle of the Netherlands, will be used as a case location (Fig. 1 Left). Within this location, a study will be done in order to find solutions for the problems of urban expansions around busy highways. The future urban plans for the city of Utrecht show an urban expansion in the south of the city by 2040 (KETELAAR, 2012). The A12 highway located at this planned area of the city connects the east with the west of the Netherlands. In the current situation, the A12 highway is not able to deal with the huge amount of motor vehicles during rush hours. This results in massive traffic jams accompanied by a great deal of noise and air pollution (Fig. 1 Right). Besides the problems of noise and air pollution, the highway also creates a disconnecting barrier effect between different parts of the city. A future urban plan exists for the city of Utrecht to make the highway wider in order to create more space for motor vehicles (KETELAAR, 2012). This will be very pleasant for the mobility and accessibility of the city but rather undesirable for the areas around the highway where new living and working space have to be created. In order to match the needs of the city of Utrecht by 2040, a solution must be found in solving the disconnecting barrier effect and the problems of noise and air pollution around the A12 highway. Only then will people of A12-zone finally be able to live in a healthy living and working environment.

1.2. Objectives
The objective of this paper is to develop recommendations, based on both the case and literature studies, to solve the problems of highway environment. The goal is to integrate the highway into a healthy living environment, where the disconnecting barrier effect and the problems of noise and air pollution are solved/reduced. Therefore, the following research questions are formulated:
Research questions

The overall design question:
How can the A12 highway be integrated into a healthy living environment, where the disconnecting barrier effect and the problems of noise and air pollution are solved/reduced?

Technical research question:
How can the problems of noise and air pollutions be solved, by integrating architecture and building technology in order to create a healthy living environmental next to the A12 highway?

1.3. Methodology
In the scope of this research paper, two scientific research methods are used.

Case studies
Studying different kinds of case projects was the first step to determine which contemporary techniques, systems and solutions are available regarding the problems of noise and air pollution. After finding and collecting different kinds of realised and conceptual case projects, in which each of them provides solutions to different aspects within the problems of noise and air pollution, a selection has been made. A short study has been composed to summarize these extended collected case projects. Within this short study, every case project is analysed with the following questions in mind:
- What kinds of techniques, systems or solutions are proposed by the case project?
- Is it possible to classify these proposed solutions into different typologies?
After this short study, different kinds of common and proven solution typologies are then formulated. These typologies consist of: building as a noise barrier, double skin façade, well insulated skin, cleaning air by vegetations, absorbing, reflecting, collecting and converting techniques, filtering and ventilating by wind. In order to comprehend these solutions typologies thoroughly, six most interesting case projects are chosen in which they represent the typologies perfectly. Next, these six case projects are then analysed and will be discussed in the following chapter. The following questions have also been used to study these six projects carefully:
- On which scale (urban, building or component) do the projects contribute solutions to the noise and air pollution?
- What are the advantage(s) and the disadvantage(s) of the proposed solutions?
- Which subject/focus within these case projects is interesting to study more about?
- To what extent are these proposed possibilities interesting to apply them for the A12-zone?
In addition, in appendix 8 a list of the other studied case projects are also shown. Finally, the case study chapter ends with a conclusion. Within this conclusion, a set of criteria's, inspired by the proposed solution from the case projects, are formulated. These criteria's will act as a guideline for the literature study.

Literature Study
Following from the case studies, different kinds of typologies of solutions were given which are interesting to know more about. Therefore, different kinds of literature, such as books, journals, articles, government report, PhD thesis and other academic writing resources have been examined. Next to the theory behind the case study typologies, some other theoretical solutions regarding noise and air pollution were mentioned within the literatures. Therefore, the literature study is not only limited to the case studies typologies, but a wider theory about other solutions are also analysed. The results of the literature studies that finally have led to the best
recommendations can be read in chapter two. Within chapter two the following questions are answered:

- What are the different kinds of noise and air pollution caused by traffic?
- What are the governmental norms and regulation regarding noise and air pollution?
- What are the theoretical frameworks behind the case projects solutions typologies?
- What other theoretical solutions are possible?
- How much can the typologies provide solutions to the reduction of noise and air pollution?

Within chapter two, a distinction has also been made between the literature study about noise and air pollution. In the first part the literature study about noise pollution is described and in the second part of chapter two the literature study about air pollution. Since the main aim of these literature studies is to find out the way how the different solutions works, to what extent they reduce the noise and air pollution and how to transform this information into recommendations. Therefore, these literature studies will bring to a conclusion in the end. Within the conclusion per each subject, such as noise and air pollution, recommendations in general on different scales (urban, building and component) are given.

As the final chapter, the information and recommendations based on both the case as the literature studies are transformed into design recommendations for the A12-zone. Within this chapter, recommendations on the three scales are described and shown. This chapter shows mainly how the theory can be transformed into urban/architectural design solutions regarding the problems of noise and air pollution.
2.1. Case study

In the scope of this research several case projects are studied. Within the case projects a distinction is made between realised and conceptual projects, since a large amount of case projects are available. The case projects which are studied carefully and shown down below represent different kinds of solution typologies regarding noise and air pollution. In the drawings down below, only the conclusion of what the projects purposed are shown. More pictures of the case projects are shown in appendix 8.

Sporenboog Funen in Amsterdam, Netherlands

Sporenboog Funen by Architecten Cie is located next to a busy railway and nearby the Central station of Amsterdam (DE BEST, 2006). This realised project is interesting because it offers a very effective solution to the noise pollution by using a building as a noise barrier. (Fig.2 Left) A long L-shaped building block is placed next to the railway. (Fig.2 Right) This building reduces the noise up to 20 dB in the area behind the building (MVIEM, 2013). The people within the L-shaped building are also protected from the noise by a double layered façade. The façades consist out of an airtight glass outer layer, a buffer zone and a well insulated inner layer. The disadvantage of this project is that the L-shaped building requires a continuous length and a building height of 27m. In most cases, buildings are not suitable to be designed that long, interruption at some places are needed. However, it’s certainly a great opportunity to analyse the interesting concept of buildings as noise barrier and this principle will therefore be studied more carefully during the literature study.

‘De Tribune’ in Amsterdam, Netherlands

This realised building by Claus en Kaan architects is located next to the busy A10 highway in Amsterdam. The Tribune, like the Sporenboog, makes use of a double layered façade. (Fig.3) The outer layer is a closed, airtight façade that consists of 50% out of glass and 50% out of well insulated Sandwich panels. Between the outer and inner layer a buffer zone is created, this zone serves as movement area where the dwellings entrances are connected to. The inner layer is made out of a closed well insulated timber frame wall. Because of the double layered façade, the noise is reduced by 40dB inside the building. A disadvantage of this project is that the building only provides solutions to the people inside the building, on an urban scale the building do not reduce any noises. However the double façade principle is quite an interesting solution on a
Boschkens in Goirle-Tilbrug, Netherlands
The Boschkes by Buro Lubbers, located next to the A58 highway, provides solution to noise pollution (BURO-LUBBERS, 2013). This project integrates a noise barrier wall together with buildings. (Fig.4) A well insulated solid wall is created next to the highway and dwellings are placed behind it. The wall is made out of thick concrete inner layer, mineral wool insulation and porous concrete blocks for the outer layer. Due the porosity of the concrete, noise will be absorbed by the outer layer. (Fig.4) Also, the wall is angled by 5%; this will send the non-absorbed reflected rays towards the sky. To create view to the outside and allow daylight in, well insulated small windows are placed in the wall. However, the wall is a monotonous continuous blockade next to the highway. From the driver point of view the monotonous appearance can become less appealing. But still, the principle of integration between noise barrier and buildings can be very interesting to study more carefully during the literature studies.

Master plan for Huizhou, China
This conceptual 410,000 m² master plan by Dom Arquitectura for the city of Huizhou in China, provides solutions for the problem of noise and air pollution on an urban scale (FURUTO, 2012). This area of the city is located next to a busy road which causes a lot of noise and air pollution. (Fig.5 Left) The noise complications are solved by using a building block parallel next to the road as a noise barrier to protect the rear areas. (Fig.5 Right) For the problems of air pollution, vegetation is used in order to reduce the pollutants and to clean the air. The vegetation is used as both the residential tower façade cladding and for the park at the ground level. The amount of vegetation that is used creates a park cool effect in which, next to the reduction of air pollutants, also creates a nice weather condition in high temperature and control the high humidity of the climate (FURUTO, 2012). This project is interesting because it shows how vegetation can provide solutions when it is integrated within the architecture and master plan of an area. The disadvantage of this project is that the used amount of vegetation requires regular maintenance and responsibility. However, the idea of vegetation as solution for better air quality needs more investigation and this will be done within the literature study.
**CO2ngress Towers in Chicago, USA**

This conceptual project by D. Mui and B. Sahagun, located at the Eisenhower Expressway in Chicago, provides solution to reduction of CO\(_2\) emissions produced by motor vehicles (ESCOBEDO, 2012). (Fig.6) The building captures polluted air at the top of the building by collectors, the captured CO\(_2\) is then transformed to algae tubes which is integrated within the building façade. The algae tubes are accessible to sunlight and through photosynthesis process they generate energy which can be used for resident’s electric cars. This project also uses a double façade principle to protect the people inside the building against noise pollution. The advantage of this project is not only reduction of air pollution, but it also converts the polluted air into clean energy which is again beneficial for the environment. Therefore, during the literature study the aspect of collecting and converting will be examined more carefully.

**The living bridge in The Hague, Netherlands**

This is a project by TU Delft student Susanne Rolaff, located above the A12 highway in The Hague. The main focus of this project is to create a concoction platform between the different sides of the highway. Next to the main focus it was also important how the connection can be made with low noise and good air quality. Therefore this project uses the principle of dilution, absorption and filtering (ROLAFF, 2010). Through different kinds of building heights configuration, the wind is used in order to dilute the contaminated air (Fig.7). Next to diluting the polluted air, different kinds of materials and vegetations are used in order to absorb and filter the contaminated air. This project is interesting because it shows how wind behaviour can be regulated by different building heights and be used for reduction of air pollution as well. It is also interesting how different materials and vegetation can absorb and filter the contaminated air. However a disadvantage of this project is when the contaminated air is entrained by the wind, this will travel further to other areas within the city. In this case, solution by dilution is only positive for the connecting platform, whilst the quality of air in the rest of the city remains contaminated. However, it is still interesting to do a literature study about the possibility of dilution by wind, albeit only for a bigger urban scale.

**Conclusion**

The case projects show a variety of solution typologies. These types of solutions are very interesting to integrate within the A12-zone. However, to be able to understand these solutions, the theory have to be studied first. Therefore, during the literature study the following solution typologies will be studied carefully: ‘Building as a noise barrier, double layered façade, well insulated wall, pollutants reduction by vegetation, dilution by wind, absorbing, filtering, collecting and converting’.
2.2. Noise Pollution

In urban landscape there are different sources of noise pollutions. Pollutants contributed by road traffic can be seen as one of the major sources within the urban landscape. This noise pollution may be up to 100 dB at certain conditions (Fig.8). Noise pollution from road traffic can be divided into three major categories (BECKENBAUER, 2013; FORSSÉN et al., 2007; SINGAL, 2005):

- Propulsion noise: produced by engine, power transmission, exhaust system and auxiliary equipment.
- Friction noise: produced by the interaction between tyre and road.
- Airflow noise: produced by the aerodynamics and the shape of the vehicles.

According to Beckenbauer (2013) and Singal (2005), the propulsion noise becomes dominate at low vehicle speeds (Fig.8). The friction noise however, increases with the vehicle speed; therefore the major contribution of noise pollution in highway context will be from the friction between the tyre and the road (Fig.8). The airflow noise becomes dominant when passenger and commercial vehicles drive above 130 km/h and 100 km/h. Since the A12 highway is chosen as context and the speed limit is 100 km/h, the airflow noise will therefore be disregarded in this study.

![Fig. 8. Sound power levels of propulsion and friction noise at the speed limit of 100 km/h. (BECKENBAUER, 2013, p. 370)](image)

The sound power levels of noise emission also depend on the type of the vehicles. The vehicles can be categorised in four main types. Light motor vehicles (passenger cars), medium heavy motor vehicles (vans and buses), heavy motor vehicles (trucks) and powered two-wheelers (BECKENBAUER, 2013). The statistics show that in a highway context in which the speed limits is at 100 km/h and where different types of vehicle are allowed, the sound power level will be around 105 dB (Fig.8). This means serious consequences towards health and quality of living for the existing and the future living environment as well next to the A12 highway.
Norms and Regulations
In the guidelines of World Health Organisation (WHO) and Dutch Building Act (Bouwbesluit), concerning sound level, different indication is given for different kind of functions (Appendix 1). In the interest of this study, figure 9 gives a short summary of the guideline values for community noise in Dwellings.

As well in Dutch Building Act as in WHO the limit for sound pressure levels in dwelling is determined at 35 dB(A) at daytime and 30 dB(A) at night time. (Fig.8) In comparison with the sound power level produced by different kind of vehicles, there is a big different to overcome. Therefore innovative solutions have to be found in order to solve the noise pollution and to be able to live next to a highway.

Solutions regarding noise pollution
The solution regarding noise pollution can be subdivided into three different categories (MARTIN, 2008):
- Solutions at the source
- Solutions at the transmission path
- Solution at the receiver

Solutions at the source
Within the source a distinction can be made between the vehicles and the road surface. The noise from the vehicles can be reduced up to 3 dB when quieter tyres are used (CROW, 2012). The noise from the road surface can be reduced up to 7 dB when the texture of the asphalt is improved (KOACWMD, 2002). The improvement of the texture is based on the types, the binder and the porosity of the materials. (Fig.10) The bigger the void content of the material is used, the better the noise reduction effect will be. However, the open porous surface materials require regular maintenance. "In addition one has to cope with a loss of efficiency of about 1 dB per year, at least at the very beginning when the surface is newly laid" (FORSSÉN et al., 2007, p. 27).

Solutions at the transmission path
The transmission path referred to the space between the source and the receiver. At this level different kind of solutions such as distance, noise barriers, tunnelling, covering or levelling can be used to attenuate the noise pollution. The distance between road and building can reduce the noise by 3 dB(A) when this distance is doubled, 5 dB(A) noise reduction can be achieved when the ground is covered by noise absorbing materials like grass (KRANENDONK & NIJS, 1976).
As argued before, keeping distance between road and buildings will not be possible in the future since this space will be needed for future dwellings. (Fig.11) Other solutions can be used in order to reduce the transmission space. (a.) By placing trees alongside the road, noise will reduce by 10-20 dB(A) at 25 m away from the road. (b.) When the roadsides are higher than the road and combined with trees, the noise reduction will improve by 15-20 m less transmission space. (c.) Lowering the road alone can also contribute to the noise reduction. The reduction of noise will start at 15 m instead of 25 m away from the highway. (d) The best solution to eliminate the noise is to place the road in a tunnel. By tunnelling the road there will be no traffic noise at ground level and this space can be used for other urban activities. (KRANENDONK & NIJS, 1976) However, these solutions are often too expensive. These thoughts are also solely from the residents perspective in which the driver experience are often neglected. More integrated solutions, which will benefit both the residents and the drivers, is the use of the buildings next to the highway as a noise barrier.

(Fig.12) A building parallel to the road in comparison of a building perpendicular to the road will work very effectively in mitigating the noise pollution. Parallel building close to the road can contribute to the noise reduction by 20-25 dB in areas behind the building (KRANENDONK & NIJS, 1979). However, shielding the road by buildings can only be effective when continuous building of sufficient length is placed next to the road, therefore the term of ‘canyonisation’ can be used. “The road can be compared in this case to a river, tamed by dykes that, of course, should not be weakened by holes”(DE RUITER, 2005, p. 45).

Also the height of the buildings by which the canyon is formed plays a major role (Appendix 3). According to Kranendonk & Nijs (1979), a continuous building of 5 m height can reduce the noise in the shadow zone with 20-24 dB. When the height of the building is 12 m, the noise in the shadow zone will reduce by 28-31 dB. However, when a second continuous building behind the first building is introduced, the noise reduction between the two buildings will be 1-4 dB lower, this is caused by the reflection of the façades. One solution can be the use of noise absorbing façade material, other solutions is to make the nearest building to the road higher (Appendix 3 (D-11)).
The canyon principle will be weakened when openings in the continuous buildings are created (Fig. 13 Left). Through these openings, noise will penetrate in the areas behind the canyon building. (Fig. 13 Right) The penetrating noise in the shadow zone can be characterized in four main categories (KRANENDONK & NIJS, 1979):

1. Straight from the source into the shadow zone.
2. Through reflection by the buildings façades into the shadow zone.
3. Through deflection alongside the buildings into the shadow zone.
4. Through deflection over the buildings into the shadow zone.

According to Krankendonk and Nijs (1979), noise into the shadow zone straight from the source and deflection alongside the building can be diminished by a second layer of buildings. As shown in Appendix 3 different variant of building mass orientation behind the openings can improve the noise penetration within the shadow zone. (Fig. 14a) One variant is to continue the buildings’ corners, depending on the length of the continued corner the shadow zone will increase by several meters. A disadvantage is when the corners are too long continued, the noise will penetrate deeper into the area (Appendix 3(P.5)).

Another variant is to overlap the buildings at the openings; a building can be placed parallel in front or behind the canyon building openings. (Appendix 3(P.19)) When a building is placed in front of the opening, noise will penetrate both the roadside and the backside of the canyon and the added building. (Fig. 14b) However when a building is placed in front of the opening, the noise will not penetrate the shadow zone behind the canyon building. On the other hand the building in front of the opening will be affected on both side by high noise pollution, therefore these building will not be available for noise sensitive function such as a dwelling. According to Krankendonk and Nijs (1979), a more effective variant is to place a second layer of building in which they are placed perpendicular to the canyon building (Fig. 14c). This way, the noise penetration will be stopped at the very beginning of the opening en will not go deeper into the rear areas. Additionally, the noise penetration into the shadow zone can be reduced by the use of higher canyon buildings and noise absorbing façade materials (KRANENDONK & NIJS, 1979).
The reflection of noise in the shadow zone through the building façades can be controlled by the orientation and the materialisation of the façades. (Fig.15) When sound rays contact a surface, a part will be reflected, another part will be absorbed and another part will be transmitted through the material. However the amount of sound rays which is transmitted to the other side of the material is relatively low. According Van der Linden & Zeegers (2006), the transmitted sound energy through a normal brick wall is only about 1/10,000 part of the impinging sound energy. The absorption of sound rays depends on the materials. Therefore, materials with porous surface are more noise absorbing than materials with solid homogeneous surface (VAN DER LINDEN & ZEEGERS, 2006). In addition, it is important to take into account that porous materials are more vulnerable and needs protestation, this issue will be explain in the following text.

An effective solution to control the reflected sound rays, is the orientation of the building façades. (Fig.16a) Façade materials made from solid homogeneous materials, such as glass, can reflect the sound rays between the canyon buildings. This will result in higher noise pollution within the canyon street and the sound rays will even go further into the shadow zone. (Fig.16b&c) However with a change in the angle of the façade the sound rays can be sent up- or downwards. When the façade angle is faced onto the ground, an in-between space with absorbing materials on the ground level is needed in order to absorb the reflected sound rays. But when the façade angle is faced upwards, the sound rays will be sent towards the sky. Therefore an in-between space is superfluous and the canyon building can be built close to the road. (ENGLISH & KOTZEN, 2009) However, with this last configuration noise can penetrate into the shadow zone over the building, but this can be solved by using absorbing materials.

Using noise absorbing materials can reduce penetrating noise. According to Van der Linden & Zeegers (2006), noise absorption based on friction through air movement in porous materials can be a very effective solution. When sound rays enter a porous material, there is friction between the incoming and outgoing air particles in the pores of the material, this transforms the sound energy into heat and the heat is absorbed into the material (VAN DER LINDEN & ZEEGERS, 2006).

The thickness of the material plays a major role in the effectiveness of the sound absorption. (Fig.17a&b) Since the most sound energy is at the $\frac{1}{4} \lambda$ ($\lambda =$ wavelength) from the wall, the sound absorbing material which will be placed in front of the wall, need a thickness of $\frac{1}{4} \lambda$ of the sound wavelength in order to absorb effectively (VAN DER LINDEN & ZEEGERS, 2006). However it is too expensive to use a very thick sound absorbing material. (Fig.17c) Therefore, a cavity between the wall and the absorbing material can be used.
Often, absorbing material (mineral wool etc.) are very porous and vulnerable, therefore they need protection from outside. (Fig.18) Protection can be created by a layer of perforated material like aluminium, copper, zinc, steel, timber, plastic or concrete and ceramic bricks. (Appendix 4) In order to not diminish the sound absorption, the perforated holes have to be higher than 20% of the total surface, otherwise the perforated surface will work as a solid wall (VAN DER LINDEN & ZEEGERS, 2006).

In appendix 5 a range of different kind of sound absorbing materials and layout based on the absorption theory, which is explained above, are shown. These materials and layout are used for sound barrier walls, therefore they give an interesting overview of what is possible by absorbing the noise from the outside. From this overview an integration can be made and materials from the sound barrier wall can be used for the canyon building façades.

**Solutions at the receiver**

Solutions at the receiver is referred to the building itself. At this level the building skin construction and the zoning inside the building can be considered as the main focus. Next to a well insulated close wall along the traffic road, the typology of double skin façade can also be used in order to protect the people inside the building from noise.

A double skin façade consists out of three functional layers. The outer layer acts as a protection against wind, cold and noise. This layer is separated from the inner layer by a cavity which is used as a buffer zone. The inner layer is well insulated and in some cases this layer is totally closed or there is a possibility to open doors or windows. There are four main typologies of the double skin façade (Fig.19a): box-window, (b) corridor, (c) multi storey and (d) shaft-box façade (KNAACK, 2007). The box-window façade provides privacy and therefore it is very suitable for loggias. Since a box is created, the noise transmission towards other boxes will be prevented if a proper insulation for the partition walls is used. A disadvantage of this typology in highway environment is that ventilation is only possible through a mechanical system; otherwise openings have to be made in the highway faced outer layer. Within the corridor façade the vertical partition walls are removed and per each story a connection is made. This type is very
suitable for movement area. Also, this type need openings in order to allow natural ventilation. In order to provide the full protection against noise and to use natural ventilation, the multi-story and shaft-box-window façade can be used. Since there is no any horizontal separation these two types can be used as an exhaust air outlet. Air form the backside of the building can be brought in and taken out from the buffer zone throughout the chimney effect created by the sun. However these two typologies do not provide space to any other functions. Therefore, a combination of the corridor and multi-story façade can be the right solution, in which the buffer zone can be used as a movement area and also for natural ventilation without openings in the outer layer faced too the highway. Acoustic wise, the double layered façade create protection by the outer layer and a well thermal insulation by inner layer. Whilst between this two layer a buffer zone is created which enhance the climate control and reduce noise within the building.

Furthermore, zoning within the building can provide solution. Some noise sensitive functions such as bedrooms need protection against noise. Therefore it is more suitable to place these kinds of functions at the backside of the building.

**Recommendations regarding A12- zone**

Based on the theory, the following recommendations can be done for the A12-zone.

**Urban scale solutions:** On this scale, it is effective to create an urban canyon by placing long continuous buildings next to A12 highway (Fig. 20 Left). Due to the canyonisation, the noise will be blocked from going into the city. (Fig. 20 Right) When openings in the canyon buildings have to be made, a second layer of building perpendicular to the road can be placed in order to reduce penetrating noise in the shadow zone.

**Building and component scale:** It’s interesting to integrate these two scales onto a few solutions. (Fig. 21 Left and middle) First it is effective to reflect and absorb the sound rays within the canyon street by the building façade. Due to different angle and materialisation of the façade, noise within the street can be reduced. (Fig. 21 Right) Furthermore, a well-insulated façade can help the reduction of noise transmission into the building. (Fig. 22 Right) A double layered façade can also be used in order to reduce noise transmission into the building. (Fig. 22 Left) Last but not least, the zoning principle within the building can be used. For example, the nearest space towards the road can be used for movement, whilst the furthest space to the road for bedrooms.

**Fig. 20. Left: Urban canyon. Right: Second layer of building when openings have to be made in the urban canyon. (Author work)**

**Fig. 21. Left: reflection by building’s façade. Middle: Absorption by building’s façade. Right: Well insulation of building’s façade. (Author work).**

**Fig. 22. Left: Zoning within the building organisation. Right: Double layered façade principle. (Author work).**
2.3. Air Pollution
The air consists out of different kinds of substances. To humans and animals harmful air substances caused by motor vehicles are:

Particulate matter (PM$_{10}$ and PM$_{2.5}$)
"Particulate matter is a complex mixture of organic and inorganic substances, present in the atmosphere as both liquids and solids" (BUTTERWICK, HARRISON, & MERRITT, 1991, p. 35). Particulate matter can be divided in two types: PM10 and PM2.5. PM10 are matters bigger than 2.5 micro-millimeter and PM2.5 are fine particles not bigger than 2.5 micro-millimeter. Particulate matters causes big health problems to human, they are often the cause of heart and lung diseases. Researchers of the Dutch National Institute for Public Health and the Environment (RIVM) and the Environmental Assessment Agency (MNP) have estimated that each year approximately 18,000 of people die prematurely rather by short-term exhibition to fine particles (PM$_x$) (OTTELÉ, 2011, p. 25). Because of the small size the particles can move over a large distances in the air, solutions on a bigger scale (urban and/or region) are therefore needed in order to reduce particulate matters in the air. The source of particulate matters regarding motor vehicles can be divided into two types of particulates. First, Particulate matter caused by the friction and combustion engines and brakes. Second, particulate matter caused by the chemical reaction of gases such as ammonia (NH$_3$), sulphur dioxide (SO$_2$) and nitrogen oxides (NO$_x$) (OTTELÉ, 2011).

Sulphur dioxide (SO$_2$)
"Sulphur dioxide (SO$_2$) is a colourless gas. It reacts on the surface of a variety of airborne sold particles, is readily soluble in water and can be oxidized within airborne water droplets" (BUTTERWICK et al., 1991, p. 31). The major source of SO$_2$ caused by motor vehicles is from the fuel combustion of the engine. A SO$_2$ concentration of 2,600 µg m$^{-3}$ or more can cause asthmatic diseases (BUTTERWICK et al., 1991).

Nitrogen oxides (NO$_x$)
"Nitrogen oxide (NO$_x$) is the collective name for compounds between oxygen (O$_2$) and nitrogen (N$_2$)" (OTTELÉ, 2011, p. 29). The major source of NO$_x$ is the burning fossil fuels during the combustion of engines. NO$_x$ have different kinds of health effect on humans and animals. These health effects can be described as: altered lung function and symptomatic effects, increased prevalence of acute respiratory illness and lung tissue damage. The health effects of NO$_x$ are more damaging for young children and human with asthmatic diseases. In addition, due to the various reaction created by NO$_x$ from vehicles, ozone (O$_3$) tends to build up in high dense urban areas. (BUTTERWICK et al., 1991)

Carbon monoxide (CO)
"Carbon monoxide (CO) is a colourless, odourless, tasteless gas that is slightly lighter than air. CO is an intermediate product through which all carbon species must pass when combusted in oxygen" (BUTTERWICK et al., 1991, p. 49). Most of the CO is immediately oxidised to CO$_2$. These gaseous is mainly released due to the combustion of fuel in the motor vehicle engine. Dry air consists out of nitrogen (N$_2$), oxygen (O$_2$), argon (Ar) and carbon dioxide (CO$_2$). The increase of CO$_2$ by traffic and other fossil fuel combustion process results in warming up of the earth. Furthermore, when CO is inhaled by humans and animals it can disrupt the supply of essential O$_2$ to the body tissues by entering the blood stream (BUTTERWICK et al., 1991).
Norms and Regulations
In the guidelines of Dutch government and European Union concerning air quality, different indications are given for different kind of pollutants (Appendix 2). According to the regulations, the limit for PM$_{10}$ is 50 $\mu$g/m$^3$ based on a daily average and should not exceed 35 days per year. For SO$_2$ the limit is 125 $\mu$g/m$^3$ on a daily average with the limitation of 3 days per year. For NO$_2$ the limit is 40/60 $\mu$g/m$^3$ based on a year average. In order to be able to reduce the air pollution to these norms, different kinds of solutions from different angle have to be studied.

Solutions regarding Air pollution
To reduce harmful substances in the air and thus to create a healthy living environment, solutions such as dilution, absorption and filtering of the polluted air can be applied (ROLAFF, 2010). The early mentioned canyonisation principle can be used for studying the wind behaviour effect on distribution and concentration of pollutants in different street canyon configuration. To understand the behaviour of wind though, a study of wind behaviour around buildings and in canyon streets have to be done beforehand.

The wind behaviour around a building appears to be dominated by two pressure systems. (Fig.23a) The first pressure system develops at the side that is hit by the undisturbed airflow. At this side of the building a high pressure zone is developed from the ground level up to the point S as shown in figure 23a. Point S is at 70 to 80% of the entire building’s height, this explains the downward diversion of the oncoming airflow. The downward flow caused by this side of the building results in a standing vortex at ground level. (VERHOEVEN, 1982) The second system is created under the influences of the first system. (Fig.23b) The wind velocity from the windward side of the building creates an underpressure area (wake region) on the leeward side of the building. As result of the pressure difference between the windward and leeward side of the building, a powerful airflow is created at the edges of the building. This powerful airflow may take a stretched lobe-shaped form, as shown in figure 23b (VERHOEVEN, 1982). “These areas stretch out away from the building for 1 to 2 building heights in the direction of the wind.” (VERHOEVEN, 1982, p. 40) Due to the high velocity airflow from the edges of the building, a returning airflow at the ground level is created from 3 to 5 of the building heights (Fig.23c). A concentration of wind is caused by this returning airflow in the wake region at the leeward side of the building.
According to ApSimon, Assimakopoulos and Moussiopoulos (2003), the scheme above will be used to study the effect of wind behaviour on the distribution and concentration of polluted air patterns within a different street canyon configuration. Figure 24 shows a symmetrical street canyon where the ratio of the street width to building height is 1 (W/H=1). The air pollution sources (motor vehicles) are located at the centre of the street, the wind direction is from left to right. The left building is called the 'Upwind building' and the right building is the 'Downwind building'. Since not every street canyon is symmetrical, the building height will also differ from each other. When the 'Upwind building' height is lower, this called 'Step-up notch'. When the 'Downwind building' height is lower, this is 'Step-down notch'. (APSIMON et al., 2003)

Fig. 24. “Definition of street canyon dimensions and indication of measurement positions of the non-dimensional tracer concentration”. (APSIMON, ASSIMAKOPOULOS, & MOUSSIPOULOS, 2003, p. 4039)

(Fig.25a) The wind behaviour, in a symmetrical street canyon where the buildings are equal in height, creates a single air vortex. The vortex centre which is denoted by a star is perfectly aligned in the middle of the two buildings. (Fig.25b) Due to the vortex the polluted air distribution creates a high concentration of air pollution at the lower 'Upwind building' corner and a low concentration at the 'Downwind building' roof. (APSIMON et al., 2003). This means that the concentration of polluted air in this situation is more effective to be absorbed or filtered at the lower side of the ‘Upwind building’ and at the roof of the ‘Downwind building’. (Fig.26a) When a ‘Step-up notch’ is created, the vortex is weaker and the ventilation in the street is lower. Because of the ‘Downwind building’ is taller, the airflow is disrupted and this makes the interaction between the vortex in the street and the airflow above the buildings weaker. Additionally, the centre of the vortex is displaced more to the ‘Downwind building’. (Fig.26b) In this case the concentration of polluted air remains closely to the ‘Upwind building’ façade, only it is lower than the symmetrical case. In comparison with the symmetrical case, the amount of air pollution exiting the street from the ‘Downwind building’ roof is lower. This is because the airflow transports the polluted air backwards. (APSIMON et al., 2003). This case shows that the air pollution concentration can be reduced by simply lowering the ‘Upwind building’. However,
still a high amount of polluted air will stay in the street, but this can be reduced by absorption throughout vegetation and different kinds of materials.

(Fig. 26) 'Step-up notch' street canyon. a. Wind behaviour. b. Pollutant dispersions patterns. (APSIMON et al., 2003, p. 4041)

(Fig.27a) When a ‘Step-down notch’ is created, the vortex also becomes weaker and the centre (noted by a star) is higher than the 'Downwind building' roof. Next to that, two secondary smaller vortexes of opposite flow direction are created at the lower corner of the 'Up- and Downwind building' façade. (Fig.27b) The two secondary vortexes lead to a formation of high air pollution concentration at both the 'Up- and Downwind building' façade. In this case the dispersion of polluted air also goes over the 'Downwind building' roof and distributes air pollution in the areas behind the canyon street. (APSIMON et al., 2003). Differently than the symmetrical and the 'Step-up notch' canyon configuration, the ‘Step-down notch’ causes a two folded problem. The concentration of polluted air within the canyon street becomes not only higher than in the other two cases, but it breaks up the canyon principle and a high concentration of polluted air goes over the building into the rest of the city. In this case, only absorbing and filtering the polluted air within the canyon street is not enough to reduce air pollution. Measures have to be taken with the buildings and streets behind the canyon as well, if this were not the case, then the canyon principle would not be fully utilized.

(Fig.27) 'Step-down notch' street canyon. a. Wind behaviour. b. Pollutant dispersions patterns. (APSIMON et al., 2003, p. 4043)

In the three cases explained above it is showed that within the ratio of $W/H=1$, the polluted air dispersion do not only concentrate within the canyon street. But in all three cases the possibility in which the polluted air can exit the street canyon over the 'Downwind building' roof is very high. A solution to this problem can be the use of the ratio of $W/H=3$. (Fig.28) In this case the street width is not equal to the buildings’ height, but the street is wider by the ratio of 3 (APSIMON et al., 2003). (Fig.28a) "For the $W/H=3$ case, the main vortex centre is shifted towards the downwind building side of the street, the flow direction close to the floor being from the downwind to the upwind building while it is elongated along the horizontal direction" (APSIMON et al., 2003, p. 4045). Next to that, a small vortex of opposite flow direction is created at the lower 'Upwind building' corner. Because of the considerable width of the canyon street in this case, the source (motor vehicles) is placed at two locations within the street. (Fig.28b) The first location is nearby the 'Downwind building'. In this case, the most polluted air concentrates at the 'Upwind building' facade. But in comparison with the case of $W/H=1$ the polluted air
concentration is not only lower, it also does not go over the 'Downwind building' roof into the areas behind the canyon. (Fig.28c) The second location where the source can be placed is nearby the 'Upwind building'. In this case the dispersion of the polluted air is even better and high concentration stays in the middle of the street. (APSIMON et al., 2003). In both locations where the source can be placed, the dispersion of air pollution is better than the W/H=1 case because the pollutant stays within the canyon street and do not enter the areas behind the canyon.

From the study of wind behaviour around buildings and in the street canyon, the following conclusion can be drawn. Since the W/H=3 case is more suitable to the highway situation and it provides the best solution, this configuration of street canyon will be used. (Fig.29) As explained before, wind from the windward side of the building creates an underpressure area (Wake region) at the leeward side of the building. This wake region creates a vortex within the street canyon. When the ratio is W/H=3 the centre of this vortex will shift to the 'Downwind building' façade, the most polluted air concentrates in this case due the vortex at the 'Upwind building' façade. This means that this façade should have an absorbing and/or filtering function in order to reduce air pollution and to prevent dispersion of pollutants in the air (Fig.29 the red ellipse). Another place which also can be taken into consideration is the roof of the 'Downwind building'. Since this roof is the last border of the canyon, some polluted air will go over this roof to the area behind the canyon because of the airflow. The same measures as the 'Upwind building' façade can be taken into account (Fig.29 Smaller red ellipse).

Absorbing and filtering the polluted air can be done by different kinds of vegetations and systems.
“Vegetation can serve to reduce the amount of air pollutants (CO₂, NOₓ, PM₁₀ and VOC’S) from the air” (OTTELÉ, 2011, p. 32). Different kinds of plants absorb air pollution through photosynthesis for their growing process. According to Ottelé (2011), a mature beech tree with a combined leaf surface area of 1600m², uses 2.4 kg CO₂, 96 kg H₂O and 25.5 kj heat energy to create 1.71 kg of O₂ and 1.6 kg glucose every hour. This amount is equal to the oxygen intake of 10 humans every hour (OTTELÉ, 2011). Next to different kinds of trees within the urban street, vertical greenery can also be used as façade cladding for buildings. (Fig.30) Green façade technology are divided into two main categories (OTTELÉ, 2011):

The first category is the rooting into the ground system. This traditional technology lets the plants grow from the ground and uses the façade surface to climb higher. The plants can climb by themself or by the use of a supporting system. Also within this category, no extra measures as in an irrigation system or adding nutrients are needed to feed the vegetation. The second category is the rooting in potting soil or artificial substrates system. In this case the plants are rooted into planter boxes at different levels instead of into the ground. Nonetheless, this system requires some extra measures such as irrigation systems and adding nutrients to the substrate. A secondary structure on the façade surface is therefore needed. (Fig.31) Within the secondary structure in which the plants can grow, four different systems can be distinguished (OTTELÉ, 2011):

1. Planter boxes
2. Foams
3. Laminar layers of felt sheets
4. Mineral wool

In Appendix 6, different kinds of climbing plants are shown which can be used as façade cladding in order to absorb and filter the polluted air.

Next to vegetation, different kinds of materials and systems can be used to absorb or filter the polluted air. Materials with catalytically processes are very effective to reduce air pollution. “A catalyst is a substance that can speed up or slow down a reaction. Unlike other compounds that participate in a

Fig. 30. Two different kinds of green façade cladding technology. (OTTELÉ, 2011, p. 9)

Fig. 31. Different types of structure for the rooted in artificial substrate and potting soil. (OTTELÉ, 2011, p. 10)

Fig. 32. Titanium dioxides as a catalyst (OTTELÉ, 2011, p. 30)
chemical reaction, a catalyst is not consumed by the reaction itself” (OTTELÉ, 2011, p. 30). A catalyst that can be integrated within the building façade materials is titanium dioxide. (Fig.32) This is a photo catalytic active material which can convert nitrogen oxides (NOx) into nitrate (NO3). Nitrate on his turn can be used as fertilizer for vegetation. Titanium dioxide material should be placed at the surface to be easily accessible to (sun) light and air pollution. (APSIMON et al., 2003). In appendix 7 the catalytically process of a building façade material with titanium dioxide is shown.

Another system based on natural process, is the use of bioreactors. “In air pollution, bio reaction is simply the use of microbes to consume pollutants from a contaminated air steam” (EPA, 2003, p. 1). Bioreactor is based on a natural process; therefore no combustion of any fuel is needed. (Fig.33) The bioreactor consist of a fan, plenum and a bed (media). The fan collects contaminated air and transports it to a plenum. Usually the plenum is placed in a rectangle box, on top of the plenum a perforated rack is placed and on top of the rack the bed is placed. The bed can be made out of different kinds of materials like: yard waste, bark, coarse soil, gravel or plastic shapes. The contaminated airflows from the plenum go through the bed (media), within the bed microbes reduce the pollutants by consumption and finally a decontaminated air is released from the bed. (EPA, 2003). Since a big surface is needed to place the bed, the roofs can be used in order to integrate this system with the canyon buildings.

**Recommendations regarding the A12-zone**

Based on the study above the following recommendation regarding air pollution can be made for the A12-zone.

**Urban scale**

On this scale the urban canyon principle can be used to capture the polluted air (Fig.34). Due to the wind behaviour the polluted air can be collected and absorbed. But it is important to take into account that wind direction change by different weather conditions. In addition, integration of trees and vegetations on an urban scale can help the reduction of air pollution. Trees can also helps to control the wind direction.

**Building and component scale**

On these two scales an integration of different solution within the building can be made. (Fig.35) The canyon buildings can work as an absorbing/filtering system. Due to the integration of plants and different materials the façades can clean the air. Furthermore, by employing collectors within the façade, pollutants can be captured and be used for other purposes.
A12-zone recommendations
Based on the studies above, a final recommendation for the A12-zone will be made. The recommendations are thought from the urban, building and component scale.

Fig. 36. Canyonisation of the A12-zone (Author work).

Based on the case and literature studies, buildings next to the A12 highway can be used in order to create a highway canyon. (Fig.36) The A12 highway will be enclosed by long uninterrupted, continuous buildings alongside of the road. The continuous building can block the noise from going deeper into the city. The highway canyon is also a very effective way to control the dispersion of air pollution. (Fig.28) When the street ratio is \( W/H = 3 \) with equal buildings height on both side of the highway, wind from southwest will create a horizontal elongated vortex within the canyon. Due to the shape of the vortex, the most polluted air will stay within the canyon. Since the most polluted air are captured in the canyon, absorption, filtering and collecting materials and technologies can be used in order to dilute the polluted air.

Fig. 37. Rest spaces created by the highway junctions (Author work).

(Fig.37) The A12 highway junctions create a lot of rest spaces. Due to the high noise and air pollution, these spaces are not suitable to live or to work in. However these spaces can be used very effectively to absorb, filter and collect the polluted air. Since vegetation can contribute to the reduction of air pollution, the rest spaces will be filled with different kinds of plants and trees. Also systems like bioreactors can be used in these rest spaces in order to clean the air (Fig.33). Therefore, these rest spaces will serve as ‘sponge zones’ where the captured polluted air by the highway canyon can be absorbed, filtered and collected.

Fig. 38. Connections between both sides of the highway (Author work).
In order to reduce the disconnecting barrier effect of the A12 highway, connections between both sides of the highway have to be realized (Fig.38). When these connections are created, openings within the canyon building have to be made. These openings will weaken the canyon, thus leading to noise penetration into the areas behind the canyon buildings.

![Fig. 39. Second layer of canyon buildings to prevent noise penetration in the shadow zone (Author work).](image)

In order to reduce the penetration of noise into the shadow zone, a second layer of buildings can be placed at the openings (Fig.39). These second layer of buildings is more effective to be placed perpendicular to the canyon building. (Fig.14c) When the second layer of buildings at the openings are placed perpendicular to the canyon building, the reflection of noise due the facade surface will be reduced, since the smaller facade surface of the second building is faced to the noise source.

![Fig. 40. A tool to combine and connect separated existing and new buildings together (Author work)](image)

The A12-zone contains many existing buildings next to the highway. In order to combine all these separated existing buildings together with new buildings to form an uninterrupted continuous canyon, a tool have to be designed. As shown in figure 40, a tool is needed to combine and connect all of the separated buildings next to the highway, only then the early mentioned recommendation of highway canyon will work. However, there are some important points to be taken in account during the design of a tool like this. Next to the creation of an entity between the separated buildings, this tool has to also allow the buildings to create their own identities. Furthermore, within these tool materials, vegetation and systems should be integrated to absorb, filter and collect air pollution.

Following the recommendations above, different design variants can be created for the A12-zone. Down below a design variant is shown which is based on the recommendation given above. As mentioned before, a tool is needed in order to connect all separated buildings into an uninterrupted canyon. For the A12-zone this tool can be a smart wall structure. (Fig.41) This structure will be designed next to the highway, and the separated buildings will be integrated to it. Different integration between the structure and the buildings are possible, one can use the wall as a massive well insulated wall, double facade, atrium or as a garden (Fig.41). Besides the integration between the structure and the buildings, this wall can also help to reduce noise and air pollution. (Fig.16) Due to the orientation and materialisation, sound rays can be absorbed and reflected towards the sky. In addition, different kinds of plants, materials and systems can be integrated within this wall structure in order to reduce air pollution. In appendix 5&6 a list of
absorbing plants and materials are given that can be used. At last, the wall structure should not only create entity, but it should also allow the buildings to create their own identity. Instead of a monotonous continuous wall next to the highway, the buildings can each represent their own identity as a result of the free choice of facade design within the structure. Summarized: the conceding structure should unify all separated buildings together, allows the buildings to create own identity, reflect and absorb noise by different facade orientations and materials, absorb and collect air pollution by integration of materials and systems.

Fig. 41. The connecting wall structure. a. used as a solid wall. b. as a double facade. c. as a atrium and d. as outside space. (Author work)

Concerning the disconnecting barrier effect of the highway, a connection in a form of a building over the highway can be designed. As shown in figure 42, this connection can give space to public and private functions. Within the towers dwelling can be realised, whilst the bridge building is filled with restaurants, supercenters or offices. Next to the different kinds of function the building will also allow pedestrians, cyclists and small animal species to crossover the highway. Therefore the roof will be a green park with different kinds of vegetation.

Fig. 42. An overview of integrated healthy highway living environment, where the disconnecting barrier effect and the problems of noise and air pollution are reduced/solved (Author work).

The above shown design is one of the design variants. However, through the results from the studies and the recommendation other design variants can also be made. Additionally, simulation programs can be used in order to test the design decisions step by step.
The objective of this paper was to develop recommendations, based on both the case and literature studies, to solve the problems of highway environment. The goal was to integrate the highway into a healthy living environment, where the disconnecting barrier effect and the problems of noise and air pollution are solved/reduced. The main focus was to solve these issues by integrating architecture and technology. Based on the studies, the most effective way to solve the problems of noise and air pollution is to address these problems from different scales. Within the different scales as in the urban, building and component, solutions and recommendations can be explored and given. Following the studies above a conclusion can be reached that within these three scales different solutions are possible.

Next to the solutions of quieter cars, porous asphalt, tunnelling, covering and levelling. Highway noise can be reduced when buildings on an urban scale are used as a noise barrier, albeit requiring some attention. First, the length and the height of the building play a key role in the effectiveness of the noise blocking effect. Second, when openings/separations are made between the buildings, noise will penetrate into the shadow zone through different ways. The penetrating noise can come straight from the source, through reflection of building facades, along or/and over the buildings into the shadow zone. Different studies show that a second layer of building can be added at the openings in order to reduce the penetrating noise. Another solution is to reduce penetrating noise by absorption of reflection. Integrating absorbing and reflecting qualities within the buildings facades can be a very interesting solution on a building and component scale. Due to different orientations and materials, sound rays can be absorbed and/or reflected towards the sky. Next to the reduction of noise outside the building, inside the building also requires some attention in order to prevent sound nuisance. First, transmission of noise through the facades can be prevented by a well insulated and airtight facade construction. Second, a double layered facade principle can be used in order to create a buffer zone. At last, noise sensitive functions such as bedrooms can be placed at the other side of the building. In this way a different zoning within the building can be accomplished.

Regarding air pollution, the behaviour of wind in relation to different kinds of building heights can provide very effective urban scale solutions. Due to the use of street canyons, wind can be used to regulate the dispersion of pollutants. The studies show that when a street to building height ratio is 3 (W/H=3), a horizontal elongated vortex will be created. This vortex contains the most polluted air within the street canyon. In addition, a high concentration of contaminated air will also be collected at one place within the street canyon due to the vortex. This collected contaminated air can then be easily absorbed, filtered or collected. Therefore, the use of different vegetations and systems integrated within the building and component scale can be very effective. Since different kinds of plants and systems are useful to absorb, filter and collect the contaminated air, an integration of this solution can be made within the building facades and roofs.

At last, the disconnecting barrier effect of the highway can be reduced by the use of different kinds of connection. Figure 42 shows that when a building over the highway is created, it can serve as a connection for people and animals between both sides of the highway.


Appendix 1

Artikel 3.2. Geluid van buiten

Een uitwendige scheidingsconstructie van een verblijfsgebied heeft een volgens NEN 5077 bepaalde karakteristieke geluidswering met een minimum van 20 dB.

Artikel 3.3. Industrie-, weg- of spoorweglawaai

1. Bij een krachtens de Wet geluidhinder of de Trajectwet vastgesteld hogere-vaardensbesluit is de volgens NEN 5077 bepaalde karakteristieke geluidswering van een uitwendige scheidingsconstructie van een verblijfsgebied niet kleiner dan het verschil tussen de in dat besluit opgenomen hoogst toelaatbare geluidbelasting voor industrie-, weg- of spoorweglawaai en 35 dB(A) bij industriewaai, of 33 dB bij weg- of spoorweglawaai.

2. Bij een krachtens de Wet geluidhinder of de Trajectwet vastgesteld hogere-vaardensbesluit is de volgens NEN 5077 bepaalde karakteristieke geluidswering van een uitwendige scheidingsconstructie van een bedrijf gebied niet kleiner dan het verschil tussen de in dat besluit opgenomen hoogst toelaatbare geluidbelasting voor industrie-, weg- of spoorweglawaai en 30 dB(A) bij industriewaai, of 28 dB bij weg- of spoorweglawaai.

3. Op een inwendige scheidingsconstructie van een gebied als bedoeld in het eerste en tweede lid, die niet de scheidingsvorm met een verblijfsgebied van een aangrenzende gebouwfunction waarop het eerste en tweede lid van toepassing zijn, zijn deze laden van overeenkomstige toepassing.

4. Een scheidingsconstructie als bedoeld in het eerste tot en met derde lid van een verblijfsruimte heeft een volgens NEN 5077 bepaalde karakteristieke geluidswering van een enkelvoudige scheidingsconstructie van een aangrenzende gebouwfunction waarvan de verblijfsruimte ligt.

### Table 4.1: Guideline values for community noise in specific environments.

<table>
<thead>
<tr>
<th>Specific environment</th>
<th>Critical health effect(s)</th>
<th>L_Aeq [dB]</th>
<th>Time base [hours]</th>
<th>L_max, fast [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor living area</td>
<td>Serious annoyance, daytime and evening</td>
<td>55</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate annoyance, daytime and evening</td>
<td>50</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Dwelling, indoors</td>
<td>Speech intelligibility and moderate annoyance, daytime and evening</td>
<td>35</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Inside bedrooms</td>
<td>Sleep disturbance, night-time</td>
<td>30</td>
<td>8</td>
<td>45</td>
</tr>
<tr>
<td>Outside bedrooms</td>
<td>Sleep disturbance, window open (outdoor values)</td>
<td>45</td>
<td>8</td>
<td>60</td>
</tr>
<tr>
<td>School class rooms and pre-schools, indoors</td>
<td>Speech intelligibility, disturbance of information extraction, message communication</td>
<td>35</td>
<td>during class</td>
<td></td>
</tr>
<tr>
<td>Pre-school bedrooms, indoors</td>
<td>Sleep disturbance</td>
<td>30</td>
<td>during sleep-time</td>
<td>45</td>
</tr>
<tr>
<td>School, playground outdoor</td>
<td>Annoyance (external source)</td>
<td>55</td>
<td>during play</td>
<td></td>
</tr>
<tr>
<td>Hospital, ward rooms, indoors</td>
<td>Sleep disturbance, night-time</td>
<td>30</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Hospitals, treatment rooms, indoors</td>
<td>Interference with rest and recovery</td>
<td>#1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial, commercial shopping and traffic areas, indoors and outdoors</td>
<td>Hearing impairment</td>
<td>70</td>
<td>24</td>
<td>110</td>
</tr>
<tr>
<td>Ceremonies, festivals and entertainment events</td>
<td>Hearing impairment (patrons:&lt;5 times/year)</td>
<td>100</td>
<td>4</td>
<td>110</td>
</tr>
<tr>
<td>Public addresses, indoors and outdoors</td>
<td>Hearing impairment</td>
<td>#4</td>
<td>1</td>
<td>110</td>
</tr>
<tr>
<td>Music through headphones/ earphones</td>
<td>Hearing impairment (free-field value)</td>
<td>85 #4</td>
<td>1</td>
<td>110</td>
</tr>
<tr>
<td>Impulse sounds from toys, fireworks and firearms</td>
<td>Hearing impairment (adults)</td>
<td>-</td>
<td>-</td>
<td>140 #2</td>
</tr>
<tr>
<td></td>
<td>Hearing impairment (children)</td>
<td>-</td>
<td>-</td>
<td>120 #2</td>
</tr>
<tr>
<td>Outdoors in parkland and conservation areas</td>
<td>Disruption of tranquillity</td>
<td>#3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#1: as low as possible;  
#2: peak sound pressure (not L_max, fast), measured 100 mm from the ear;  
#3: existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low;  
#4: under headphones, adapted to free-field values
### Appendix 2

<table>
<thead>
<tr>
<th>Stof</th>
<th>Genoot op</th>
<th>Norm</th>
<th>Niveau</th>
<th>Status</th>
<th>Status (^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zwaardvlizoxide ((\text{SO}_2))</td>
<td>Mens</td>
<td>Daggemiddelde; overschrijding is toegestaan op niet meer dan drie dagen per jaar</td>
<td>125 (\mu\text{g/m}^3)</td>
<td>Grenswaarde (^2)</td>
<td></td>
</tr>
<tr>
<td>Mens</td>
<td>Uurgemiddelde; overschrijding is toegestaan op niet meer dan 24 uur per jaar</td>
<td>350 (\mu\text{g/m}^3)</td>
<td>Grenswaarde (^2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mens</td>
<td>Uurgemiddelde waargenomen gemiddelde drie opeenvolgende uren in een gebied van minimaal 100 (\text{km}^2)</td>
<td>500 (\mu\text{g/m}^3)</td>
<td>Alarmsdrempel (^3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natuur</td>
<td>Jaargemiddelde en wintergemiddelde (van 1 oktober tot en met 31 maart)</td>
<td>20 (\mu\text{g/m}^3)</td>
<td>Grenswaarde (^3)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Stikstofdioxide \((\text{NO}_2)\) | Mens | Jaargemiddelde | 40/80 \(\mu\text{g/m}^3\) | Grenswaarde \(^4\) |
| Mens | Uurgemiddelde; overschrijding is toegestaan op niet meer dan 18 uur per jaar | 200 \(\mu\text{g/m}^3\) | Grenswaarde \(^3\) |
| Mens | Uurgemiddelde waargenomen gemiddelde drie opeenvolgende uren in een gebied van minimaal 100 \(\text{km}^2\) | 400 \(\mu\text{g/m}^3\) | Alarmsdrempel \(^3\) |

| Stikstofzuidden \((\text{NO}_x)\) | Mens | Jaargemiddelde | 30 \(\mu\text{g/m}^3\) | Grenswaarde \(^7\) |

| Fijs stof \((\text{PM}_{10})\) | Mens | Jaargemiddelde | 40 \(\mu\text{g/m}^3\) | Grenswaarde |
| Mens | Daggemiddelde; overschrijding is toegestaan op niet meer dan 35 dagen per jaar | 80 \(\mu\text{g/m}^3\) | Grenswaarde |

| Eerste fractie van fijn stof \((\text{PM}_{2.5})\) | Mens | Jaargemiddelde | 25 \(\mu\text{g/m}^3\) | Grenswaarde \((2015)\) |
| Mens | Jaargemiddelde; gemiddelde op basis van metingen op stedelijke achtergrondlocaties, de zogeheten boosstellingconcentratie | 20 \(\mu\text{g/m}^3\) | Grenswaarde \((2015)\) |
| Mens | Jaargemiddelde, gemiddelde op basis van metingen op stedelijke achtergrondlocaties, de zogeheten boosstellingconcentratie over de jaren 2009 tot en met 2011 respectievelijk over de jaren 2018 tot en met 2020 | 0-20% (15% vermindering voor Nederland \(^6\)) | Struifwaarde \((2020\text{, ten opzichte van 2010})\) |
| Mens | Jaargemiddelde | 20 \(\mu\text{g/m}^3\) | Grenswaarde, indicatief \((2020)\) |

| Benzpaas \((\text{C}_6\text{H}_6)\) | Mens | Jaargemiddelde | 5 \(\mu\text{g/m}^3\) | Grenswaarde |

| Koolmonoxide \((\text{CO})\)* | Mens | Hoogste voortschrijdend 8-ur Gemiddelde | 10.000 \(\mu\text{g/m}^3\) | Grenswaarde |

| Ozon \((\text{O}_3)\)* | Mens | Hoogste voortschrijdend 8-urGemiddelde per dag; overschrijding is toegestaan op niet meer dan 25 dagen per jaar; gemiddeld over drie jaar | 120 \(\mu\text{g/m}^3\) | Struifwaarde \((2010)\) |
| Mens | Uurgemiddelde | 180 \(\mu\text{g/m}^3\) | Informatiedrempel |
| Mens | Uurgemiddelde | 240 \(\mu\text{g/m}^3\) | Alarmsdrempel |
| Mens | Hoogste voortschrijdend 8-urGemiddelde per dag; overschrijding is niet toegestaan; per kalenderjaar | 120 \(\mu\text{g/m}^3\) | Langtermijnindustelling \((\text{geen jaar gegeven})\) |
| Natuur | AOT40, gemiddeld over vijf jaar | 18.000 \(\mu\text{g/m}^3\) | Struifwaarde |
| Natuur | AOT40, gemiddeld over mei tot en met juli | 6.000 \(\mu\text{g/m}^3\) | Langtermijnindustelling \((\text{geen jaar gegeven})\) |

1) Tussen haakjes het jaar waarin uiterlijk aan de normstelling moet worden voldaan. Indien geen jaartal is vermeld, moet al aan de normstelling zijn voldaan.
2) Overschrijding van deze grenswaarde is in Nederland al lange tijd niet meer aan de orde. Zie voor meer informatie onder andere het Jaarverslag Luchtwaallit 2013 (Mooibroek et al., 2013). Zie ook Zwaardvlizoxideconcentratie, 1995-2010 (tijdelijk onder de kop ‘Normstelling’).
3) Overschrijding van deze grenswaarde is in Nederland al lange tijd niet meer aan de orde. Zie voor meer informatie ook het Jaarverslag Luchtwaallit 2010 (Mooibroek et al., 2011).
4) Nederland heeft uitstel gekregen tot 1 januari 2015; alleen voor de agglomeratie Heerlen-Kerkrade geldt het uitstel tot 1 januari 2013. Tot genoemde datum geldt in de betreffende gebieden een verhoogde grenswaarde van 60 \(\mu\text{g/m}^3\) voor de jaarlijkse gemiddelde concentratie van zwaardvlizoxide.
5) Overschrijding van deze grenswaarde is in Nederland al lang niet meer aan de orde. Zie voor meer informatie ook het Jaarverslag Luchtwaallit 2010 (Mooibroek et al., 2011). Zie ook Stikstofdioxideconcentratie, 1990-2010 (tijdelijk onder de kop ‘Concentraties’).
6) Overschrijding van deze grenswaarde is in Nederland al lange tijd niet meer aan de orde. Zie voor meer informatie onder andere het Jaarverslag Luchtwaallit 2010 (Mooibroek et al., 2011).
7) Deze grenswaarde is van toepassing op gebieden met een oppervlak van ten minste 1000 \(\text{km}^2\) die op een afstand van minimaal 5 \(\text{km}\) van bebouwing, inrichtingen of autowegen zijn gelegen. De Europese luchtwaallitstelling stelt een aantal eisen aan de omvang van natuurgebieden en aan de locatie van monometeringspunten van stikstofzuidden. Nederland heeft de richtlijn in dit opzicht strikt geënteerd met als uitslag dat er in Nederland vrijwel geen natuurgebieden respectievelijk meteorologische stations zijn waardoor de eisen aan de richtlijn voldoen. Natuurgebieden in Nederland waarop de Europese norm voor stikstofzuidden wel van toepassing is, liggen in het uiterste noorden van het land.
8) Zie ook ‘Toelichting norm PM\(_{10}\) hieronder.’
9) Zie ook ‘Toelichting normen ozon’ hieronder.
10) Vaak gesteld op basis van de gemiddelde blootstellingsindex van de jaren 2009 tot en met 2011. Zie ook ‘Toelichting norm PM\(_{10}\) hieronder.’
Appendix 3

11.3. Doornsden

D-1. Het relatieve geluidniveau langs een weg indien geen geluidwerende maatregelen worden getroffen. De geluidreductie is van toepassing boven een ‘grasbodem’. Bij drukke wegen moet een vrij grote afstand worden aangehouden, als men zonder afscherming een laag geluidniveau wil bereiken.


D-3. Hoe hoger het gebouw, des te langer de geluidniveaus in de ‘ge- luidschaduw’.

D-4. Indien op het gebouw uit figuur D-2 een schuin dak met brede tophoek wordt geplaatst, neemt de hoogte van het gebouw toe, waardoor een grotere afscherming kan worden verwacht. Door de vorm van het dak wordt de afschermende werking echter wat minder. Het blijkt dat het totale effect gering is; de geluidniveaus aan de achterzijde zijn vrijwel dezelfde als in figuur D-2.

D-5. Het toevoegen van een tweede oneindig lang gebouw aan de situatie van figuur D-2 geeft een verhoging van het geluidniveau met 1 tot 3 dB(A) in het tussengebied. Verondersteld is dat het tweede gebouw niet hoger is dan het eerste; als dit wel het geval is, is de verhoging van het geluidniveau groter.

Noise reduction effect of different building height when the building next to the road is used as noise barrier. (KRANENDONK & NIJS, 1979, pp. 28-29)
D-6. Als aan het hoge gebouw uit figuur D-3 een tweede even hoog gebouw wordt toegevoegd is de verhoging van het geluidsniveau in het tussengebied 3 à 4 dB(A). De geluidniveaus blijven echter lager dan in figuur D-5.

D-7. Indien ten opzichte van figuur D-6 alle afstanden worden verdubbeld, zullen de geluidniveaus met 2 tot 4 dB(A) dalen.

D-8. Een verdubbeling van de afstand tot de weg ten opzichte van de figures D-5 en D-6 heeft in het schaduwgebied geen effect. De afschermende werking van het eerste gebouw wordt minder; dit verlies wordt gecompenseerd door de grotere afstand.

D-9. Als een achterliggend gebouw hoger is dan het gebouw aan de weg, zal op de bevonante verdieping van het tweede gebouw een beduidend hoger geluidniveau heersen dan op de onderste verdieping.

D-10. Het vergroten van de afstand tot de weg en het verdubbelen van de onderlinge afstand der gebouwen geeft, vergeleken met figuur D-9, nauwelijks verbetering voor de hogere verdiepingen.


Noise reduction effect of different building height when the building next to the road is used as noise barrier. (KRANENDONK & NIJS, 1979, pp. 29-30)
11.4 Plattegronden

P.1. Lijnen van gelijk relatief geluidsniveau langs een weg (relatief geluidsniveau) toepassen. Dit noemen we de "omtrek" van de gebouwen.

P.2. Het plaatsen van een tweede gebouw evenwijdig aan de eerste heeft bijzondere voordelen. Dit neemt de geluidsenergie van de gebouwen weg. Bij de gevels met een geluidsniveau van 5 dB(A) hoger dan de vijf veldsituatie. Aan de afgeschermd zijde ontstaat een "geestesbeeld". De begrenzing van het schaduwgebied is afhankelijk van de lange en hoogte van het gebouw.

P.3. Indien in een overblik van de openingen evenwijdig aan de weg een gebouw wordt geplaatst veranderen de geluidsniveaus, die door het verkeer worden veroorzaakt in sterke mate. Bij de gevels van de lauwelaste gebied wordt een reductie van geluidsniveaus van 2 à 3 dB(A) hoger dan de vijf veldsituatie. Bij een zeer lang gebouw wordt het geluidsniveau in het schaduwgebied uitsluitend bepaald door het geluid dat over het gebouw komt.


P.5. Door omzetten van de gebouwen wordt de geluidssituatie aan de afgeschermd zijde verbeterd. Bij de gevels met een geluidsniveau van 5 dB(A) hoger dan de vijf veldsituatie. Bij een zeer lang gebouw wordt het geluidsniveau in het schaduwgebied uitsluitend bepaald door het geluid dat over het gebouw komt.

P.6. Bij vlakke gevels is het geluidsniveau in de zijstraat even hoog als in de vijf veldsituatie. Bij een lang gebouw wordt een reductie van geluidsniveaus van 2 à 3 dB(A) hoger dan de vijf veldsituatie.

P.7. Door verbreden van de openingen wordt het lauwelaste gebied groter. Verdubling van de breedte van de openingen geeft een toename van het geluidsniveau met 3 dB(A). Indien beslist openingen nodig zijn is het aan te bevelen deze zo klein mogelijk te kiezen.

P.8. Indien de opening ten opzichte van de weg geplaatst is aan beide zijden, worden lauwelaste gebieden ontstaan. Bij de gevels van het gebouw dat dwarst wordt geplaatst zijn aan beide zijden lauwelaste gebieden ontstaan.

P.9. Door het vlak van de openingen dus op de weg wordt gesterbeept hebben de gebouwen een sjieke en een ruimtege- zijde. Aan de achterzijde van het gebouw langs de weg wordt dicht bij de opening de geluidssituatie verbeterd doordat reflexie van geluid tegen de koppervel.

P.10. Door toewijzen van de openingen aan de situatie van figuur P.3 wordt het geluidsniveau in het schaduwgebied hoger. De toename van de geluidsniveaus wordt veroorzaakt door geluidreflexies tegen het erbij komende gebouw.

Different building mass study in order to prevent noise penetration into the shadow zone (Kranendonk & Nijs, 1979, pp. 31-34).
Different building mass study in order to prevent noise penetration into the shadow zone (Kranendonk & Nijs, 1979, pp. 34-37)
P-20. Het plaatsen van een geluidabsorberend gebouw voor een opening in een randbebouwing beperkt de grootte van het lawaaigebied achter de opening (vergelijk fig. P-4). Bij het afzonderen van openingen kunnen de reflecties van het afzonderende obstakel worden beperkt door een absorberende uitvoering, of een schuine stand van het reflecterende vlak.

P-21. Ook met Z-vormige verlagingen is een ruimere ruimte en een stilte zijde te realiseren.

P-22. De geluidniveaus tussen de gebouwen kunnen worden beperkt door de openingen aan de wegzijde kleiner te maken. Door situering van de tweede rij gebouwen, evenwijdig aan de weg op grotere afstand dan in het voorbeeld, is een verdere verligging van de geluidniveaus tussen de gebouwen te bereiken.

Different building mass study in order to prevent noise penetration into the shadow zone (KRANENDONK & NIJS, 1979, pp. 37-38)
Appendix 4

MDF board Absorption coefficient of the different perforations (ROLAFF, 2010, p. 53).

MDF board perforation whole and dimensions (ROLAFF, 2010, p. 52).

Appendix 5

Section of sound absorbing perforated aluminum noise barrier wall (ENGLISH & KOTZEN, 2009, p. 138)
Different kinds of noise barrier wall section with absorbing qualities (ENGLISH & KOTZEN, 2009, p. 137)
Appendix 6

TABLE 8  Estimation of effectiveness of the most important species for reduction of concentrations of particulates, nitrogen oxides and ozone in the air.

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>PARTICULATES PM10</th>
<th>NITROGEN NO+NO₂</th>
<th>OZONE O₃</th>
<th>EMISSIONS OF VOLATILE ORGANIC COMPOUNDS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SHRUBS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amelanchier lamarckii</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Berberis xfricarri</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Chaenomeles</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Corylus colurna</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Euonymus (deciduous)</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Euonymus (evergreen)</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Hedera</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Ilex xmaserveae</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Lonicera (deciduous)</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Lonicera (evergreen)</td>
<td>■</td>
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<td>■</td>
<td>■</td>
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<tr>
<td>Mahonia</td>
<td>■</td>
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<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Potentilla fruticosa</td>
<td>■</td>
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<td>■</td>
<td>■</td>
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<tr>
<td>Rosa</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Spiraea</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
</tbody>
</table>

| **CLIMBING PLANTS** |                   |                 |         |                                        |
| Clematis | ■ | ■ | ■ | ■ |
| Fallopia | ■ | ■ | ■ | ■ |
| Hedera | ■ | ■ | ■ | ■ |
| Lonicera | ■ | ■ | ■ | ■ |
| Pyracantha | ■ | ■ | ■ | ■ |
| Rosa | ■ | ■ | ■ | ■ |
| Wisteria | ■ | ■ | ■ | ■ |

COLUMN SPECIES  
* Stated properties also apply to cultivars of the stated species.

COLUMN PARTICULATES (CAPTURE), NITROGEN OXIDES (ABSORPTION) AND OZONE (ABSORPTION)  
■ : Least effective  
■■■ : Most effective

COLUMN OZONE  
+ Species which are effective for ozone concentration reduction in urban areas (based on English research)

COLUMN EMISSIONS OF VOLATILE ORGANIC COMPOUNDS  
■ : Very limited emissions  
■■■ : Considerable emissions

SOURCE  
1. Takahashi et al, 2005  
2. Donovan et al, 2005  
3. Stewart and Hewitt, 2002  
4. Nowak et al, 2002

Different kinds of vegetations with absorbing qualities (HIEMSTRA, SCHOENMAKER-VAN DER BIJL, & TONNEIJCK, 2008, p. 28)
Appendix 7

1. Electrons in the TiO₂ become energized by UV light.
2. These electrons transfer energy to oxygen and water in the air.
3. Free radicals are formed by the transferred energy (C₂⁺, *OH⁻).
4. The free radicals attack and destroy organic matter via oxidation.
5. *OH free radicals called hydroxyls group on the surface of EcoClean.
6. The hydroxyls make the building surface super slick. Instead of beading up on the surface, the water collapses on the surface and runs off, undercutting dirt and grime.

The process of ecoclean panels (ACOA)

Appendix 8

Sporenboog (Funenpark) in Amsterdam (CIE, 2013).
Sporenboog (Funenpark) in Amsterdam (CIE, 2013).

De tribune in Amsterdam (STARINK, 2011).

Boschkens in Goirle-Tilbrug, Netherlands (BURO-LUBBERS, 2013).
In collaboration with fellow student Bao Ngoc Le during this study, some other case projects were chosen. These projects can be divided among the solution typologies discussed in this research paper. The matrix on the next page gives an overview of what these projects are and what they proposed.