GREEN INFRASTRUCTURE
TO ACHIEVE TRAFFIC NOISE MITIGATION

A CREATIVE PROJECT
SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
OF THE DEGREE
MASTER OF LANDSCAPE ARCHITECTURE

BY
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CHAPTER I: INTRODUCTION

Motor vehicles are one of the important symbols of modern civilization. They bring convenient transportation to our society, but also unpleasant traffic noise in human living environments (See Figure 1). This creative project will identify landscape architecture design principles that can be applied to the green infrastructure elements that mitigate traffic noise while also providing a linear open space and greenway system for people in Indianapolis, IN along the I-65/ I-70 downtown 'spaghetti bowl'.

The initial motivation for this project was because: noise pollution is so excessive that it may jeopardize the human physical health, stress levels, and quality of life. Traffic is the primary source of noise pollution in urban areas. Urban areas have the most traffic flow, especially urban freeways. This topic is relevant and important to the profession of landscape architecture because highways have noise pollution issues.

Figure 1. Undesired neighborhood conditions for homeowners and renters. Source: EPA. 1981.
In addition to mitigating traffic noise, this creative project will have three main benefits. First, using both green infrastructure and sound walls along freeways will attenuate noise and offer visual screens for highway drivers and noise barriers for adjacent populations. Vegetated green walls will also be able to absorb carbon dioxide, which will help to improve air quality. Second, building accessible and visible parks can improve the quality of life for downtown residents. The new park will provide green scenery for residents and visitors. Third, this project will offer accessible and safe pedestrian walkways to access parks, and also provide separate cyclist and pedestrian routes. Because cyclists drive fast along trails, many accidents happen. This project will consider building separated routes to reduce pedestrian and cyclist conflicts.

1.1 Problem Statement

Nowadays, one of the important symbols of modern civilization is motorized transportation. People travel by different transportations every day. In urban core area, because of the high value of land and high density of individuals, government tends to use every piece of land to build something. But, there are still vast acres of spaces along traffic intersections were unutilized, because of loud noise and other conditions.

1.1.1 RESEARCH QUESTION

What are the green infrastructure elements that can be applied to the landscape
architecture principle to mitigate traffic noise while also providing a linear open space and greenway system for people in urban core areas?

1.1.2 SUBQUESTIONS

1. Do different vehicle types produce different type of sound?

Traffic intersections are messy and complicated areas. There are various kinds of vehicles passing by the site daily.

2. What decibel level needs to be mitigated so that people could realize it and they will feel comfortable with the decibel level?

In urban core areas, because of the high value of land, population density is much greater than other sectors. And also, open spaces are fewer than suburban and rural areas. There are a lot of unused areas surrounded highways, but because of the noise / safety problem, they are still vacant.

3. How to design and construct sound barrier structures that integrate plant materials?

Excessive traffic sound in urban areas is one of the most common complaints among United States' residents (FHWA, 2011). Sound reducing barriers are the most efficient method to mitigate excessive sound, but most of these are simple concrete walls.

1.2 Delimitations, assumptions, and definition of terms

1.2.1 ASSUMPTIONS

The site of this project will be Intersection 38, which is in Indianapolis IN, at the I65/
I70 downtown 'spaghetti bowl.'

1) This creative project assumes that the study site is surrounded by residential areas that are receiving noise pollution from adjacent roadways. And the surrounding residents and landowners want to build noise barriers.

2) This creative project assumes the local government will support the proposed development strategies.

3) The project anticipates future development, specifically, an abandoned railway along I-70 will be reconstructed as a light railway. This project assumes the government will build a transit stop in this area.

1.2.2 DELIMITATIONS

Because of time constraints, the following issues will not be addressed in this project:

1) This project will not include how to build noise barriers.

2) This project will not cover other pollution issues in the area, such as water runoff, air pollutions, and heat island issues.

3) This project will not involve the discussion of cost estimation and funding.

1.2.3 DEFINITION OF TERMS

1. Decibel (dBA)

   Unit of sound measurement.
2. Noise

Any unwanted sound. Because it is loud, interferes, or unpleasant for human Auditory system.

3. Noise Pollution/ Noise Disturbance

Noise pollution or noise disturbance is the disturbing or excessive noise that may harm the activity or balance of human or animal life.

4. Sound Masking

Sound masking is typically distributed by unseen speakers that are through an area to reduce interference or to provide privacy when needed.

5. Noise Barrier

A noise barrier is a designed outdoor structure to protect inhabitants of sensitive land use areas from noise pollution.

6. Green Infrastructure

Green Infrastructure is building with nature to provide a green space network for solving urban and climate challenges. It also uses natural, living systems to provide environmental services that refer to constructed features, such as calming traffic, creating wildlife habitat, shading and cooling buildings and streets, and capturing and cleaning stormwater.

7. Sound Attenuation

Attenuation is a measurement of the energy loss of sound. It is usually expressed in decibel or dBA.
1.3 Methodologies

The following methodologies will guide the design process of green infrastructure elements that mitigate traffic noise while also providing an open space and greenway system for people in urban core areas. This project will use research and a government design handbook to guide the design. The methods of this project will utilize and integrate a combination of observation, literature reviews, and site inventory.

1.3.1 LITERATURE REVIEW

The literature review explores the research questions that will guide the design process of green infrastructure elements that mitigate traffic noise, while also providing an open space and greenway system for people in urban core areas. Also considering the facts of noise, sound attenuation, current trends about noise mitigation strategies, and government policies about how to mitigate sounds.

This project also involves investigating transportation-related precedents as part of literature reviews. It is helpful to explore different precedents to learn the design method, design guidelines, and other design information.

1.3.2 OBSERVATION AND MEASUREMENT
This creative project will include data collection and site inventory. First, according to the main question and subquestions, this project will involve asking the following questions: What existing land uses surround the site? Who are the main user groups in these areas? How many parks or green spaces are around the site? Where is the existing pedestrian system around the site? What is the current noise condition on the site? The observation data collected will help to direct the program of this project. Second, this project will provide inventory photos during site visits and sketches/diagrams to show the existing site conditions, and also providing an on-site noise measurement chart.

1.3.3 PROJECT DEVELOPMENT

The last step is based on literature review, observation, and case studies to design and develop this project. According to literature review, use appropriate research to guide different design aspect of this project. For example, studying the existing highway route and site conditions will help to identify different types of effective noise barriers. Looking at existing pedestrian systems could help to develop how to connect them with new pedestrian walkways. The existing user groups' observation could help to separate each area with different focuses.

This creative project will first look at the project program-making process and use it to help to develop the design program. The second step is to find out what design
strategies the project should be used to mitigate noise, summarize them and develop
design strategies for this project. Third, according to different case studies' design
principles and post evaluations to discuss how to provide safe walkways for surrounding
residents. Fourth, looking at how each project uses green infrastructure strategies along
the roadway, and then, according to observed existing site conditions, to develop
strategies for this creative project.
CHAPTER II: LITERATURE REVIEW

2.1 Introduction

The following literature review addresses research questions that will guide the design of green infrastructure elements that will help to mitigate traffic noise while also providing a linear open space and greenway system for people in the urban core area. The initial motivation for this project is to reduce noise pollution that may jeopardize the human physical health, stress levels, and quality of life. Proposed site programming will be developed from design strategies found in precedent investigations. This creative project will be looking at how decibel level affects human feelings. By looking at the facts of traffic noise and considering how much decibel needs to be mitigated on-site, this information can be used to develop how to design and construct noise barrier structures that integrate plant materials. Finally, this literature review will discuss how to provide safe walkways for surrounding residents. Design principles and guidelines are consulted from research, design handbooks, and case studies.

2.2 Current Trends

Noise pollution is considered one of the most important issues in urban environmental management. Traffic is the primary source of noise pollution in urban areas. The U.S. Department of Housing and Urban Development (HUD) mentioned street noise more often than all other undesirable neighborhood conditions (HUD, 2009).
Urban areas have the most traffic flow, especially urban freeways.

Highway traffic noise has been a Federal, State, and local concern since the first noise barrier was built in 1963 (FHWA, 2007: 1). Years of experimentation resulted in different designs of concrete walls (Texas, F-shape, and constant slope). By 1997, California had more than 1,600 miles of concrete and metal freeway barriers across the state (Clevenger, 2013: 1301).

Urban highways should contribute to the beauty of the regions through which they pass, from the standpoint of both the users and viewers of the facility (Rapuano, 1968: 20). The U.S. Department of Transportation has stated the need for an alternative to traditional concrete and metal beam barriers because they can be expensive and difficult to install, and not sustainable for sites. After that, the technology and methodology of sound barrier design are substantially advanced to have occurred in design, concept, and technique. Increased community and motorist interest have fueled the push to provide better, less expensive, and more environmentally friendly barrier designs (FHWA, 2007).

2.3 Decibel Level with Human Feelings

Sound waves are changes in pressure and are represented by sine waves (Figure 2). Once a source vibrates, it will cause the surrounding air molecules to move. The surrounding atmosphere is temporarily displaced from its normal configuration if the sources move and vibrate. The pressure changes combine with oscillations so that the
sound can be heard by the human ear, which is also known as frequencies. The human ear can perceive the frequency of 20 to 20,000 oscillations per second or hertz (Abbas, 2011:10).

According to Indiana Department of Transportation (INDOT), Sound levels are measured in decibels (dBA) and typically range from 40 to 100 dBA. There are three different human-detected decibel levels (See Figure 3 below):

"A 3 dBA increase can barely be detected.

A 5 dBA increase is clearly detectable.

A 10 dBA increase is twice as loud as the starting noise level" (INDOT).
According to the research, INDOT requires that noise barriers achieve a 5dBA reduction at a minimum, which will affect greater than 50% of the impacted receptors. If a barrier cannot achieve this acoustic goal, abatement is considered not to be acoustically feasible (INDOT, 2011).

In residential areas, the Noise Abatement Criteria (NAC) is 67 dBA for outdoor uses. INDOT defines "approaching the NAC" as within 1 dBA (for example, 66 dBA for

Figure 3: Sound Levels (INDOT, Noise Barriers Fact Sheet)
residential areas). So, locations, where noise levels are predicted to be 66 dBA or higher, are considered "impacted" (INDOT).

Constant exposure to noise constitutes a health risk. There is sufficient scientific evidence that noise exposure can induce hypertension, ischemic heart disease, sleep disturbance, decreased school performance and hearing impairment. The effects of noise exposure takes place within economic and social environments. For example, some people have a particular sensitivity to noise and will be more susceptible to one of its effects than other people (Passchier, 2000). These health issues give the view that noise abatement strategies for public health protection are needed. Therapists must be attentive to such matters as air quality, freeway noise, and airplane flight paths, all of which influence the environment in which they practice (Bechtel, 2003: 139). Attention needs to be given to the construction of green infrastructure to maintain noise mitigation function amongst those who suffer from these conditions and to help promote a better quality of life. Positive associations between personal health and physical or visual access to green space have been observed in the elderly, children, and families in military and low-income housing, and persons with limited mobility (Baldauf, 2013: 16).

2.3.1 The Facts About Traffic Noise

According to the Noise Barriers Fact Sheet published by the Indiana Department of Transportation, three factors influence the level of highway traffic noise:
• Volume of traffic

• Speed of traffic

• Number of vehicles

Noise levels increase if any of these factors increase. Conversely, terrain, vegetation, distance, or human-made obstacles can decrease traffic noise (INDOT).

Traffic noise impacts can be reduced by modifying either the source of the noise, such as volume, speed, or number of vehicles on the highway. It could also be reduced by the location of the receiver, such as a person who passes by or otherwise hears the noise by which the sound reaches the receiver. It is hard to reduce the speed, volume, or type of vehicles on a highway. And it can also be very difficult to relocate residences solely due to noise impacts. So, the most common approach to mitigating noise is the construction of noise barriers, also called sound walls (INDOT).

The U.S. Environmental Protection Agency (EPA) has established regulations that set noise emission level standards for newly manufactured medium and heavy trucks. They have a gross vehicle weight rating (GVWR) of more than 4,525 kilograms. These are the maximum weight for one truck to drive on a street or highway. Table 1 shows the EPA noise regulations that the maximum noise emission levels allowed for these vehicles (See Figure 4) (FHWA, 1995:2).
Table 1: Maximum Noise Emission Levels as Required by EPA for Newly Manufactured Trucks with GVWR Over 4,525 Kilograms

<table>
<thead>
<tr>
<th>Effective Date</th>
<th>January 1, 1988</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Noise Level 15 Meters from Centerline of Travel Using the Society of Automotive Engineers, Inc. (SAE), test procedure for acceleration under 56 kph</td>
<td>80 dBA</td>
</tr>
</tbody>
</table>

Figure 4: Table 1: Maximum Noise Emission Levels (FHWA, 1995)

In "Highway traffic noise: analysis and abatement policy and guidance" published by Federal Highway Administration (FHWA), a few general relationships are posted to help understand sound generation and propagation.

First, it could be perceived by an observer to be a doubling or halving of sound if a decrease or increase of 10 dBA in the sound pressure level, which is shown in Table 2. For example, a sound at 60 dBA will sound twice as loud as a sound at 50 dBA (See
Second, when the square footage of the distance from the source changes, the sound intensity will decrease in proportion. Each doubling of distance shows that the sound levels for a point source will decrease by 6 dBA. On the roadway, the closely spaced continuous line of vehicles becomes a line source. As a result, each doubling of distance and produces a 3 dBA decrease in sound level. However, sound from a highway to "soft" ground such as cultivated farmland, grass, or crops will mitigate 4.5 dBA per distance doubling. In traffic noise analyses, this 4.5 dBA is often used as standard reduction rate (FHWA, 1995).
2.3.2 Green Infrastructure As Noise Barrier

Green infrastructure creates a network that enhances and protects the natural environment. Highways create a network for improving mobility and moving goods efficiently. They all attempt to establish a connected network in the same landscape areas. Because the transportation network, especially highways, disconnected green infrastructure network. So, there is a conflict between green infrastructure planning and transportation planning. In last ten years, the United States has several promotions to link transportation with environmental concerns (Marcucci, 2013).

Excessive traffic noise in urban areas is one of the most common complaints among United States residents. Noise barriers are the most efficient method to mitigate those noises. But, most of them are simple concrete walls.

One of the most common construction materials around the world is concrete. Almost half of the noise walls constructed in the United States are made of concrete. By using a concrete wall, even at a thickness wall is well within any Sound Transmission Class requirement. But the concrete wall is not sustainable (FHWA, 2007). Unfortunately, sound walls act as psychological barriers, and their scale is often visually overwhelming (Blair, 2001: 43). The essential tools for softening the sound walls were landscape features and architectural treatment of the barriers (Blair, 2001: 47).

As shown in Figure 6, noise barriers could reduce the sound which enters a community from a busy highway. They are transmitting it, absorbing it, or reflecting it
back to the motorway. Noise barrier may also force the sound to take a longer path. This longer path is called as the diffracted path (FHWA, 2007).

![Diagram of noise barrier and sound paths](image)

Figure 6. Barrier absorption, transmission, reflection, and diffraction (FHWA, 2007)

Diffraction around the acoustic wave can occur both at the top and around the end of the barrier layer. This diffraction can occur like other wave phenomena such as light or water waves. Because the nature of the acoustic wave, the diffraction does not bend evenly over all frequencies. Higher frequencies (shorter wavelengths) are diffracted to a lesser extent. Lower frequencies (longer wavelengths) diffuse deeper into the "shadow"
area behind the barrier. In general, the barrier is more effective at attenuating higher frequencies (most cars and motorcycles) than the lower frequencies (trucks). (See Figure 7) (FHWA, 2007).

Figure 7. Barrier diffraction (FHWA, 2007)

The noise can be reflected back and forth between the barriers if a barrier is established on both sides of the road (Bendtsen, 2009). There are different solutions to help resolve the reflection problem from the noise screening installations. The first solution is to install sound absorbent material on the road-facing side of the noise barrier. The sound absorbent elements help to reduce the reflection. An example shows that 10-foot high steel noise barrier constructed with absorption components and support for vegetation as well (see Figure 8).
The second solution is that with different types of tops above noise barriers (See Figure 9). There is very little literature that considers the character of various shapes of the noise barrier tops. The fundamental principle of the technique is that by increasing the amount of diffraction occurring at the top of the barrier layer, additional sound attenuation can be achieved (FHWA, 2007).
The T-profile top barrier is one of the mostly used noise barrier tops (See Figure 10). It provides an additional 2.5 dBA sound attenuation over the conventional top barrier (FHWA, 2007). An example shows a noise barrier that has T-profile top barrier to increase the noise reduction (See Figure 1).
Figure 10. T-profile Top Barrier

Figure 11. Sound reflection diagram for T-profile Top Barrier
The noise barrier can be erected obliquely so that the sound is reflected up into the air, where it does not interfere with anyone. In Figures 12 and 13, to reduce the disturbance of residents along the road, a 6-foot high visually transparent noise barrier is tilted away from the road.

Figure 12. Tilted away noise barrier, at National Road 152 in Naestved, Denmark (Bendtsen, 2009)
This type of noise barrier achieves approximately 5 to 10 dBA sound reduction. Taller barriers that cover more of the road have a greater positive effect (Bendtsen, 2009). An example shows a noise barrier in Austria that is bending over the highway to increase the noise reduction (Figure 14 and 15).
Figure 14. Steel noise barrier-bending over the highway, Vienna, Austria (Bendtsen, 2009)

Figure 15: Sound Reflection Diagram for Curved Barrier
The third solution is to plant vegetation between the road and the noise barrier (see Figures 12 and 16). The other way is to plant vegetation on the backside of noise barrier (See Figure 8 and 18). Because plants can disperse noise before and after reflection, it is important to choose vegetation that has as dense, high, and broad a form as possible (Bendtsen, 2009).

Figure 16. Danish transparent noise barrier with vegetation that can reduce the noise reflection (Bendtsen, 2009)

Highway infrastructure causes ecosystem impairment, landscape fragmentation, and loss of habitat connectivity. Green infrastructure includes working landscapes, natural landscapes and various forms of open space. It creates a network and function to maintain ecological values and processes (Marcucci, 2013). Urban green infrastructure along vehicular routes offers insights on additional potential advantages of
implementing vegetation to mitigate traffic noises. It also has benefits for aesthetic views, air quality, and stormwater regulation (Rapuano, 1968).

A case study project shows green noise barriers protect development area in Baden-Wurttemberg, Germany, which was implemented in October 2014. This green noise barrier is about 330 feet long, 8.5 feet high, and 2 inches thick. It is a double-sided planting wall with pre-cultivated Hedera helix (See Figure 17). It mentions on the website that “The wall provides better sound insulation than conventional systems; it also looks much better and quite incidentally makes use of the roof water from the nearby REWE supermarket and adjacent houses, which thus improves the climate in the immediate environment” (Green noise barrier, Helix). According to the measurement for this green noise barrier, the sound insulation is 26 dBA, and the sound absorption is 9 dBA. It generates 120 lb of Oxygen in 30 days, and the Carbon dioxide reduction is about 160 lb on site (Green noise barrier, Helix).
In this project, one of the core concepts is to use green infrastructure to build network connectivity with surrounding green spaces. The green wall will collect stormwater, and after treating it, use it as irrigation water for plantings. Therefore, these green barriers along vehicular routes may help to decrease stormwater water runoff issues on the site.

It is also important to consider the height of a noise barrier for road users. A five foot tall barrier will affect the motorists' visibility, and a 16-foot high barrier will screen all views of the surroundings. So, one must consider the material, the color, and the form to resolve this kind of problem. The first solution is to plant lower growing vegetation in front of the noise barrier and taller vegetation behind it. The second solution is to use transparent materials (Bendtsen, 2009). Figure 18 shows a 15-foot high partially transparent noise barrier with several tall trees behind.
2.3.3 Plants As Attenuators

Plant materials have not been shown to be as efficient as a noise barrier in sound attenuation. However, the leaves, branches, and twigs of trees do have ability to absorb some of the vibration of sound waves (Robinette, 1972). Different type, height, and location of plant material can achieve different sound attenuation (Dragonetti, 2011). The vegetation could also help to control climate and water runoff (Robinette, 1972). This project will also use plantings to create a living green wall as a secondary noise barrier.

Robinette mentioned, "The information already available allows us to guess how vegetation will attenuate sound. Assuming that forests, on the average, will attenuate a
1,000 Hertz sound by 7 dBA per 100 feet, the next example indicates the value of this reduction. We know that sound energy will be reduced as the distance from the source increases. The power of a sound measured at 25 feet will be reduced by 14 dBA at 125 feet. However, if 100 feet of the forest lies between the source and observer the reduction alone, one would have to be 250 feet from the source. Therefore, the substitution of vegetation for distance as a sound screen seems to be a promising way of restoring some quiet to our environment” (Robinette, 1972: 42).

Dense planting areas are needed to achieve sound attenuation. But planting schemes also affect the sound attenuation result. If the screening is as close as possible to the road or as close as possible to the area needing protection, the best noise reduction is achieved. If the sound barrier is between the road and the noise sensitive area, the noise reduction effect will be significantly less than another (Bendtsen, 2009). Dragonetti has several experiments about planting schemes in green buffer zones between traffic areas and park zones (See Figure 19) (Dragonetti, 2011).
Five factors were considered to measure the sound attenuation results. The five elements are the first-row position, spacing between tree trunks, planting patterns, number of tree rows, and tree trunk diameter (See Figure 20) (Dragonetti, 2011).
Dragonetti continues: “To fully exclude changes in source emission over time, sound propagation over a rigid plane has been recorded after each measurement and the insertion loss (IL) of the trees compared to this reference has been calculated” (Dragonetti, 2011:2). Insertion Loss is also known as acoustic attenuation.
In summary, this study shows (See Figure 21):

1. It is a significant influence to plant the first row of the plants as near as possible with the source to achieve maximum noise mitigation effect.

2. For the planting pattern, both the random and helix configuration are the most effective pattern at the shielding effect.

3. The use of more rows of trees will achieve more impact on mitigating noise.

4. By increasing the tree trunk diameter, the sound attenuation also increases.

Another similar case study (Figure 22) shows that using a 100-foot wide green buffer with a 12-foot high landform can achieve 10 to 15 dBA sound reduction (6.4 Green buffer, USDA).
Figure 21. Test measurement results (Dragonetti, 2011)
Figure 22. Sound attenuation level by different landform (6.4 Green buffer, 2016)
2.3.4 Planting Selection

Plant selection for noise reduction is critical and associated with other design aspects of sound abatement structures. First, plants do not grow well next to sun-heated metal panels. For example, vines have difficulty in gaining a foothold on coated panels.

Second, careful consideration needs to be given to the selection of plants. It should consider which accept adequate watering and, which have seasonal interest (FHWA, 2007: 69). Successful designs would match plant species with each site and with the site's purpose, to achieve optimal performance for the service life of the project (Baldauf, 2013: 16).

Plant materials help attenuate sound and people feel "calm." Some types of plants are better than others at performing this function (Green, 2008). The plants with broad leaves and dense structure form are most useful for sound reduction. In areas where the existing landscaping is distributed, consideration of replacing or supplementing such vegetation with new plants will be given. These plants can be in the form of shade trees, shrubs, and vines. Various methods have been utilized to plant vines, which ultimately climb the barrier. One way to create a noise barrier covered with vines is to drill angled holes through the barrier. The vines could then be planted behind the barrier and allowed to grow through the holes toward the highway side. This kind of strategy could be used on the road side which does not have enough space for plants to grow (FHWA, 2007). In terms of choosing different species of plants can also be obtained by varying
the species, colors, and sizes of vegetation. It is essential that the landscape plan is coordinated with the engineering of the noise barrier and with its aesthetic design.

According to the post-evaluation of the Squaw Peak Parkway, by comparing landscape and public art preferences 88 percent of respondents preferred using plants, rather than art to soften the impact of the noise walls. Almost 62 percent pointed to the living and attractive nature of plants as an active mitigation screen (Blair, 2001: 47).

The visual character of noise barriers needs to be considered in relationship to their environmental setting. The barriers should reflect the nature of their surroundings as much as possible. Where strong architectural elements of adjoining activities occur close to barrier locations, the barrier design should be considering a relationship with color, material, and surface texture. In those adjacent roadway structures or other transportation elements, proposed noise barriers should have a strong visual relationship, either in design concept aspect, physical aspect or to the roadway elements (FHWA, 1995:28).

In the meantime, beautiful views and scenic vistas should be preserved to the extent possible. In general, it is better to utilize a consistent surface treatment and color in landscaping elements, when designing noise barriers. It is usually best to avoid unnecessary details in noise barrier design, as it tends to increase the visual dominance of the wall (FHWA, 1995:28).
Research indicates that the psychological effect on the passing motorist must also be considered. Noise barriers should be designed to fit the site context, such as dense urban setting areas, open suburban areas, and rural areas. They should also be designed to avoid monotony for the motorist. Because of the high speed of many roadways, the visual perception of noise barriers tends to be of the overall form of the barrier. A good way to achieve visually pleasing noise barriers is to avoid a tunnel effect through significant variations in material type, surface treatment, and barrier form (FHWA, 1995:28).

In this creative project, the design approach for noise barriers may differ considerably depending upon roadway design constraints. For example, the design problem will be considered from a visual and acoustic standpoint. It is substantially different when design a vertical highway alignment then a horizontal highway alignment (FHWA, 1995:28). This creative project will involve the design of different barrier types according to the existing land conditions and aim to approach developing a visually pleasing barrier.

Barriers often interfere with the normal drainage patterns in many highway contexts. Surface runoff paths run both parallel and perpendicular to the freeway. This model requires special treatment within and adjacent to the barrier. So, a variety of sizes and shapes of openings in barriers have been employed to carry water out of the freeway. One of the primary considerations in highway barrier design is to ensure that the size and location of openings do not result in any significant degradation of the barrier's
acoustical performance. The effect of a continuous gap of up to 7 inches at the base of a noise barrier is usually within 1 dBA (FHWA, 2007). Green infrastructure uses vegetation and other elements to treats and reduces stormwater runoff from site, such as green roof, living wall, permeable pavement, and so on (Green infrastructure, 2016).

2.3.5 Summary

In summary, the literature and precedent investigation suggests that a noise barrier is the most efficient way to mitigate traffic noise. If just using plants as the only attenuator will not effectively mitigate the noise. While comparing different types of sound barrier tops, this creative project will deal with T-type and curved type posts and panels as noise barriers. These two separate kinds are the most helpful strategy to achieve more sound attenuation along different traffic conditions. These two types of top both consist of noise barrier panels mounted between foundation-supported posts.

Second, for at-grade highways, it is best to use existing vacant spaces beside the highway to plant trees and shrubs to increase noise reduction effect. The literature review shows that dense planting areas could achieve addition sound attenuation. The dense planting area should at least 100-foot wide to achieve a noticeable sound reduction effect. And it should also include both tall trees and shrubs to cover the ground in order to mitigate more noises. For the plants species, it is better to choose the
species with broad leaves, these kinds of species may absorb more noises than the others.

Third, for elevated highway areas, it is best to integrate plants with noise barrier as living green wall along the road edge to serve as a secondary noise barrier. Vegetation in urban settings can provide benefits beyond aesthetic improvements. These benefits include noise reduction, improved air quality, storm water management, carbon sequestration, and the experience of nature. To use the living green wall as a secondary noise barrier, it may need to have an underground water tank for irrigation.

2. 4 HIGHWAYS AND PEDESTRIAN / OPEN SPACE PLANNING

The previous literature review addressed the physical and acoustic science part in this creative project. This following part will focus on how to address the social aspect in the project.

Currently, in urban areas, a high significance is served for cars that are more than pedestrians, and priority is for cars. Passengers and finally pedestrian should arrive at a destination with anxiety. There are unutilized lands along the highway which did not use because of space is not welcoming for people.

Urban space is acting as a generator of cultural and social and interactions. Behavioral patterns define how to use space in urban areas (Pushkarev, 1975). So, a successful urban design is based on how it fulfills human needs. With a rise of motor
vehicles, separated pedestrian path seemed to be inevitable to provide pedestrians safety (Movahed, 2012).

Jan Gehl is a Danish architect. He divides, and simplifies outdoor activities in public spaces in a city into three different categories, which is necessary activities, optional activities, and social events. Each of these places very different demands on the physical environment (Movahed, 2012).

First, appropriate activities, such as shopping, going to work or waiting for a bus. This group includes a large majority of those related to walking. Because the activities in this unit are necessary, the solid framework influences their incidence only slightly. Second, optional activities are those pursuits that are participated in if time and place make it possible and wish to do so. This category includes some activities such as sitting and sunbathing, standing around enjoying life or taking a walk to get a breath of fresh air. Third, social events are all activities that depend on the presence of others in public spaces. These are supported whenever necessary and optional activities are given better conditions in public spaces (Movahed, 2012).

Through these behavior studies, this project will conclude different pedestrian activities to provide separated pedestrian ways with sufficient spaces to encourage people to walk.

In the cities, pedestrian accidents that lead to injury and even death are some serious difficulties. To increase safety, proper regulation frameworks for buildings to provide safe walkways are necessary (Pushkarev, 1975). Each walkway should be paid
attention that the concept of security walkway is hard to achieve (Movahed, 2012). In many areas, walkers are much more than pavements in crowded streets and even, and sometimes roads are used instead of pavements. So, the design should provide sufficient spaces for pedestrians to safely passing.

To provide greenways with plantings also considered a safe solution and more ecologically beneficial compared to concrete. This greenway system will also allow wildlife movements, which meets safety requirements (Rapuano, 1968. Wan, 2003).

Green infrastructure also can be used to conserve and create a network of ecosystems. Green infrastructure system tends to work as hub and corridor. Hubs are often large, continuous, unsegmented ecologically vast spatial regions, while corridors are linear residues that are usually small in size and provide connections between the various hubs and other links. In large scale, green infrastructure is park systems or urban forests. In the site-scale, green infrastructure could be green streets, green roof, and green wall. (Marcucci, 2013) In this creative project, it will use the existing soccer field park as one hub, and the central space in the intersection as another green hub. Use both visual and physical connections to build green corridors.

2.4.1 Pavement Infrastructures
Pavement should be designed and executed in streets and roads for traffic safety for both day and night use. It should be constructed to have different facilities to support safety walkways. Especially in places where there is both vehicular and pedestrian activity, lights should be installed. Because of vision limitation at night, various dangers threatened both drivers and pedestrians. Pedestrian accidents occurred when a little illumination has existed (Movahed, 2012). So, streets with heavy traffic need to provide full light illustrations on both sides of the way.

When illumination alone will not suffice, separated pedestrian walkways will ensure the safety feeling for people and the central island which is designed well also can help pedestrian to cross the street more safely. Most accidents are related to walking on the sidewalks, and most of them consist of crossing streets for getting on a bus or after getting off (Movahed, 2012). So, in this project, all stations will be accessible for all pedestrians and considered the security of pedestrians.

Traffic lights and safe pass zones are also helpful to provide security (FHWA, 2007). In Queensboro Plaza, NY, the designer redirecting the flow of traffic and adding traffic lights to direct pedestrians. These safety improvements in Queensboro Plaza marked the first year in 2011 that no deaths were recorded along Queens Boulevard (Gardner, 2012).

Another case study in Buenos Aires, the city government focused on turning parts of the town into walking zones. Particularly, some central streets downtown areas. By taking a quite chaotic central part of the city into two programs that give pedestrians and
public transportation priority over cars.

The sidewalks in 9 de Julio Avenue were set on grade with the street, lined with furnished and planted with trees. Cars can still use these roads but with tight speed restrictions. Pedestrians walking by or crossing are given preference. Some streets had bike lanes added or expanded the existing bike lanes to create a 300-kilometer bicycle lane network. Currently, bicyclists, pedestrians, and drivers travel together and, combined, create a vibrant urban space (Martignoni, 2014).

This dynamic transformation system won the ninth annual award for sustainable transport in 2014, which recognized the city's improvements to public safety, and mobility for cyclists and pedestrians. The new pedestrian streets have positive influences and benefits beyond transit. The outdoor areas of cafes and restaurants blend seamlessly with this new pedestrian-friendly environment. It provides spaces for tourists and office workers to enjoy at all times of the day. And in these places, the city feels like a friendlier place to be (Martignoni, 2014).

2.4.2 Summary

To be useful, safe and valued pedestrian space adjacent to highways should build necessary activities on the site. It may help to provide both visual and physical connection with the existing soccer park and Monon Trail to attract more visitors to visit the site, via the provision of safe walkways. It is necessary to separate pedestrian walkways and bikeways. According to the literature review, this strategy helps to reduce the conflicts on site and also let pedestrian to feel welcome to walk. In summary of the
research and case study review, it is necessary to provide access friendly entrance to improve social aspect on site.
CHAPTER III: SITE DESCRIPTION

The location for this creative project is Indiana Interchange 83, along interstate 65/70, located in Marion County, IN at N39.78338° W86.14165°. It has a complex transportation system, includes Interstate Highway 65, Interstate Highway 70, 10th Street and Massachusetts Avenue, pedestrian walkway, and for future, it plans to have an express busway and a bus stop station. These complex transportations routes generate excessive noise level, which likely impact surrounding residents (See Figure 23).

Figure 23. Indianapolis, Indiana (Google Earth)
The site is currently proposed to be developed as a busway. By observing the surrounding conditions, this site has various transportation systems and it has unavoidable traffic noises. There are residential and commercial land uses surrounding the site. And there are few green spaces between the residential area and driveways. The Indiana Cultural Trail is passes through part of the intersection, and the Monon Trail North Entrance is located beside these involved roads. These unique conditions make this site is perfect location for this creative project (See Figure 24).

Figure 24. Interchange 83, Indianapolis (Google Earth)

The site is an interstate highway interchange located near the Indianapolis urban core area. It has a complex transportation system, includes Interstate Highway,
vehicular ways, and pedestrian walkway. These complex transportations had excessive noises, which may influence surrounding residents.

The focus area of this site is the intersection and its central land. The site boundary may define by highway and existing geographic conditions (See Figure 25). Because this project aims to provide a green visual park and safe walkway system, so it needs to looking at existing sidewalks and surrounding green spaces.

![Figure 25. Site Map](image)

This site is located northeast of Monument Circle. Monument Circle is one of the landmarks in Indianapolis. Indianapolis is the largest city in Indiana, with 12.8 percent of
the state's total population. Interstate 70 (I-70) is one of a major Interstate Highway in the United States that runs from Baltimore, Maryland to Cove Fort, Utah. Massachusetts Avenue is direct going to Monument Circle. At the north of the site is the Frank & Judy O'Bannon Soccer Park, a recreational park that offers several unique sports complexes that are open to the public for leagues, groups or family (See Figure 26). Currently, there is a group of urban planners working on a new proposed specific busway along Interstate 70, which could result in a future express bus station near the site. This will be a great opportunity because there will be more people using this area in future. It is necessary to mitigate traffic noise and provide safe pedestrian walkway.
Figure 26. Indianapolis Map (Google Earth)
CHAPTER IV: SITE INVENTORY AND ANALYSIS

4.1 Site Context Analysis

The selected site is surrounded by various types of land uses. Most of the west side is residential, which is where noise barriers will be most necessary to mitigate noise and create some open outdoor gathering space for the residents. The north side of the site is an existing soccer park, and it will provide an excellent opportunity to connect the central open space with the park. It may invite more people to visit both the site and the soccer park. The east side of the site is adjacent to the Monon Trail and some commercial areas. The south side of the site is adjacent highway routes, the Indianapolis Cultural Trail, and some commercial areas. These two trails will provide more accessibility to connect the site and surrounding areas. The park could also help to attract more people to visit Indiana Cultural Trail and Monon Trail. There are four schools around the site - Indianapolis Public School, The Oaks Academy Middle School, Arsenal Technical High School, and HL Harshman Middle School. This project will focus on providing easy access entrance and future pedestrian walkways to connect the schools to the site. There is great potential for this project to provide public activities that welcome more students to the site (See Figure 27).
4.1.1 Site Transportation Condition Analysis

There are complex highway routes surrounding the site. The north part of the site is an elevated highway I-70 and ramps to connect with I-65. Because of the existing elevated condition, building noise barrier which integrate plantings is critical. (Figure 28). The west part of the site is on-ground highway I-70 and elevated highway I-65. The south part of the place is an on-ground ramp, which connects I-65 and I-70. Along these roads, because there are some unutilized lands along the motorway, it may be desirable to use the combination of noise barrier and dense plantings behind the barrier. The east part of the site is the Monon Trail. Currently, there is just a fence and a single gate to access the vacant central space. It is also an excellent opportunity to build a welcome plaza as the main entrance to access the site (See Figure 29).
Figure 28. Site Topography
Figure 29. Existing Highway Route Diagram
4.1.2 Site Noise Analysis

A decibel detector was used to observe the decibel levels during the site visit. The site visit for sound measurement started at the Monon Trail South Entrance at 7:40 p.m. Thursday, September 1, 2016. The Monon Trail South Entrance had a decibel level around 85 dBA. It is higher than the average noise level for an outdoor recreation area. The second observation location was standing on the Monon trail (See Figure 24 at Location No. 2), and there is no green buffer between highway and trail, the decibel is shown higher to 90 dBA. The third location is standing on the Monon trail, where plantings existed between road and trail. The decibel level here was approximately 84 dBA. There are 5 dBA changes of noise level between the highway has a green buffer or not. It results in that to build a green buffer along highway did reduce the noise level. The fourth observation location was standing inside of the central area of the highway interchange. The decibel was approximately 80-84 dBA. Again, this is higher than the acceptable noise level for the outdoor recreation area. In order to use the central space as a green open park, it will be important to mitigate the noise first. Therefore, steps need to be taken to mitigate sound levels along the highway to reduce the noise level. The fifth location was standing at the southeast entrance of the soccer park, where the decibel level was 78 dBA. Because of the distance from the highway, this place had the lowest noise level on the site. So, it may be sufficient to simply plant more trees to create a visual connection with the central area (See Figure 30).
4.1.3 User Group Observation

During the site inventory, there are a total of 36 people on the Monon Trail and 12 individuals in the soccer park. Two groups of cyclists were observed on-site. One of the groups was riding on the Monon trail. Another group was resting in the vacant central area of the intersection. This suggests that the central area on the site is being used for gatherings, but it may need to be more provision for safety and security for people gathering together. Several runners and skaters were using the Monon Trail. This all suggests that the Monon Trail could be an excellent resource to bring visitors to the site. There were 24 males and 12 females. And their ages are mostly around 20-40 years old. People in the soccer park seemed like practice soccer, and two people were walking along the outside walkway around the soccer park (See Figure 31). So, to attract more visitors, the site may need to provide some public events for different ages of groups.
Figure 30. Site Noise Observation
Figure 31. User Group Observation Diagram
4.2 Conclusion

The selected site has a real connection to schools, walkways, commercial area and residential area, which gives it great potential to become a central green space to connect with the existing soccer park. The Monon Trail would bring visitors to the site for relaxing (See Figure 32).

The condition of the site, because of the traffic noise, is just vacant land in the center of a highway intersection. And the sidewalk system is so weak that residents nearby cannot access the site, except via the Monon Trail.

In summary, the site needs:

- A noise barrier to mitigate traffic noise
- Landscape screening around the edge to create and define the space
- An improved sidewalk system
- Site programming and landscape interests
Figure 32. Site Inventory
CHAPTER V: SITE DESIGN

5.1 Goals and Objectives

Goal 1 - Use green infrastructure to mitigate and create ecologically “healthy” landscape

a. Design environmentally sensitive noise barriers
   - Integrate planting materials to augment sound attenuation and create visual interest
   - Choose an appropriate variety of plantings for noise barrier

b. Use an underground tank to store stormwater for irrigation

c. According to different highway conditions, design different type of noise barriers (both at-grade and elevated highway contexts)

Goal 2 – Once Goal 1 is accomplished improve accessibility between the site and surrounding areas

a. Reduce the conflicts between pedestrian flow and bicycle flow
   - Use different pavement patterns to separate pedestrian walkway and bike trail
- Designated bicycle circulation around the site

b. Design access from surrounding context through the site

- Build welcome plaza between Monon Trail and the site
- Create pedestrian plaza between soccer field walkway entrance and the site

Goal 3 – Once Goal 1 is accomplished use resulting space to create social opportunities on site

a. Connect the existing soccer park and Monon Trail with potential central green space

- Use vegetation to create visual connection for pedestrians
- Develop gathering spaces for public activities and community events (such as yoga, exhibition, and so on)

b. Provide comfortable outdoor space for social activities

- Use vegetation to define different outdoor spaces
- Provide sufficient outdoor furniture and shaded areas
- Offer adequate bicycle parking on site
- Provide comfortable functional and attractive sidewalk seating

5.2 Design Process

Based on the site analysis in Site Inventory and Analysis Chapter, and design goals and objective above, the design first focuses on how to build green noise barriers to mitigate traffic noise.

In the first design draft, based on the literature review to modify types of a curvilinear tunnel noise barrier, with plantings was considered to achieve noise barrier mitigate with plants to achieve a maximum effect on noise mitigation (See Figure 33).

However, this plan was impractical due to average highway width on the site was over 80’, a width and necessary height for which would make construction almost impossible.

The second design draft shows a site concept design (See Figure 34), which indicates a pedestrian circulation system for the site which is a walking loop pedestrian circulation on site is a walking loop start from a central plaza. On the west side of the site is another open lawn area. However, this area is adjacent to the highway, which may cause safety issues on-site.
5.2.1 Green Noise Barrier

This project will use four types of green noise barrier according to the existing site conditions (See Figure 35). By using different types of barriers, it will help to achieve a cost-effective budget with maximum noise mitigation.

The Type A type sound barrier uses a transparent panel covered by a wall-mounted trellis panel and plants (See Figure 36). This barrier will be located along the highway that is adjacent to the pedestrian walkway and where there is insufficient space for dense plantings. According to the literature review, the tall curved panels will attenuate more noises. The height of the barrier is 20 feet high, and the top of the trellis panel is greater than the transparent panel to allow plants to grow. These panels should reflect more noise and also provide some aesthetic views for drivers (See Figure 37). There is an underground water tank to store runoff for irrigating plants. Stormwater collected from the road surface and the plastic panel would be channeled to the underground tank (See Figure 38).
Figure 35. Green Noise Barrier Typologies
Figure 36. Green Noise Barrier – Type A

Figure 37. Green Noise Barrier - Type A
Green noise barrier Type B is designed for the elevated highway that is adjacent to a pedestrian walkway. According to the literature review, because of the sound reflection waves, the elevated highway has less noise impact than the at-grade highway. So, for this condition, the noise barrier will use a transparent plastic panel, half-covered trellis panel, and plants (See Figure 39). The form of this curved noise barrier is the same as Type A, but has less planting coverage.
The Type C of the noise barrier uses a concrete panel, a partially-covered wall-mounted trellis panel, and plants (See Figure 40). The concrete panel has drill angled holes through the barrier to covered with vines. The vines could then be planted behind the barrier and grow through the holes toward the highway side. This type of barrier is designed for the at-grade highway. And it also has more than 100 feet wide of vacant spaces adjacent to it for dense plantings. According to the literature review, dense planting areas of 100 feet in length could effectively mitigate noise levels. It is a 20-foot
high concrete panel placed between steel supports with custom rock ashlar pattern. This type of noise barrier is used most often in Indianapolis because of its cost-effectiveness. And the 100 feet dense planting areas behind the barrier will help to achieve maximum sound reduction (See Figure 41).

Figure 40. Green Noise Barrier – Type C
Noise barrier Type D is designed for the elevated highway that has more than 100 feet spaces adjacent to it. This type of noise barrier will use the same type of concrete panel with type C, but has less planting coverage. Because the elevated highway has less noise impact than the at-grade ones. So, it will use 100 feet of dense planting areas as secondary noise mitigation strategy for this kind of situation (See Figure 42).
5.3 Site Design

The final design utilized all four types of green noise barriers (See Figure 43), each with its own characteristic characteristics which carefully address the unique site conditions (See Figure 45).

The final design creates multiple accessible entrances between the site and surrounding areas (See Figure 44). It also provides separated route systems for pedestrians and cyclists (See Figure 46). The sidewalk system extends from the Monon Trail to surround the central lawn area and connects with the existing Soccer Park's walkway on the north side. The proposed bike lane begins at the welcome plaza, located east of the site, and loops around the central lawn, and back to the plaza. There is parking for 24 bikes at the north side of the welcome plaza.
The site is divided into four functional areas: gathering area, open lawn area, planting area, and outdoor activities area (See Figure 47). A disappearing water fountain is located in the welcome plaza at the east side of the site. The splashing water provides sound masking for the site (See Figure 48).
Figure 43. Master Plan
Figure 44. Site Plan
Figure 45. Green Noise Barrier
Figure 46. Site Circulation
Figure 47. Site Functional Areas
A children's playground area is located in the pedestrian near the north side of the site (See Figure 49). Fencing, trees, and seating combine to define the space and
provide a safe and comfortable gathering and play experience. Rubber paver is applied in the safe zone (See Figure 50).

Lighting is another important aspect to provide a feeling of security on-site (See Figure 51 and 52). The central lawn area provides gentle slopes to create subtle landforms for both passive and active use (See Figure 55). The lawn area is approximately 15,000 square feet, and can accommodate social events, such as outdoor fitness, art exhibition, community events and so on.
Figure 49. Pedestrian Plaza / Children Playground
Figure 50. Children’s Playground Perspective View
Figure 51. Perspective View – Daytime
Figure 52. Perspective View - Night
5.3.1 Landscape Planting

The planting area serves as a sound attenuator on the site. The overall strategy of landscape planting design in this project is to use native and non-invasive naturalized plants. It includes a variety species of trees, shrub, and groundcover species to provide visual interest for visitors, as well as flowerbeds along the walkway to provide annual
interest (See Figure 56). Fiveleaf Akebia is a twining type climbing vine, which is a good planting material for green noise barrier. It grows fast and makes an excellent cover for trellises.

Figure 56. Seasonal interest plantings on site
CHAPTER VI: CONCLUSION

This creative project incorporates green infrastructure as a noise barrier for an urban highway intersection. The design anticipates decreasing the noise level on site, while also provides open green spaces for surrounding residents. There are four different types of noise barrier for each different site conditions. Using such green noise barriers will mitigate at least 20 dBA of traffic noise, resulting in a significantly more usable and enjoyable outdoor activity environment. The project introduces 36,000 square feet of open space, including plaza, pedestrian walkway, bike route, planting area, and open lawn area.

The final destination for this creative project is to become a prototype for other urban highway intersections. There are countless highway intersections located in urban areas similar to this. In the future, if these sites become redeveloped, the adaptive design in this creative project can be a precedent for their future development.
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