ABSTRACT

Recent researches indicate that in the Netherlands a trend is to be noticed in people moving to cities, which are denser areas, due to the fact that these provide easy access to facilities and mobility. Areas along highways provide the necessary space for expansion, but as these areas are highly polluted by noise and air pollution, a careful planning and designing of the architecture in those areas is needed. In general, the most obvious way of dealing with buildings along highways and railways is by means of sound barriers. Lately there are diverging developments of a transition to an integrated architecture which provides a different angle to deal with the issues along highly polluted areas. These development not only provide solutions for the pollution, but at the same time contribute to the social, spacial and architectural values of the to be developed areas. This paper is an investigative research on two main topics in relation to architecture, noise pollution and air pollution and shows that the noise and air pollution can be reduced at different scale levels, namely from urban scale up to a detailed scale. This paper provides the necessary technical information to firstly understand the workings of noise and air pollution and secondly provides an angle for an architectural design.

Key words: noise pollution, air pollution, highway, urban canyon, noise reflection, absorption, air filtering.
Utrecht is an attractive city, especially by its central location in the Netherlands. It is one of the fastest growing cities in the Netherlands and will grow further in the coming decades. The lack of space will rise with time. The space around the A12 highway has it potentials by the accessibility and the surrounding landscape and can be used to solve the lack of space in Utrecht. The A12, the main traffic axis of the Netherlands, crosses an urban area with various functions such as residential areas, areas with offices, furniture malls and green zones for recreation. Till now, the city and highway were developed unrelated to each other. This causes that the highway is the back of the districts, and can be seen as a barrier. By solving the issues around these problem areas a big amount of high value areas will become available for building in the Netherlands.

More and more people want to live along the highways because of the good accessibility. Decisions about infrastructure will always have an impact on the spatial possibilities of a large area. Connections can create opportunities but can also form a barrier which constrain developments. The A12-zone will be developed to a multifunctional dynamic working- and living area which also makes place for recreation. To create an attractive living environment along the A12 highway it is necessary to solve the problems around the highway. For now traffic dominates the area. There is a lot of noise and air pollution. The highway also creates a visual and physical barrier. The challenge is to solve the environmental issues by integrating architecture and building technology to create a lively area with many functions in a healthy environment.

Areas along highways and railways are more and more desired in the future due to the fact that these locations are near to transportation facilities and city centres. As the population will grow further in the coming decades, there is a need for more space and areas along highways provide the necessary means to solve the issue of lack of space. By this paper research is conducted to pose solutions for the high- and railways’ negative influences on the health of people. Living along these areas cause many health problems because of noise and air pollution. By this research and design the possibilities of making these polluted areas liveable are investigated. The design is according to a specific site, so the design is a specific solution. But at the same time, the research is posed as an example for sites along other highways or railways, so the results are generic. The conclusion is not focussed on the A12 highway, because this is not necessary to understand this paper.

The overall design question for my research is ‘how to design an urban living environment with dwellings and offices along the A12 highway which copes with noise and air pollution and a good accessibility to the A12?’ and the thematic research question is ‘how to create a healthy living environment in a high polluted area which has to deal with extreme noise and air pollution?’. To pose a satisfactory answer to the thematic research question, a set of subquestions are seriated as follows: ‘what are the permitted norms for dwellings regarding noise and air pollution?’, ‘why it is important to reduce the noise and air pollution?’ and ‘how to reduce noise and air pollution caused by the highway?’. By answering these subquestions consecutively the main question is to be answered.

Essentially this paper is a collection of all conducted research to understand in a technical perspective how noise and air pollution function and how these affect surroundings. The conducted research also provides the necessary means to develop a set of tools for designing in the described areas. The paper starts off by putting the research into perspective by describing the implemented methodologies. This provides the necessary background to understand the way of working on the research. The core of the research consists of two parts: noise pollution and air pollution. Noise and air pollution are to be seen as the two biggest problems when building along highways and railways. Eventually, the findings of the research are related to the assignment and a conclusion is presented.
For this research there is made use of three different types of research methodologies namely case studies, literature study and research by design. Doing research by analysing case studies is essential and helpful to know what existing solutions there are for reducing noise. Among others, the Cyclops by Nio, the Boschvens by Buro Lubbers and the Droogbak by Rudy Uytenhaak, are examples of analysed reference projects. The reference projects are all in the Netherlands and along a highway or railway and hereby exposed to high values of noise pollution. The reference projects are analysed based on the program and facades.

The second research methodology which is used is literature study. There is made use of different kinds of literature, such as government reports, books, articles, PhD thesis and other academic writing recourses for the research. Searching for solutions for reducing noise and air pollution are the main goal for the research and thereby the collected information will finally lead to the best solutions regarding noise and air pollution.

The last type of methodology which is used is research by design. In this part the information collected by means of literature sturdy is implemented along the A12 highway and developed further. The placement of the building blocks is researched by designing with 3D programs and maquette models. As mentioned in the introduction, the A12 highway can be seen as a visual and physical barrier. Research by design is also a very helpful tool to find a solution whereby the A12 highway is not a barrier anymore. This type of methodology is the designing part of the project.
The importance of noise pollution is pointed out by many researches which implicate that noise could have a negative effect on health. Being exposed to high levels of sound or exposure to frequent irritating noises effect health negatively on a psychological and physical way. Noise can be described as unwanted sound and is to be divided into two categories: frequent and occasional noise. In comparison to frequent noise, occasional loads bother people more, but what really gets to people is still frequent noise. A noise average of about 50 dB at daytime is enough for people to get moderately annoyed and at night people start to get annoyed at 30 dB (Stewart, 2011, p. 15). But noise is not just an annoyance, it is also damaging health. Annoyance leads to feelings of anger, agitation and helplessness. When sleep is disturbed by noise, work efficiency and health might suffer and it has a negative impact on the performance levels the next day. Many people suffer from gradual loss of hearing and most of the time it is because of the exposure to loud sounds over time. Noise responds with a stress reaction, which means that it indirectly affects other parts of our body too. Stress gives rise to bodily responses such as increases in blood pressure, increased heart rate, contraction of muscles and so on (Stewart, 2011, pp. 47-55). The World Health Organisation (WHO) defined health broadly as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” (World Health Organization, 2014). For a healthy living environment along a highway it is necessary to reduce the noise pollution.

There are different sources of noise pollution. Traffic can be seen as one of the major sources of noise pollution. The noise pollution along the highway A12 may be up to 80 dB. In comparison to the norms regarding noise pollution the actual situation shows dramatically high values. The permitted norms for noise pollution in the Netherlands is 35 dB for dwellings, and even 30 dB in bedrooms (Bouwbesluit, 2012). A difference of about 45 dB has to be bridged. There are many ways to reduce the noise. The solutions can be divided in three categories, namely emission, transmission and immission (De Ruiter, 2004, p. 17), which are respectively related to sound at the source, transmission and receiver.

Firstly, noise can be reduced by reducing noise by emission. By emission the noise will be reduced at the source, in this case, the vehicle on the highway. The noise of a vehicle is created by rolling noise and propulsion noise. Rolling noise arises when the tyres interact with the road. Using quieter, innovative tyres will help to reduce the noise up to 3 dB. Using quieter asphalt can cut noise to 7 dB (KOAC-WMD, 2002). Quieter asphalt can be reached by improving the texture of the asphalt. This is related to the types, the binder and the porosity of the materials. The more porous the asphalt, the better it reduces the noise. It would also maximise the benefits of any quieter tyres. An other cause of noise from the vehicle is propulsion noise. This is produced by the engine, the power transmission, the exhaust system and the auxiliary equipment. The technical and operational measures could cut the noise significantly, but they may not be cost-effective, because of the growing car industry. Industrialising countries are spending much money to reduce noise, and this will continue. These vehicles can be replaced by all-electric or hybrid-electric vehicles. This will help to reduce the noise which is created by propulsion.

Secondly, noise can be reduced at the transmission path as shown in figure 1. Without any obstruction the noise pollution can reach a long distance. Obstructing by trees, will reduce the noise pollution by 10 to 20 dB at 25 meters away from the highway. Small earth mounds of about 1,5 meters provide by 15 to 20 meters less transmission space. It is also possible to reduce noise by positioning the highway lower than the ground level. In this case the reduction will start at 15 meters instead of 25 meters. Another variant is to make the highway ‘disappear’. By tunnelling the highway there will be no traffic noise. The ground level will continuously go over the highway (Kranendonk & Nijs, 1976, pp. 31-32). By this, the space above the highway can be used for other
activities. It seems that this will be the best solution regarding noise pollution, but on the other hand this solution proves to be expensive. Another issue in regard to the solution of tunnelling the highway is that even though this solution provides the necessary in regard to residents, the experience of car users passing throughout the tunnel is deteriorated by this option. The residents would not have annoyance from the highway, but at the same time the drivers experience is totally neglected in this situation. The solution has to be in such a way that both the residents as well as the drivers will benefit from the situation.

By means of a sound barrier sound can be blocked at the transmission path. A sound barrier will block most of the noise. In figure 2 how a noise barrier works is shown. When there is no sound barrier, the noise will reach the dwellings as shown in figure 2a. The sound barrier does not necessarily have to be a straight, not-ending screen. Figure 2b and 2c show little differences regarding the screen, but in both cases the same amount of area will be protected from noise. The length of the barrier can be reduced by angling the ends of the barrier to the outsides. When the sound barriers are interrupted, there has to be an overlapping barrier. The overlap can differ in length, but in that case the distance between the barriers on the front and the barriers behind differs too. The placement of the barriers should be as close to the highway as possible. If there is any slope, the barrier should be placed at the top of the cutting slope, as shown in 2d. The sound barrier should be equal or higher then the buildings in the area behind. In case of the building is far away from the barrier, it is not necessary to have the barrier as high as the building. Reflection is a main problem regarding noise pollution. The reflection can be maintained by angling the barriers, as shown in figure 2e. When the sound barriers are angled, the reflection of the sound is upwards. Otherwise, the reflected sound will reflect back to the dwellings. Another problem is the reflection of noise between the vehicle and the barrier. Facing a barrier with a sound absorptive material greatly reduces the strength of the reflected rays. Otherwise, there will be multiple reflections between the barrier and the high sided vehicle which is also shown in figure 2f.

Fig. 1: Reducing noise at the transmission path by: (a) trees, (b) earth mounds, (c) different levels and (d) tunneling (Kranendonk & Nijs, 1967, pp. 31-32).

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reducing noise by immersion. Buildings can be designed in such a way that they function like a sound barrier. The building will be the receiver of the noise. Reducing noise at the receiver can be done at different scales or levels, namely on urban, building and dwelling scales. On urban level the ordination of the building, the height of the building, and the distance of the building to the road have an impact on the penetration of noise to the areas behind. On building level the facades are important because of the reflection and absorption properties. On dwelling level the zoning of the interior program may have an impact on the acceptable noise levels.

Because of the extension of the sound barrier is proving to be an effective measure against noise pollution, the sound barrier can be used more effectively in relation to a building as the main difference between a sound barrier and a building which functions as a sound barrier is that a building can not be elongated as the highway proceeds. Even though the sound barrier is a more easy way to deal with noise pollution, the building can be designed in such a way that this is evenly effective as the sound barrier itself. Because of the fact that the building can serve as well as the sound barrier, this makes the sound barrier not necessary any more. A building which serves as a sound barrier is described as a canyon building. A canyon building acts as a sound barrier and protects the areas behind from noise pollution. As there are limitations for sound barriers’ protection, there are also limits on the effects of a canyon building as this can not protect every area behind the building. The area behind the canyon building is called the ‘shadow zone’ and the noise will reach the shadow zone in different ways namely, straight from the source to the shadow zone, by reflection from other buildings, by deflection over the building or by deflection along the building. By optimal positioning of the building masses, it is possible to reduce the area where the noise will penetrate. Positioning the building perpendicular to the highway does not have any influence on the noise levels, while when the building is positioned parallel to the highway the noise levels will be lowered with 15 to 20 dB as shown in figure 3a. When there is an opening between the buildings, as shown in figure 3b, the noise will penetrate to the shadow zone. By doubling the width of the opening, the noise level will be raised up with 3 dB. By folding the top edges of the building from the highway, as shown in figure 3c, the shadow zone will be better protected from noise pollution. The effectiveness of the folds depend on the length of the folded edges. The longer the folded edges, the deeper the noise will penetrate into the area, but this can be decreased by using absorbing facade materials whereby there is less reflection between the buildings. By placing another layer of buildings perpendicular to the canyon buildings, as shown in figure 3d, the noise would not penetrate that deep into the area, but will be diffused at the beginning of the opening and thus will get into the shadow zone. By placing another building on the front of the opening as shown in figure 3e, the noise will be blocked better. However, the building on the front is exposed to high levels of noise on all sides.

Fig. 3: Positioning of the building masses: (a) parallel to the highway, (b) with an opening, (c) opening with folded
edges, (d) second layer of building perpendicular to the canyon building and (e) another building on the front of the opening (Kranendonk & Nijs, 1979, pp. 31-37).

The situation in figure 3c seems to be the best solution. This way of positioning makes it easier to control the noise. There are many more approaches to decrease the influence of the noise penetrating in the shadow zone by positioning the building masses. These are shown in Appendix 1.

The height of the building may also affect the noise level. The shadow zone will be protected better from noise when the building is higher. This is shown in figure 4a and figure 4b. The higher the building, the lower the noise level. When the building is that high as shown in 4b, deflection over and along the building can be neglected. By placing a second building, parallel to the canyon building as shown in figure 4c, the noise level will be raised due to the reflection of the buildings. When the distance to the road and the distance between the two buildings will be bigger, as shown in figure 4d, the noise level will be lowered. More approaches are shown in Appendix 11.

As a matter of fact a canyon building functions at the same way as a sound barrier does. Angling the sound barrier ensures the reflection towards the sky. Angling the facade of the building create the same effect. It is also important that the canyon building can absorb the noise. When the facade is very flat, the noise will reflect too much and this will aggravate the noise pollution.

In essence, handling sound can be done by three main principles. Firstly, by means of shaping objects in specific ways the direction of sound can be engineered, which can be seen as the working of a corrugated panel as a sound diffuser. Secondly, at a molecular scale the structure of the material can be engineered specifically to make it porous or not, to enhance absorption or reflection properties. Last but not least, by managing the hardness or softness of a material sound can be either absorbed or reflected. Choosing the right material for the facade is essential. There are many absorptive materials. Absorptive facade materials contain porous elements that absorb noise. Robust materials can form directly the surface of the facade. Absorptive materials which are less robust such as mineral wool has to be protected and enclosed with a skin. Than the skin facing to the noise has to be perforated. These skins are mainly made of timber, steel or aluminium sheeting and brick (English & Kotzen, 2009, p. 135).

While doing the case study it is noticed that in some reference projects a double facade is used. The case study which is done for the research is shown in Appendix 111. The reference projects made it clear that it is also possible to protect the dwellings from noise by using a double facade. The double facade creates the possibility to have a buffer zone between the highway and the dwellings. There are different principles of a double facade. Each one is based on design principles such as the airflow within the cavity, the configuration of the facade and also the form in which the intermediate space is divided. The four main principles are the box facade, the corridor facade, the shaft-box facade and the multi-storey facade. These are shown in figure 5.

![Fig. 4: Height of the buildings: (a) height of 5 meters, (b) height of 12 meters, (c) two buildings with height of 12 meters and (d) two buildings with a bigger distance to the road and between each other with height of 12 meters (Kranendonk & Nijs, 1979, pp. 28-29).](image-url)
Double facade principles: (a) box facade, (b) the corridor facade, (c) the shaft-box facade and (d) multi-storey facade (own ill.).

The box facade which is shown in figure 5a, is a modular single-storey unit and is divided into structural bay widths. This causes a lot of privacy for the residents and is very suitable to use as loggias. The natural ventilation of the box facade has to be done by the outer facade layer. The noise on this side make this impossible, which is a big disadvantage. The box facade can only be ventilated by a mechanical system. The corridor facade which is shown in figure 5b, is a single-storey facade and has no vertical partition walls, except those who create a connection between the different stories. This type is suitable for circulation. The disadvantage from this type is that it has to have openings on the side of the highway for natural ventilation, like the box facade. An option is to ventilate via the staircase, but in that case, the entrance of the staircase has to be on the side where there is no noise, whereby the noise would not penetrate into the cavity. But it is still doubtful whether it will be enough. The shaft-box facade which is shown in figure 5c, is only divided vertically. The lack of any horizontal dividers makes it possible to ventilate the cavity naturally. Air from the backside of the building where there is no noise can be brought in and taken out from the cavity throughout the chimney effect. The multi-storey facade which is shown in figure 5d, has not any dividers, neither horizontal nor vertical. The cavity of the multi-storey facade can be ventilated in the same way as the shaft-box facade. A disadvantage of the shaft-box facade and the multi-storey facade is that they do not offer any possibilities to use the cavity for any other function (Regazzoli, 2014). The corridor facade can be the best solution when it is combined with the multi-storey facade. In this case the cavity can be used for example circulation or even balconies and other functions and can be ventilated naturally without any openings in the facade facing the highway.

Another fact that comes forward from the analysis of the case studies is that the floor plans of a dwelling are designed according to the noise sensitivity. The functions which are more sensitive such as bedrooms, need more protection against noise. Hence, it is obvious to place the more sensitive and the long-stay functions at the backside of the building. The short-stay functions such as storage, can be placed at the side which is facing the highway.
The second main problem along highways is the air pollution which is produced by the vehicles. The vehicle emissions degrades air quality which threatens health. Vehicles contribute to air pollution in two ways, namely combustion and evaporation, whereby combustion is the major source of air pollution. Combustion is the burning of fuel, whereby the fuel and the surrounding air undergo oxidation. The oxidation products which arise by burning of the fuel are carbon monoxide, carbon dioxide, oxides of sulfur, oxides of nitrogen and particulate matter. The particulate matter is characterised in size. The smallest particles are the most hazardous particles, like those under 10 microns in diameter, PM	extsubscript{10} and those under 2,5 microns in diameter, PM	extsubscript{2,5}. Actually, the particles with a diameter under 0,1 microns in diameter; the ultra fine particles, are the most dangerous, because these can penetrate deep into the lungs. Motor vehicle emissions are the main source of these small particles (Stewart, 2011, pp. 68-69). Long-term exposure to air pollution can threaten health by, among others, increasing mortality, threatening respiratory health, damaging cardiovascular function and increasing cancer risk (Stewart, 2011, p.80).

To live in a healthy environment along highways, the residents have to be protected from air pollution. The norms regarding air pollution differ for the different kind of pollutants. According to the norms, the limit for CO is 1000 µg/m\textsuperscript{3} based on the highest progressive 8-hours average. For SO\textsubscript{2} the limit is 125 µg/m\textsuperscript{3} on a daily average with the limitation of 3 days per year. For NO\textsubscript{2} the limit is 40/60 µg/m\textsuperscript{3} based on a year average. The limit for PM\textsubscript{10} is 50 µg/m\textsuperscript{3} based on a daily average and should not exceed 35 days per year (Compendium, 2013).

Reducing air pollution caused by traffic can be achieved in different ways. Firstly, the wind behaviour regarding air pollution will be described in different situations. Secondly, the impact of vegetation will be described. Lastly, methods to reduce air pollution by the building design itself will be described.

Structures such as noise barriers impact pollutant transport and dispersion. The dispersion will lead to increased vertical mixing due to the upward deflection of air flow caused by the structure. Buildings and other roadside solid structures may have similar effects as noise barriers (Bailey et al., 2009). The effect of structures next to the highway is studied by the wind-tunnel experiment. The wind-tunnel experiment is a study which refer to a simulation of toxic emissions from vehicle exhausts in a street canyon within an urban environment. As shown in figure 6 the building height (H) is equal to the width (B), where B=H=60 mm. The sources (motor vehicles) are placed between the two buildings, in the middle of the street where the width (W) is either 60 mm. The building on the left is called the ‘upwind building’ an the building on the right is called the ‘downwind building’. The micro scale model ‘MIMO’ designed to take into account pollution dispersion in the vicinity of buildings, is validated against the two-dimensional wind-tunnel experiment for a square (W/H=1) and a deep canyon (W/H=1/2) configuration. Since not every street canyon is symmetrical as shown in figure 6. The building height will differ from each other. This will be described further on. When the upwind building height is lower, this is called the ‘step-up notch’. When the downwind building height is lower, this is called the ‘step-down notch’.

![Fig. 6: Definition of street canyon dimensions and indication of measurement positions of the non-dimensional tracer concentrations (Apsimon et al., 2003, p. 4039).](image)

When the buildings are equal in height there is a single vortex created by the wind behaviour, as shown in figure 7. The vortex, which is indicated by a star, is in the middle of the two buildings. Due to the vortex the
polluted air distribution creates a high concentration of air pollution at the lower upwind building corner and a lower concentration at the roof of the downwind building.

Fig. 7: (a) Wind field and (b) pollutant dispersion, as computed by MIMO for upwind building height of 0.06 meters (Apsimon et al., 2003, p. 4040).

When the upwind building is made lower, a step-up notch is created. The ventilation inside the canyon is reduced and the vortex is weaker. The centre of the vortex is displaced to the downwind building which is shown in figure 8a. The highest concentration of polluted air remains closely to the upwind building.

Fig. 8: (a) Wind field and (b) pollutant dispersion, as computed by MIMO for upwind building height of 0.03 meters (Apsimon et al., 2003, p. 4041).

The difference in compare to the symmetrical case is that the concentration is lower now. Also the concentration of the downwind building roof is lower in compare with the symmetrical case, because the amount of pollutant exiting the canyon above the downwind building roof is reduced by the wind field, which transports the pollutant backwards.

When the downwind building is made lower as shown in figure 9, a step-down notch is created. The main vortex becomes weaker and it is displaced upwards with its centre. As shown in figure 9a, there are also two secondary vortexes created at the lower corner of the up- and downwind building and this lead to a formation of high air pollution concentration at both the up- and downwind building facade. The polluted air disperse over the downwind building roof and goes to the areas behind. In the step-down notch situation the concentration of the polluted air becomes higher than the symmetrical or the step-up notch situation, and it also breaks the canyon principle by leading the polluted air to the area behind.

Fig. 9: (a) Wind field and (b) pollutant dispersion, as computed by MIMO for downwind building height of 0.03 meters (Apsimon et al., 2003, p. 4043).

From the analysis of the three cases, which are shown above, we can conclude that the polluted air dispersion does not only concentrate within the canyon street. The possibility that the polluted air can exit the street canyon over the downwind building roof is very high in the three situations. By making use of higher aspect ratios (wider streets, W/H=3) this problem can be
3. RESULTS

solved. “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). This is shown in figure 10a. There is a small vortex created at the lower upwind building corner. When the pollution source is placed close to the upwind building, which is shown in figure 10b, pollutants disperse better compared to the square canyon case, but there are high pollution levels remain on the facade of the upwind building. When the source is placed close to the downwind building, which is shown in figure 10c, the concentration of pollutants on the facades of the up- and downwind building lower compared to the square canyon case and the pollutants disperse even better. The pollution concentration levels are low at the facades of the up- and downwind building. Both situation shows that the polluted air does not go over the downwind building roof to the areas behind. 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 (Apsimon et al., 2003, pp. 4037-4049).

To conclude, the W/H=3 is more suitable to the highway situation. This provide the best solution. To protect the facades of the canyon buildings it is essential to place the source closer to the downwind building, whereby the higher polluted concentration levels remains at the street as shown in figure 10c. When the situation in figure 10b is applied, the concentration of pollutants will be collected on the facade of the upwind building.

Vegetation, such as trees, bushes and green walls, will affect air pollution also. It will reduce the air pollution by absorbing the gaseous pollutants through the pores of the leaves and capture particulate matter on their surfaces (Kessler, 2013). The leaves may also filter out other pollutants such as NOx and CO2 (Ottelé, 2011, p. 33). Increasing deposition by the planting of vegetation in street canyons can reduce street-level concentrations in those canyons by as much as 40% for NOx and 60% for PM. In figure 11 is shown that when the facade of the canyon building is covered with vegetation the concentration of particulate matter will be much lower. This is more effective when H/W=2. The effect of covering the facade with vegetation is much better than covering the roof with vegetation, but this will help to reduce air pollution also. Moreover, even when the traffic source is removed, the vegetation will continue offer benefits in reduction of pollution, and so improve the street level air quality (Hewitt et al., 2012). Beside vegetation, flowing water may also reduce air pollution.

The building design may also help to reduce air pollution. Indoor air filtration will minimise exposures to pollutants. The installing of air filtration devices in

Fig. 10: (a) Wind field and (b & c) pollutant dispersion (b) and (c), as computed by MIMO for W / H = 3 (Apsimon et al., 2003, p. 4046).

Fig. 11: Reduction of noise by use of vegetation (Hewitt et al., 2012).
buildings which are ventilated mechanically can remove pollutants and improve the indoor air quality (Epa, 2014). Studies shows that high efficiency filtration reduce indoor PM$_{2.5}$ and ultra fine particle levels by up to 90% relative to incoming outdoor levels when doors and windows are kept mostly closed. Placement of the air inlets on the backside of the building, will make little difference in terms of exposure. Placing the openable windows just on the backside will also help to reduce air pollution (Air Resources Board, 2012).

### 3. RESULTS
4. CONCLUSION

The lack of space can be solved by using the spaces along high polluted areas. Living along a highway can damage health because of the noise and air pollution. For creating a healthy living environment it is crucial to reduce the noise and the air pollution at a acceptable level. Reducing noise can be divided in three categories, namely emission, transmission and immission. Emission is the reducing of the noise at the source. In this case the source is the vehicle itself. The noise can be reduced by innovative tires and engines, quieter/porous asphalt and by all-electric or hybrid cars. These solutions would not be cost-effective. Reduction of noise at the transmission path can be done by the placement of an obstruction between the receiver and the source of noise. Placing for example trees or earth mounds is a way of achieving this. Also by placing the highway lower than the ground level and by tunnelling the highway the sound can be blocked. Then again, these solution will be too expensive, and by tunnelling the drivers experience is neglected.

Reducing noise by immersion is to reduce the noise at the receiver. A building along a highway can act as a sound barrier. Reducing noise at the receiver can be done on an urban scale, building scale, and dwelling scale. A building can not be infinitely long. Hereby the noise will reach the shadow zone. Between the openings noise will penetrate to the shadow zone. This can be solved on urban scale. By optimal positioning of the building the noise which penetrates the shadow is reduced. Folding the edges of the buildings from the highway proves to be the best way of reducing noise. The height of the building as a barrier is also crucial. The higher the building, the better it will reduce the noise. This is shown in figure 12.

On building scale there are a few ways to deal with the noise pollution. Angling the canyon building ensures that the noise will be reflected upwards, whereby it will not reflect to the buildings. The program of the building is also crucial. Functions which are less sensitive to noise pollution have to be placed closer to the source of noise, than the more sensitive functions. This will be a strategic intervention regarding technique and the requirements of the functions. The angling of the building and the use of a varying program are shown in figure 13.

Fig. 13: Reducing of noise on building scale (own ill.).

It also important that the canyon building absorb the noise. The handling of the sound can be done on dwelling scale in several ways. Firstly, by shaping objects in specific ways the direction of sound can be engineered. Secondly, at the microscale. The structure of the material can be engineered specially to make it porous or not to enhance absorption or reflection properties. The last but not least, by managing the hardness of softness of a material sound can be either absorbed or reflected. Choosing the right material for the facade is essential. A facade of absorptive material contain a porous element that absorb the noise. Robust materials can form directly the surface of the facade. Materials which are less robust have to be enclosed with a skin which has to be perforated. To protect the dwellings from noise it is also possible to use a double facade. The corridor facade can be the best solution when it is combined with the multi-storey facade. In this case the cavity can be used for example for circulation and can be ventilated naturally without any openings on the

Fig. 12: Reducing of noise on urban scale (own ill.).
highway side. Designing the plans of the dwellings can be also effective. It is better to place the more sound-sensitive functions of a dwelling, such as a bedroom, at the ‘backside’ of the building where there is no noise. The solution at dwelling scale, namely the combination of the corridor facade and the multi-storey facade and the zoning of the program of the dwelling, is shown in figure 14.

The air pollution can be reduced in different scales also. On urban scale, buildings along the highway have an impact on pollutant transport and dispersion. The dispersion will lead to increased vertical mixing due to the upward deflection of air flow caused by the structure. This effect is studied by the wind tunnel experiment. The wind-tunnel experiment is a study which refers to a simulation of toxic emissions from vehicle exhausts in a street canyon within an urban environment. This experiment shows that it is obvious to place the source closer to the downwind building, when assumed the wind is coming from the left. Hereby the higher polluted concentration levels remain at the street. This is shown in figure 15. When the source is in the middle, the pollutants will be collected on the facade of the upwind building.

The air pollution can also be reduced on building scale by the use of vegetation. Vegetation will reduce the air pollution by absorbing the gaseous pollutants through the pores of the leaves and capture PM on their surfaces. Increasing deposition by the planting of vegetation in street canyons can reduce street-level concentrations in those canyons. The effect of vegetation on the facade is better than vegetation on the roof. Flowing water may also reduce air pollution. The use of vegetation is shown in figure 16.

On dwellings scale indoor air filtration will minimise exposures to pollutants. Placing the air inlets on the other side of the building and making no openable windows on the side of the highway, as shown in figure 17, will help to reduce air pollution.

This paper provides the necessary technical information to firstly understand the workings of noise and air pollution and secondly provides an angle for an architectural design.


5. REFERENCES


APPENDIX

I. POSITIONING OF THE BUILDING MASSES

Fig. 18: Positioning of the building masses in order to reduce noise (Kranendonk & Nijs, 1979 pp. 31-34).
Fig. 19: Positioning of the building masses in order to reduce noise (Kranendonk & Nijs, 1979, pp. 35-38).
APPENDIX

11. BUILDING HEIGHTS

Fig. 20: Section of the building masses in order to reduce noise (Kranendonk & Nijs, 1979, pp. 28-30).
The reference projects which are analysed are all along a highway or railway and thereby exposed to high values of noise pollution. The source of the noise is on all the reference projects below on the left. The analyses are based on the program and facades. The analysis of the program are divided in the long-stay and the short-stay functions. The following colours are used for the different functions:

- Short-stay functions
- Long-stay functions

The Cyclops

The first reference project I have analyzed is the Cyclops in Hilversum (Diependaal), designed by Nio. The Cyclops is a row of twelve houses which form an integral part of a soundproof dike along a secondary road. The houses act as a sound barrier. The sound barrier houses cause that the rest of Diependaal is not been influenced by noise pollution. Most of the time, drivers do not know what is behind the sound barrier. The houses can not be seen from the road (Nio, 2002). The plans of the houses are designed in such a way that the spaces where you do not have to be for a long time are situated next to the dike. The long-stay spaces such as bedrooms and living rooms are situated on the other side, which is shown in figure 21.

The Meerval

The Meerval is located in Nieuw-Vennep and is designed by A. Venema. These dwelling is designed in such a way that the noise is blocked by the dwelling itself as shown in figure 22. On the front side there is a serre which act as a buffer zone. This buffer zone is used for circulation. The long-stay spaces are situated on the back of the dwelling (De Ruiter, 2004, p. 103).

The Groene Lunet

The Groene Lunet is located in Utrecht along a railway and is designed by SAS Architecten. This dwelling is build with the back to a soundproof dike which protects the dwelling from noise pollution. This causes that the long-stay and the short-stay functions are placed in a mixed way (De Ruiter, p. 102).

The Stadstuinen

The Stadstuinen is located in Amersfoort along a highway and is designed by Han van Zwieten. The houses work as a sound barrier. The houses are placed higher which creates a nice view to the landscape. As shown in figure 24 the program is organized in such a
way that the short-stay functions are situated on the side where the highway is, and the long-stay functions are situated on the other side where the view is (Van Zwieten, 2014).

Fig. 24: Analysis of the Stadstuinen: (a) elevation, (b) ground, (c) first and (d) second and (e) third floor plan (own ill).

The Droogbak
The Droogbak is a residential building in Amsterdam designed by Rudy Uytenhaak and is located along the railway. The building functions as a sound wall and inside as a residential wall which protects the neighborhood from noise pollution. The living room and the main bedroom are located as fas as possible from the railway as shown in figure 25 (De Ruiter, 2004, p. 104). The other bedrooms and the kitchens on the northside, the side where the railway is, have large glass doors to the workbalconies, which are equipped with soundproof glass screens and provide a nice view to the IJ (Uytenhaak, n.d.).

Fig. 25: Analysis of the Droogbak: (a) section and (b) second floor plan (own ill).

The Spoorwegzone
The Spoorwegzone are houses in a row, which are located in Amersfoort along a railway and is designed by Han van Zwieten. The houses are three levels high on the railway side for creating a urban allure. The houses opens itself towards the park/ water and the building height is lower. The long-stay functions are situated on the park/ water side, as shown in figure 26. The three levels high part of the building acts as a buffer zone and is used for circulation (Van Zwieten, n.d.).

Fig. 26: Analysis of the Spoorwegzone: (a) section (own ill.).

The Albatros
The Albatros is a residential building which is located in Etten-Leur and is designed by van Ardennen Architecten. The glass curtain wall protects the dwellings from traffic noise and provide extra residential quality. The space between the glass curtain wall and the wall from the dwellings, the buffer zone, serves as circulation area, as shown in figure 27. The buffer zone causes that the long-stay and the short-stay functions are placed in a mixed way without any problem of noise pollution (De Ruiter, 2004, p. 105).

Fig. 27: Analysis of the Albatros: (a) section and (b) first floor plan (own ill.).

The Tribune
The Tribune is a residential building block in Amsterdam and is designed by Claus en Kaan Architecten. The Tribune is a ‘wall’ of 200 meters long, with different kind of functions such as living, working, sports etcetera
for different target groups. The outer facade protects the residentials from noise and airpollution. When the facade consists of full glass, it should be ventilated by airco and this would be unpleasant. The bufferzone of the Tribune has a semi-outside climate. It has extended parapes whereby great negges arise which blocks the sun. The ventilation takes place via the stairwells. The extended parapes are from steel gratings with soundproof and sound absorbtive panels along the corridor. The open structure of the gratings create a dynamic facade image (Wind, 2011). The analyse of the Boschkens is shown in figure 28.

![Fig. 28: Analysis of the Tribune: (a) section and (b) floor plan (own ill.)](image)

**The Boschkens**

The Boschkens, shown in figure 29, is a residential wall, which is located along the A58 highway in Goirle, designed by Buro Lubbers and Crepain Binst.

![Fig. 29: Analysis of the Boschkens (own ill.)](image)

In contrast to the Cyclops the Boschkens give the drivers an idea of what is behind the wall. The trees in front of the wall announce the forest. The small windows in the wall break the visual barrier and creates a link between the highway and the houses behind the wall. The 14 meters high wall is from porous concrete to absorb the noise and is slanted 5 degrees backwards to reflect the noise upwards. The wall is well insulated and makes is possible to live in a healthy environment in the houses behind the dwellings. Still the short-stay spaces are situated next to the wall and the long-stay spaces such as the living room and bedrooms are situated on the other side (Buro Lubbers, 2009).

To conclude, the analyzed references show different ways of protecting the building from traffic and railway noise. The Cyclops is protected by the integration of the houses with the soundproof dike. Also the Groene Lunet makes use of the soundproof dike. The other references have all a buffer zone which is used as a circulation area. The references show also that the long-stay spaces are located as far from the source of noise pollution as possible.

**APPENDIX**