The Use of Total Building Performance Approach to Assess the Negative Acoustical Impacts

Amer Zaal Odeh Al Hout

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Approval of the Institute of Graduate Studies and Research

Prof. Dr. Ali Hakan Ulusoy
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Architecture.

Prof. Dr. Rafooneh Mokhtar Shahi Sani
Chair, Department of Architecture

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Architecture.

Prof. Dr. Sadiye Müjdem Vural
Supervisor

Examining Committee

1. Prof. Dr. Sadiye Müjdem Vural
2. Assoc. Prof. Dr. Polat Hançer
3. Asst. Prof. Dr. Nazgol Hafizi

ABSTRACT

Despite the importance of building acoustic quality in creating comfortable and healthy indoor environments, existing building facades often have limited or outdated insulation, glazing, and materials that compromise acoustic performance. In North Cyprus this issue is seen in myriad number of dwellings old and new, where the acoustic or rather the noise issue is not considered in both the design and in the construction stage of the project. This research will analyze a dwelling in relation to its acoustic conditions and introduce three different proposed kinetic façades onto the existing building to see if the proposed solutions have any effect on the indoor acoustic comfort. Thus, the phase of three-dimensional modelling will be conducted using Building Information Modeling (BIM) software such as Revit to model the dwelling and Grasshopper plugin software will be used to model the proposed kinetic façades, then lastly, they will be simulated using Pachyderm, acoustic software which is another plugin for the software Grasshopper and Rhinoceros, will be used for the acoustic simulation. These simulations conducted will focus on how the Adaptive Façades will interact with the sound generated from a source, as well as how it will affect the indoor acoustic quality.

Keywords: Acoustic quality, Revit, Adaptive Façade, Noise, Acoustic Simulation, Grasshopper, Pachyderm

ÖZ

Konforlu ve sağlıklı iç mekan ortamları yaratmada bina akustik kalitesinin önemine rağmen, mevcut bina cepheleri genellikle sınırlı veya güncelliğini yitirmiş yalıtım, cam ve akustik performanstan ödün veren malzemelere sahiptir. Kuzey Kıbrıs'ta bu sorun çok sayıda eski ve yeni konutta görülmekte olup, projenin hem tasarım hem de inşaat aşamasında akustik, daha doğrusu gürültü konusu dikkate alınmamaktadır. Bu araştırma, bir konutu akustik koşullarına göre analiz edecek ve önerilen çözümlerin iç mekan akustik konforu üzerinde herhangi bir etkisinin olup olmadığını görmek için mevcut binaya önerilen üç farklı kinetik cepheyi tanıtacaktır. Böylece konutun modellenmesi için Revit gibi Yapı Bilgi Modelleme (BIM) yazılımları kullanılarak üç boyutlu modelleme aşaması gerçekleştirilecek ve önerilen kinetik cephelerin modellenmesi için Grasshopper eklenti yazılımı kullanılacak, ardından son olarak Pachyderm kullanılarak simüle edilecektir. Akustik simülasyon için Grasshopper ve Rhinoceros yazılımlarının bir diğer eklentisi olan akustik yazılımı kullanılacaktır. Gerçekleştirilen bu simülasyonlar, Uyarlanabilir Cephelerin bir kaynaktan üretilen ses ile nasıl etkileşime gireceğinin yanı sıra iç mekan akustik kalitesini nasıl etkileyeceğine odaklanacak.

Anahtar Kelimeler: Akustik kalite, Revit, Adaptif Cephe, Gürültü, Akustik Simülasyon, Grasshopper, Pachyderm

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LIST OF SYMBOLS AND ABBREVIATIONS

3D	Three-Dimensional
AEC	Architecture Engineering Construction
AI	Artificial intelligence
AKF	Adaptive Kinetic Façade
AKE	Acclimated Kinetic Envelope
ASTM	American Society for Testing and Materials
BIM	Building Information Modelling
CAD	Computer Aided Design
CDC	Centers for Disease Control
dB	Decibels
EEA	European Environment Agency
Ft/s	Feet Per Second
HVAC	Heating, ventilation, and air conditioning
Hz	Hertz
KA	Kinetic Architecture
M/s	Meters Per Second
STC	Sound Transmission Class
STI	Sound Transmission Index
SPL	Sound Pressure Level
TRNC	Turkish Republic of North Cyprus
TL	Transmission Loss
W/m^2	Watts Per Square Meter
WHO	World Health Organization

Chapter 1

INTRODUCTION

The significance of building acoustics in the realms of architecture and engineering has surged in recent years. Building acoustics bring forth a spectrum of challenges contingent on factors like design, but a universal and paramount concern revolves around noise. Therefore, comprehending the intricacies of noise and formulating strategies to forge environments that effectively manage or deflect it becomes imperative.

This research endeavors to bridge this perceptible gap and delve into the potential of adaptive facades in retrofitting existing structures with noise control and redirection in mind, with a particular focus on environmental noise sources. The ultimate aim is to unravel how adaptive facades might serve as potent tools in enhancing indoor acoustic performance. Hence, the research problem statement is defined: to investigate the efficacy of BIM Revit and Pachyderm acoustic simulation software platforms when applied to existing buildings, with a specific emphasis on examining how sound sources interact with adaptive facades and influence indoor acoustic quality.

1.1 Problem Statement

The topic of building acoustics has gained significant importance in the fields of architecture and engineering. Building acoustics can present varying challenges depending on the location and design of the structure, but a common and crucial issue that always requires attention is noise, particularly unwanted noise. Unfortunately, noise is often overlooked during the design process, which can negatively impact both the building's occupants and its overall design. Therefore, it is essential to comprehend the nature of noise and devise strategies to create environments that effectively control or insulate against it.

Traditionally, efforts to address noise have focused on interior elements of the building, such as walls, ceilings, and double-glazed windows, which contribute to room acoustics. However, one crucial element that acts as a barrier between the interior and the external environment, namely the façade, has been largely neglected. This research aims to bridge this gap and explore the role of adaptive façade in optimizing existing buildings with noise control and redirection in mind, specifically addressing environmental noise sources. The goal is to better understand how adaptive facades can be effective to enhance the indoor acoustical performance. Therefore, the problem statement for this research is to investigate the effectiveness of BIM Revit and Pachyderm acoustic simulation software platforms on existing buildings to analyze how the sound sources react with adaptive facades and the indoor acoustic quality.

1.2 Research Aim and Objectives

The goal is to evaluate the simulation of adaptive facades in relation to acoustics and evaluate how the results can be effective to tackle in solving the issue of noise pollution. The overall aim of the research is to contribute to the knowledge and understanding of how acoustic simulations can be effectively used by measuring the sound pressure levels on the outdoor and how it interacts with the said adaptive facades in addition to the speech transmission index in the indoors and its effects in the speech intelligibility. Thus, to enhance and optimize the acoustic performance of adaptive facades and their impacts on the building’s acoustic indoor quality. By achieving these aims, the research targets to inform and support decision-making processes in the field of building design, ultimately leading to the creation of more acoustically comfortable and efficient architectural environments. Overall, the objective of the literature review in this research study is to assess the existing conditions of the research on Acoustics in the form of noise pollution, Building Information Modelling (BIM), Adaptive Façades, blueprints in the guise of software such as Grasshopper with aid of Pachyderm which is a plug-in for acoustic simulations. The assimilation of the aforementioned elements could show an understanding of how facades in a building can adapt themselves in a manner to insulate the noise pollution propagating from noise sources in the context.

- Effectiveness of acoustic simulations
- Acoustic performance in relation to adaptive façades
- The use of adaptive façades in the field of acoustics.

1.3 Research Methodology

The research has conducted descriptive research in which the analysis delved into the body of literature regarding the issues of noise such as their sources, health impacts, and their impact on building design. Moreover, the research also conducted a thorough research on facades and their typologies, approaches, and the way they operate kinetically. Lastly, the research conducted a quantitative research methodology by simulating 3D models with the aid of Autodesk Revit to module the case study. However, the current body of literature demonstrates a noticeable absence of simulation tools that cater to the needs of designing, analyzing, and evaluating the sound insulation capabilities of façade elements in building structures, particularly in scenarios where higher frequencies are involved (Cheng et al., 2020). Furthermore, the research has imported the 3D modules into Pachyderm a plugin for Rhino and Grasshopper to achieve the simulation results.

1.4 Research Limitation

Limited acoustic insulation, the building used as a case study lacks acoustic insulation in various façade elements, including sliding doors and walls without soundproofing materials, which could affect the accuracy of the research. Façade design and material variability, the effectiveness of the façade in acting as an insulator depends on the absorption coefficient of the materials used and the design of the façade, introducing potential variability in results. Accuracy of modeling software the accuracy of the BIM Revit model, as well as the Grasshopper and Pachyderm acoustic simulation algorithms used for analysis, may impact the research outcomes. Data availability and accuracy the availability and accuracy of data related to existing building facades may present challenges and potentially affect the precision of simulations and analysis. Complexity of acoustic phenomena acoustic behavior in buildings is influenced by a multitude of factors, including room geometry, surface materials, occupant behavior, and environmental conditions. Capturing the full complexity of these acoustic phenomena in simulations can be challenging and may not entirely replicate real-world acoustic conditions within the building.

1.5 Incorporating Software Tools

Various software tools have been used to execute distinct tasks to achieve the desired research results and objectives, the software tools will be described briefly in the following paragraphs below, pertaining their objectives to fulfill the research’s aims.

1.5.1 Autodesk Revit 2023

Autodesk Revit is an advanced Building Information Modeling (BIM) software, providing architects, engineers, and construction professionals with a diverse set of tools and functionalities. The software has been used to extrude the exact measurements of an imported plan from Autodesk AutoCAD and then producing a three-dimensional model using the integrated architectural elements in Autodesk Revit. From the three-dimensional model Revit enables the extraction of detailed sections and elevations, which will be used to depict the aims and targets of this research.

1.5.2 Rhino 7 and Grasshopper

Rhino is a powerful and versatile 3D modeling tool used by designers, architects, engineers, artists, and other professionals to create and modify 3D models for various purposes. Some of the key features and capabilities of Rhino 7 is Parametric Modeling. Rhino 7 with the aid of Grasshopper visual programming language which acts as an integral part of the software, it enables users to create parametric models by defining relationships between various elements, making it easier to explore and modify design options. Rhino 7 offers plugins and add-ons for performing various analyses and simulations, such as structural analysis, environmental analysis, and acoustical analysis. In the case of this research the aim is to use the module made in Revit, will be imported to integrate the newly made façade design using Rhino 7 and simulating it with an acoustical simulation tool Pachyderm.

1.5.3 Pachyderm Simulation Tool

Pachyderm Acoustic Simulation comprises a set of acoustic simulation algorithms that serve to forecast noise, depict the propagation of sound, and enable critical auditory examination of designed environments. Even though the software is new and lacking in documentation of the usage and application of its embedded tools, it is very effective in calculating and measuring acoustic parameters such as sound pressure level, speech transmission index, reverberation time, early decay time, and clarity.

1.6 Thesis Framework

The research consists of six distinct chapters, each dedicated to specific facets. In the initial chapter, a concise overview outlines the fundamental concepts and elements of the entire study, encompassing the problem statement, research goals, objectives, limitations, and the software integrated into the research. The second chapter delves into noise-related concerns concerning façade arrangements. The third chapter explores the utilization of BIM and Rhinoceros related plug-ins and simulation tools. The fourth chapter delves into the case study. By combining these tools and referencing relevant literature, the study aims to achieve an optimized solution for the existing building's façade in addressing noise pollution concerns. Finally, the fifth chapter provides a summary of the findings derived from both the comprehensive analysis of the literature review and the results obtained through the conducted simulations.

The chapter dedicated to noise pollution and façade organization collected comprehensive data on various aspects of noise, including its definitions, propagation, properties, sources, and effects on human health and building design. The noise-related section of the chapter aimed to establish a foundation for understanding these factors as a reference or guide. Additionally, valuable information on adaptive facades was gathered, encompassing their types, design approaches, and behavior in diverse environments, particularly in relation to adaptive facades and their responses to environmental conditions. In conclusion, the chapter outlined effective strategies for how kinetic or adaptive facades should react to address noise-related issues, such as mitigating and insulating external noise sources, particularly traffic-related noise sources.

The subsequent part of the research delved into several advanced software platforms extensively utilized in the fields of architecture and engineering, including Autodesk Revit, Rhino (along with the Grasshopper plug-in), and Pachyderm, which also functions as a plug-in within Grasshopper for acoustic simulations. This chapter focused on exploring the unique significance of these technologies in architecture, elucidating how they synergistically work together to achieve the study's objectives, thereby clarifying their intended applications. Furthermore, the study outlined the benefits of utilizing these software platforms to model adaptive facades with precision and optimize the building's acoustical concerns, particularly related to noise, by employing Grasshopper in conjunction with the Pachyderm plug-in for noise simulations.

This section of the study had the objective of assessing the sound pressure level and the speech transmission index in an existing residential building located in Famagusta, TRNC. The choice of this specific context was motivated by the lack of attention to acoustical issues and their detrimental effects on human health and building design. Additionally, the building's location near one of the city's busiest and heavily trafficked streets further underscored the importance of the investigation. The assessments were based on sound properties and guidelines, including sound pressure level (SPL) and the speech transmission index (STI). Furthermore, the study proposed three distinct adaptive façade design solutions for sound insulation.

Ultimately, the data obtained through the Pachyderm simulation tool provided insights into the most effective alternative for achieving an optimized façade design that effectively mitigates noise pollution originating from the contextual sources.

Finally, the research delves into the outcomes and the results of what the previous chapters have outlined. The results are of how the proposed adaptive façade concepts are designed for optimizing building acoustics. Moreover, the simulation results of the aforementioned adaptive facades and the case study's simulated results without the proposed facades, to show and compare their sound pressure level and the speech transmission index results of them individually. Thus, determining the optimum façade that has ideal acoustical qualities in relation to noise pollution.

Chapter 2

RELATION OF NOISE POLLUTION AND FAÇADE ORGANIZATION

In the vast landscape of human experience, sound is a ubiquitous phenomenon that takes on various forms and meanings across different disciplines. From the precise realm of Linguistics, where it can disrupt the subtleties of speech, to the broader arenas of acoustics, electronics, and physics, where it is often used interchangeably with the term "sound," this concept carries diverse connotations and implications. But it is in the intersection of these fields, where sound meets the human experience, that we begin to unravel the intricate tapestry of noise and its profound impact.

In this exploration, we navigate through the multifaceted dimensions of noise, examining its role in shaping our understanding of communication, acoustics, and the environment. Beyond the technical distinctions, noise emerges as more than just an inconvenience. It morphs into a pervasive force known as noise pollution, which disrupts the delicate balance of our auditory and non-auditory well-being. This environmental disturbance extends its reach into the intricacies of social interactions, the execution of complex tasks, and the depths of human annoyance. In this research, we delve into the profound significance of noise, recognizing its power to shape our lives in ways we may not have fully appreciated.

2.1 Noise Pollution

In the field of Linguistics, noise refers to sounds that disrupt the identification and understanding of the spectral details in speech (Chen et al., 2014; Fu et al., 1998). In the fields of acoustics, electronics, and physics, the terms "sound" and "noise" are often used interchangeably, but they carry different implications when applied to listeners. Noise pollution constitutes an environmental disturbance and a source of stress. It has an impact on both auditory and non-auditory well-being, altering social conduct, disrupting the execution of intricate tasks, and inducing annoyance (Chandrappa, & Das, 2021).

In engineering, noise carries an additional meaning of signals that lack meaning or coherence over time, while sound signifies signals that have significance. However, describing noise as simply unwanted sound overlooks the current understanding of its detrimental effects on both humans and animals. It also suggests a subjective aspect to the evaluation of noise, with the listener's complaint about noise incorporating a value judgment (Fink, 2019). The issue of noise pollution has been discussed for several decades. Concerns about excessive noise and its impact on human health and the environment have been raised since the early 20th century. However, it was in the mid-20th century that noise pollution began to receive more widespread attention. The classification of a sound as noise depends on its acoustic characteristics as well as its disruption to designed events. In one of Stewart J's book “Why Noise Matters”, he presented an alternative analogy that explores how individuals perceive sound and noise, which can vary based on the specific settings and activities in which they are engaged. This approach helps to unveil the authentic essence and understanding of sound and noise. Stewart stressed this by saying, “So when does sound become noise?

There is no simple answer to that question. There is no clear dividing line. There is no point at which an increase in decibel levels automatically turns sound into noise. One person’s sound can be another person’s noise. The beat of the background music in a department store, for example, is enjoyed by some shoppers but drives others to distraction.” (Stewart, 2011).

In the United States, the issue gained prominence in the 1960s and 1970s with the passage of the Noise Control Act of 1972. This legislation aimed to establish a national policy to promote an environment free from noise that could jeopardize public health or welfare. It led to the creation of the Environmental Protection Agency's Office of Noise Abatement and Control, which was responsible for addressing noise pollution issues. Internationally, the World Health Organization (WHO) has been actively involved in addressing noise pollution since the 1970s. In 1999, the WHO published its first set of guidelines on community noise, which provided recommendations on acceptable noise levels for different environments and activities. These guidelines have been revised and updated over the years to reflect new research and knowledge. Since then, noise pollution has remained a topic of ongoing discussion and concern. Efforts have been made to regulate noise levels in various settings, including residential areas, workplaces, and transportation systems.

2.1.1 How Sound Travels

To comprehend the concept of sound and its transmission, it's crucial to start by understanding the nature of sound itself and how it moves through different mediums. Sound is essentially produced when an object vibrates within a medium, which can take the form of a solid (such as the Earth), a liquid (like water), or a gas (such as air). Sound is conveyed through mechanical waves, which represent disturbances that transport energy from one location to another within the selected medium. These waves are subsequently detected by the human ear, embarking on a journey that spans from the outer ear and extends to the eardrum, as illustrated in Figure 1. In the case of sound, these disturbances originate from the vibrations of an object, while the medium can consist of interconnected and interactive particles. This fundamental principle allows sound to propagate through gases, liquids, and solids alike (Basnet, 2023).

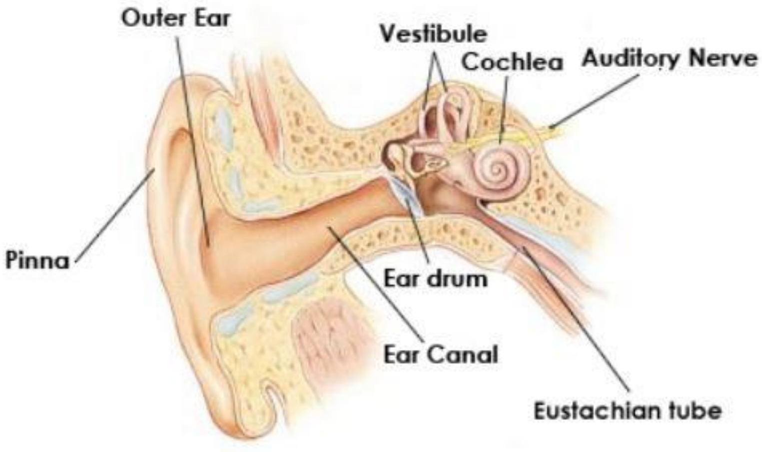


Figure 1. Ear Diagram (Harris, 2021)

2.1.1.1 Acoustic Waves

Sound predominantly travels through the air in our atmosphere. To understand this process, let's examine a basic vibrating object, like a speaker. When a speaker is emanating music, it undergoes vibration, causing it to flex in and out. As it flexes outward, it pushes the surrounding air particles on that side, leading to a chain reaction of collisions between the air particles. This series of collisions is known as compression (Hawkins, 2023). On the other hand, when the bell flexes inward, it pulls in the surrounding air particles, resulting in a decrease in pressure.

This pressure drop pulls in more air particles around it, creating another pressure decrease, and this process extends further out. This decrease in pressure is referred to as rarefaction as can be seen in Figure 2.

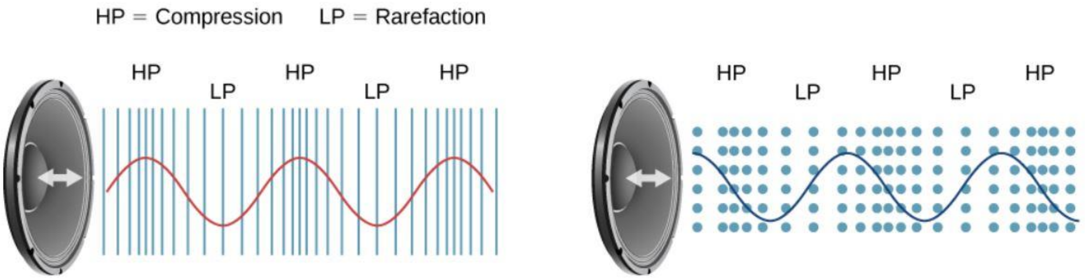


Figure 2. A visualization of how a sound is travelling from the source “speaker” and creating the compression and rarefaction effects (OpenStax, 2016)

Thus, a vibrating object generates a wave of pressure fluctuations throughout the atmosphere. The distinct sounds that are heard from various vibrating objects are due to differences in the frequency of the sound waves. A higher frequency indicates quicker back-and-forth switches in air pressure fluctuations, which translates to a higher pitch. Conversely, lower frequency implies fewer fluctuations in a given time period, resulting in a lower pitch. Additionally, the amplitude of the wave, representing the air pressure level in each fluctuation, determines the loudness of the sound. When an object vibrates in the air, it causes the surrounding air particles to move, and these air particles, in turn, transmit the vibration through the air, propagating the sound (Hawkins, 2023).

Ears are remarkable organs with the ability to detect and capture all the sounds present in their surroundings, converting this auditory information into a format that the brain can comprehend. What makes this process truly fascinating is that it operates entirely through mechanical means. Unlike the senses of smell, taste, and vision, which rely on chemical reactions, the hearing system is solely dependent on physical movements to function (Harris, 2021).

2.1.1.2 Acoustic Intensity

Sound intensity refers to the amount of sound energy that passes through a unit area in a specific direction per unit of time. It is a measure of the strength or power of sound waves at a particular point in space. Sound intensity is typically expressed in units of watts per square meter (W/m^2). The intensity of a sound wave is directly related to the amplitude of the wave, which represents the maximum displacement of the air particles caused by the sound (Britannica, & Editors of Encyclopaedia, 2013). As the amplitude of a sound wave increases, so does the sound intensity. The sound intensity level, often measured in decibels (dB), is a logarithmic representation of the sound intensity relative to a reference level. The decibel scale is used because sound intensity can vary over a wide range, and the logarithmic scale allows us to express these variations in a more manageable form (OpenStax, 2016).

2.1.1.3 Speed of Acoustic Waves

The speed of sound refers to the velocity at which sound waves propagate through a medium, such as air, water, or solids. The speed of sound is dependent on the properties of the medium through which it travels, including its density, compressibility, and temperature (Britannica, & Editors of Encyclopaedia, 2013).

Figure 3 illustrates significant variations in the speed of sound across the air medium. In dry air at room temperature (around 20 degrees Celsius or 68 degrees Fahrenheit), the speed of sound is approximately 343 meters per second (m/s) or about 1,125 feet per second (ft/s).

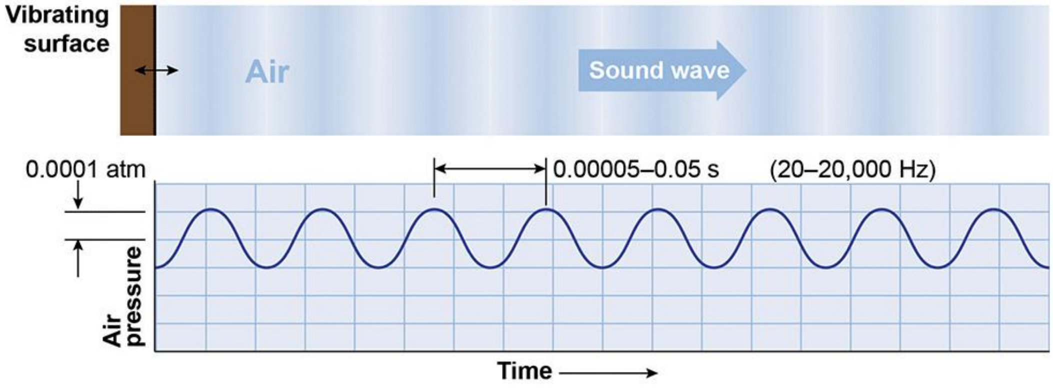


Figure 3. A sound wave is generated by a source, which vibrates at a specific frequency (URL 1)

However, this value can vary slightly depending on factors such as humidity, pressure, and composition of the air. In general, sound travels faster in denser and less compressible materials. For example, sound travels faster in water than in air, and even faster in solids like steel or iron. In water, sound travels at around 1,480 m/s (4,850 ft/s), and in steel, it can reach speeds of about 5,960 m/s (19,550 ft/s) (OpenStax,2016).

2.1.2 Acoustic Properties

First an understanding of how movement of sound from one point to another should be met. Moreover, Acoustics can be viewed as the intermediary link between a sound source and a listener, encompassing elements such as speakers, air, reflections, and the ears of the listeners.

2.1.2.1 Sound Reflections

A reflection in acoustics refers to a sound that has bounced off one or multiple surfaces while traveling from its source to a listener. Unlike directional sound sources that emit sound directly to our ears in a straight line, most sound sources emit sound in countless directions. Consequently, reflections occur on various surfaces, affecting the sound. When sound signals are abundant with reflections, the original pure sound directed towards us becomes indiscernible as can be seen in Figure 4. While some sound from the source reaches our ears directly, a significant portion bounces off surfaces like walls, ceilings, floors, or facades first. The time delay of these reflected audio signals significantly impacts our perception of the sound. Extended delays create an echo effect, while brief delays result in blurring or fuzziness of the directed sound source (Support Technology Pty. Ltd., 2018).

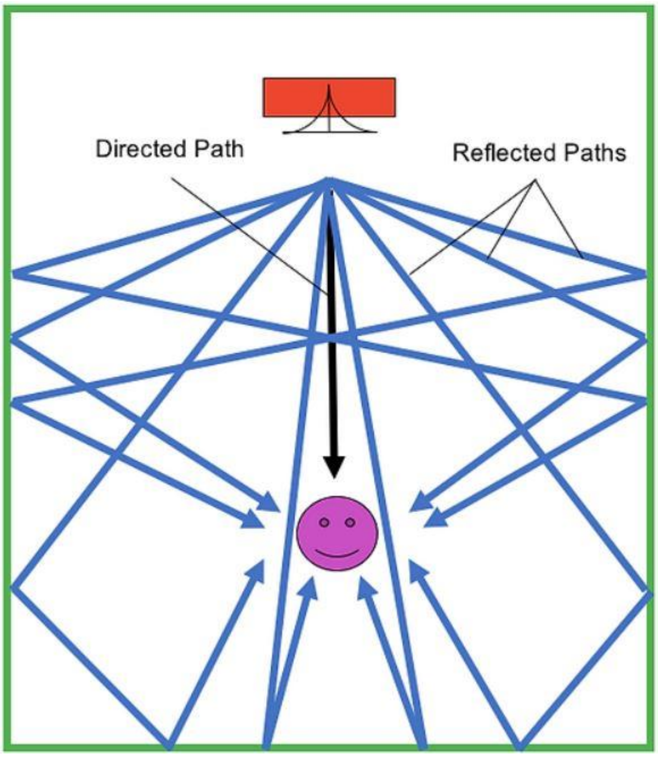


Figure 4. How sound is reflected in a space (Support Technology Pty. Ltd., 2018)

2.1.2.2 Sound Absorbers

Definition of an absorber is that absorption occurs when a portion of the incoming sound dissipates into the surface it encounters. Although the sound continues to travel within the room, it does so with reduced energy as some of it gets absorbed by the surface. Consequently, the sound rapidly loses its energy, resulting in a shorter duration of sound presence within the room (Vreede, 2018). All surfaces have sound absorption properties, which vary based on the materials used. Hard surfaces tend to absorb minimal sound and reflect most of the acoustic energy as can be seen in Figure 5. On the other hand, softer surfaces like plasterboard absorb certain frequencies at different audio levels and reflect the rest. To address the adverse effects of reflections, acoustic treatments known as absorbers are employed. These absorbers come in various forms and function like acoustic vacuum cleaners, converting sound energy into heat energy through a resistive process. As a result, very little, if any, sound is reflected off an absorber.

Figure 5. Illustration of sound absorption when hitting a surface (Vreede, 2018)

The effectiveness of an absorber is determined primarily by its thickness, which contrary to common belief, mainly affects the range of sound absorbed, rather than the quantity of sound absorbed. For instance, a 1" (25mm) thick absorber absorbs sound across a range from 1,000 Hz to 20,000 Hz, a 2" (50mm) thick absorber from 500 Hz to 20,000 Hz, and a 4" (100mm) thick absorber from 250 Hz to 20,000 Hz (Support Technology Pty. Ltd., 2018).

2.1.2.3 Sound Diffusion

Diffusion occurs when sound is dispersed or scattered in various directions upon hitting a surface as depicted in Figure 6. Unlike reflection, sound loses its directional nature during diffusion. The significant distinction lies in the perception of sound location: with reflection, one can discern the source's direction, whereas in diffusion, the sound emanates from all directions. Hard and non-smooth surfaces are particularly effective in facilitating sound diffusion (Vreede, 2018).

Figure 6. Illustration of sound Diffusion when hitting a surface (Vreede, P, 2018)

2.1.2.4 Sound Transmission

When sound travels through air and strikes a surface, such as a wall, floor, or ceiling, it behaves like other energy. Some of the sound energy is reflected back off of the surface, some is absorbed into the material or construction assembly, and some is transmitted directly through it as shown in Figure 7 (Shravage, 2015).

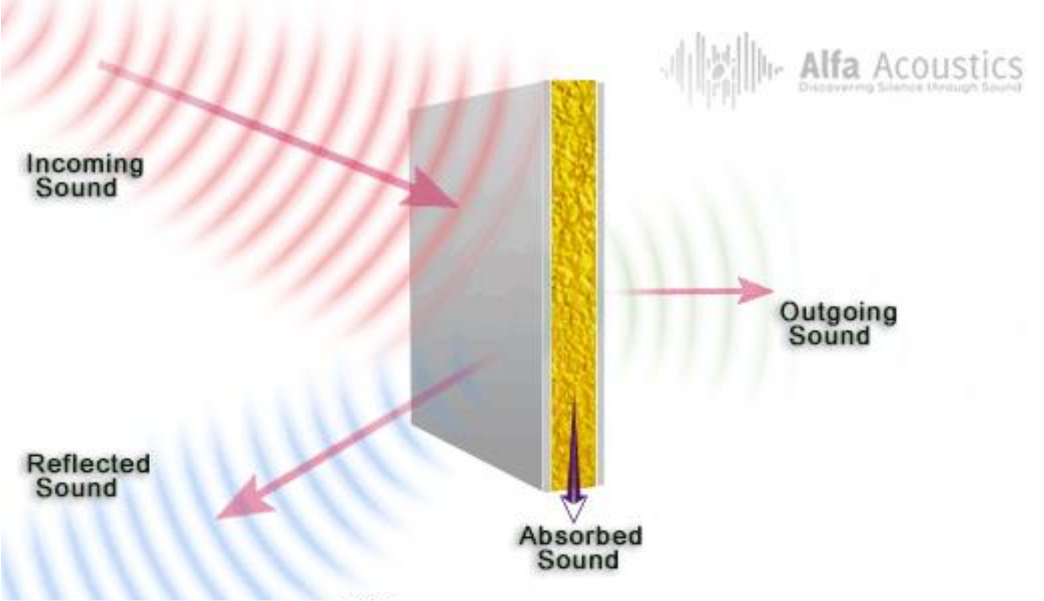


Figure 7. Illustration of sound Transmission when hitting a surface (Shravage, 2015)

This is directly akin to light, which can be reflected off a glossy surface, absorbed into a dark surface, or transmitted through a translucent material. Similarly, different amounts of sound energy can be reflected, absorbed, or transmitted when striking different surfaces, materials, and assemblies in buildings. Below is a condensed overview of the terms and measures associated with the principles of managing sound transmission between spaces (Arsenault, 2016).

- Transmission Loss (TL) is a crucial measure of a material or building assembly's capacity to obstruct or diminish sound passing through it. TL is gauged in decibels at various frequencies to assess the amount of sound transmission lost at each frequency. A TL of 10 signifies that the sound on the receiving end is 10 dB quieter compared to its source.
- Sound Transmission Class (STC) is ascertained using ASTM E90 (American Society for Testing and Materials) test methods, specifically for measuring airborne transmission loss in interior walls and ceiling/floor assemblies. A

higher STC rating indicates that the component or assembly blocks more airborne sound. Conversely, lower STC ratings imply that more sound passes through, leading to an increase in background noise within the space. It is essential to note that sound does not pass through a structure as commonly believed. Instead, sound generated on one side of a wall energizes the wall structure and sets it in motion, akin to a diaphragm. Consequently, the wall becomes a transmitter of sound energy, which can be heard on the opposite side by the listener. As a result, ASTM test methods to determine STC ratings focus on this direct transmission process, although testing procedures have evolved over the years, meaning that STC results posted before 1999 may not yield the same outcomes today.

2.1.3 Noise Sources

Noise sources in the built environment can be categorized as external noise sources and internal noise sources. The noise sources can vary from one location to another, whether the sources are external or internal.

2.1.4 External Noise Sources

Here are some common examples of external noise sources according to (Ogunsote & Ganiyu, 2010). that can contribute to noise pollution:

1. Traffic Noise: Roadways, highways, and intersections can generate significant noise from vehicles, including cars, trucks, motorcycles, and public transportation.
2. Public Transportation: Noise pollution can arise from buses, trams, subways, aircraft noise, and railway noise such as trains and subways.

3. Construction and Demolition: Construction sites and demolition activities produce high levels of noise due to heavy machinery, power tools, and other equipment used in the process.
4. Industrial Noise: Industrial facilities, factories, and manufacturing plants can produce substantial noise due to machinery, processing equipment, ventilation systems, and other industrial processes.
5. Commercial and Entertainment Venues: Noise can emanate from commercial establishments, restaurants, bars, nightclubs, stadiums, and other entertainment venues, especially during peak hours or events.
6. Outdoor Equipment and Activities: Noise pollution can be caused by outdoor activities like landscaping, gardening, recreational activities, and outdoor events that involve loudspeakers, musical performances, or amplified sound systems.
7. Adjacent Buildings: Noise can transmit from adjacent buildings, especially in densely populated urban areas, where shared walls or inadequate sound insulation can lead to sound transfer.

Thus, in some contexts there can be more external noise sources and internal than others as can be visualized in Figure 8. It's important to note that the specific noise sources and their intensity can vary based on the geographical location, time of day, and other local factors.

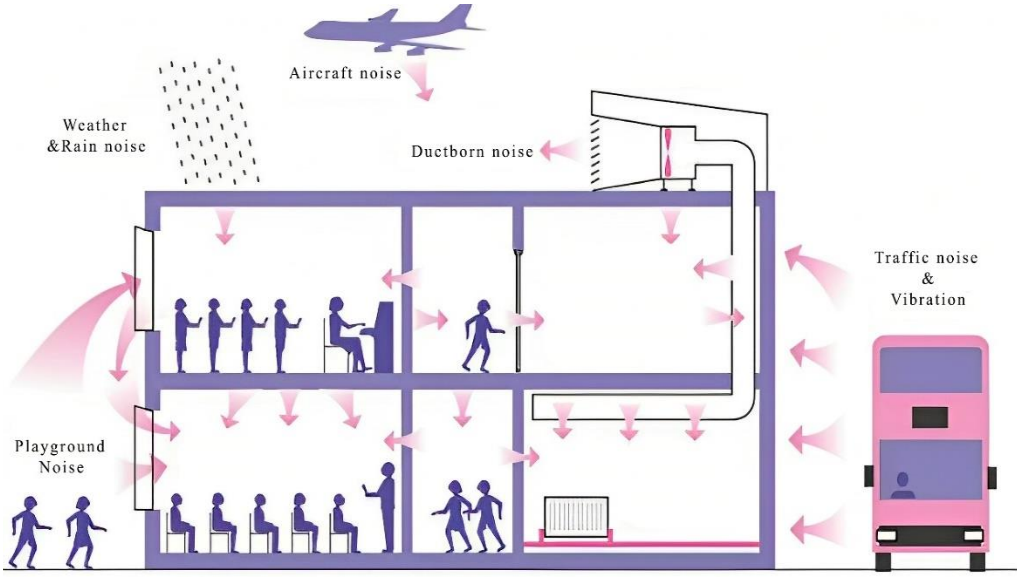


Figure 8. Sources of Noise in Buildings (The Constructor, 2021)

2.1.5 Noise Impacts on Human Health

The impact of noise pollution on human health, such as sleep disturbances, hearing loss, and increased stress levels, continues to be studied and addressed by researchers, policymakers, and urban planners worldwide. Prolonged exposure to environmental noise has been linked to various detrimental effects, which can be alleviated through appropriate sound treatments (Chepesiuk, 2005). Chepesiuk discusses the health issues associated with harmful noise, such as tinnitus, elevated blood pressure, restricted cardiovascular function, and hearing loss. These effects, in turn, result in social limitations, decreased productivity in the workplace, and impaired communication between students and teachers. It is crucial to acknowledge these potential health consequences and implement strategies to decrease noise levels in our environment. By employing noise reduction techniques, utilizing sound insulation materials, establishing areas of tranquility, and following noise regulations, we can alleviate the negative effects of noise on human well-being. Extreme exposure to excessive traffic noise presents a multitude of risks to human well-being. These sounds disrupt daily activities, as can be seen in Figure 9, they can hinder peaceful rest, and have the potential to evoke negative emotions and decrease productivity (Öhrström et al., 2006).

Figure 9. Effects of noise levels of road traffic of greater than 55 dB (Nađ, 2023)

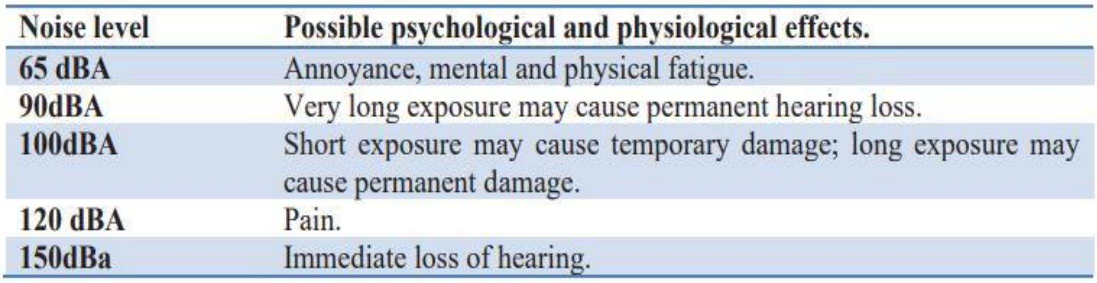
The impact of ambient environmental noise directly affects human health. The Centers for Disease Control and Prevention (CDC) even recognizes occupational hearing loss as one of the most common work-related illnesses in the United States (National Institute for Occupational Safety and Health, 2018).

2.1.5.1 Physical Noise Health Impacts

Physical noise can have various health impacts on individuals, depending on the intensity, duration, and frequency of exposure. It's important to note that the impact of noise on health can vary among individuals, and some people may be more sensitive to noise than others.

Noise regulations and guidelines are often in place to protect people from excessive noise exposure in occupational and community settings, Table 1 depicts how various noise levels have negative psychological and physiological impacts.

Table 1: Effects of sounds on both psychological and physiological aspects (Ogunsote, 2010).



Noise level	Possible psychological and physiological effects.
65 dBA	Annoyance, mental and physical fatigue.
90dBA	Very long exposure may cause permanent hearing loss.
100dBA	Short exposure may cause temporary damage; long exposure may cause permanent damage.
120 dBA	Pain.
150dBa	Immediate loss of hearing.

To minimize the health impacts of physical noise, it's essential to implement appropriate noise control measures and use hearing protection, when necessary, especially in environments with high noise levels. Some classifications of negative noise health impacts According to (Basner et al., 2014) are classified below:

1. Hearing Damage: Exposure to excessive noise levels can lead to hearing damage or loss. Prolonged or intense exposure to loud noises can cause permanent damage to the delicate structures of the inner ear, resulting in hearing impairment.
2. Cardiovascular Issues: Prolonged exposure to high noise levels has been associated with cardiovascular problems. Noise-induced stress can lead to increased blood pressure, elevated heart rate, and an increased risk of heart disease and stroke.
3. Tinnitus: Exposure to loud noise can also cause tinnitus, which is the perception of ringing, buzzing, or other sounds in the ears when there is no external sound source. It can be a temporary or chronic condition.

2.1.5.2 Psychological Noise Health Impacts

Environmental noise pollution has myriad severe psychological health impacts, according to (Yu et al., 2020; Cantuaria et al., 2021) supports that there’s an all-rapid growing risk of cognitive disorders in relation with noise pollution. The annual toll of more than one million healthy lives yearly in Western Europe can be attributed to traffic noise alone. This includes the adverse effects of noise-related disabilities and diseases.

Additionally, it can activate stress pathways, stimulate the autonomic nervous system and the endocrine system, and influence physiological as well as psychological functions by triggering the release of stress hormones (Babisch, 2002; Selander et al., 2009). Moreover, on the related psychological noise health Impacts can be classified and categorized according to (Lim et al., 2018; Minakawa et al., 2019; Irwin and Vitiello, 2019) as following:

1. Sleep Disturbance: Noise has the potential to disrupt sleep and impact its overall quality.
   Noises during the night, such as traffic, construction, or loud neighbors, can disturb sleep, resulting in insufficient rest, daytime sleepiness, and reduced cognitive functioning.
2. Stress and Anxiety: Continuous exposure to noise can increase stress levels and contribute to feelings of anxiety and irritability. Chronic noise exposure triggers the release of stress hormones, affecting the body's physiological responses and overall well-being.
3. Impaired Concentration and Performance: Noise can impair concentration, attention, and cognitive performance.

In work or educational settings, excessive noise can decrease productivity, hinder learning, and lead to errors or reduced efficiency.

4. Communication Difficulties: High noise levels can interfere with effective communication. It becomes challenging to hear and understand speech, leading to misunderstandings, frustration, and impaired social interactions.
5. Mental Health Issues: Noise pollution has been linked to mental health problems such as anxiety, depression, and mood disorders. Chronic exposure to noise can contribute to the development or exacerbation of these conditions.

2.1.6 Noise impacts on Architectural Design

Noise pollution has a significant impact on architecture, and the design of buildings. Several influences of noise pollution according to (Rieper, 2012; Bhatia, 2014) are:

- Consideration to the contextual factors when selecting a site for a building is of high importance. Noise sources such as highways, airports, or industrial areas can generate high noise levels that need to be mitigated. Site planning may involve locating noise-sensitive spaces, such as bedrooms or study areas, away from high-noise sources (Bhatia, 2014).
- Building Design: Architects employ various design strategies to minimize the transmission of noise within buildings. This includes careful placement of windows, walls, and insulation materials to reduce external noise infiltration. Building layouts can be designed to create barriers or buffer zones between noisy and quiet areas, ensuring noise-sensitive spaces are shielded from high-noise sources.
- Acoustic Design: Architects incorporate acoustic design principles to control and enhance sound within buildings. This involves selecting appropriate

materials, finishes, and construction techniques that absorb or reduce unwanted noise.

From an architectural perspective, mitigating the impact of noise on a building and its design requires considering different design strategies and features, as discussed earlier. However, it is crucial to focus on addressing the root cause of the noise issue itself, which involves identifying and dealing with the noise sources effectively.

2.2 Kinetic Architecture Systems

Kinetic Architecture as an interpretation in a recent study done by “LIBART” is described as Kinetic Architecture (KA) and characterized as a concept that involves designing spaces and objects capable of physically reconfiguring themselves to adapt to evolving requirements. To effectively cater to the dynamic, flexible, and ever-changing needs of today, kinetic architecture relies on motion as a key element.

By integrating motion into architectural designs, it offers occupants additional dimension through which they can engage and interact with their environment (Libart USA, 2018). Interactive architecture, also known as Kinetic Architecture (KA) as mentioned earlier, encompasses multiple facets or aspects including environmental considerations, functional facets, and aesthetic elements. Based on the aforementioned definitions, the term "Kinetic Architecture" can be described as buildings or building elements that respond to changes in their surroundings, whether indoors or outdoors, and influenced by environmental or human factors.

Although the formal definition of "Kinetic Architecture" emerged in 1970, various kinetic solutions existed prior, ranging from individual building components to entire structures. These kinetic solutions served different purposes, including protection (bridges), entertainment (stages and revolving restaurants), medical applications (sanatorium and solarium), and residential use (Fouad, 2012).

Presently, kinetic trends in architectural environments primarily address practical or human-oriented conditions, and often a combination of both. These trends can be classified into four categories:

1. Spatial optimization systems
2. Multi-function design
3. Contextual adaptability
4. Mobility.

As per the findings of (Siham, H. et al., 2022) research study, the definitions of these facets are as follows:

1. **Environmental considerations Facets**: The design of a building can be aimed at managing its internal environment or controlling external factors in the surrounding environment that may have a detrimental impact. The building can function as a regulator, adapting its state, characteristics, and structures to govern key climate elements essential for human comfort. This includes regulating variables related to thermal energy (temperature, air movement, humidity), lighting (visible daylight, ultraviolet rays, infrared rays), and acoustics (noise).
2. **Functional facets**: An interactive building can be purposefully designed to fulfill functional objectives, such as enhancing the efficiency of functional areas and implementing self-operating systems.

It also aims to provide greater flexibility and adaptability to the building, enabling improved utilization and effectiveness. The distinction between adaptive space and interactive architecture lies in the extent of interaction involved. Previous approaches relied on user manipulation to modify the geometric forms of project components, manually adjusting aspects such as size, color, shape, or position of the elements comprising the space.

3. **Aesthetic elements facets**: Certain interactive buildings are specifically designed with an aesthetic objective, aiming to encompass aesthetic and psychological characteristics that cater to the user's needs and create a unique architectural experience with evolving visual qualities.

These qualities aim to evoke a sense of intrigue, suspense, and fascination, breaking away from the monotony associated with traditional architecture.

Interactive architecture goes beyond merely facilitating lifestyle; it also influences the viewer's perception by reimagining the role of the physical environment in shaping their overall experience. Another slightly similar interpretation is that the concept of kinetic architecture involves designing buildings with elements that can transform and operate automatically. This allows the building's shape to be altered to accommodate the needs of the people and adapt to varying environmental conditions (Elmokadem, Ekram et al., 2018).

Kinetic structure systems refer to buildings or building components that possess the ability to change their mobility, location, and/or geometry. These structures offer various performance options, such as folding, sliding, expanding, transforming in both size and shape, and the development process of such systems must consider the integration of kinetic structures as an integral component of the overall interactive system, rather than treating them as separate entities. This approach ensures the creation of more suitable solutions and enhances effectiveness in achieving desired outcomes. Kinetic structures can be labeled into three distinct types embedded, dynamic, and deployable as shown in Figure 10.

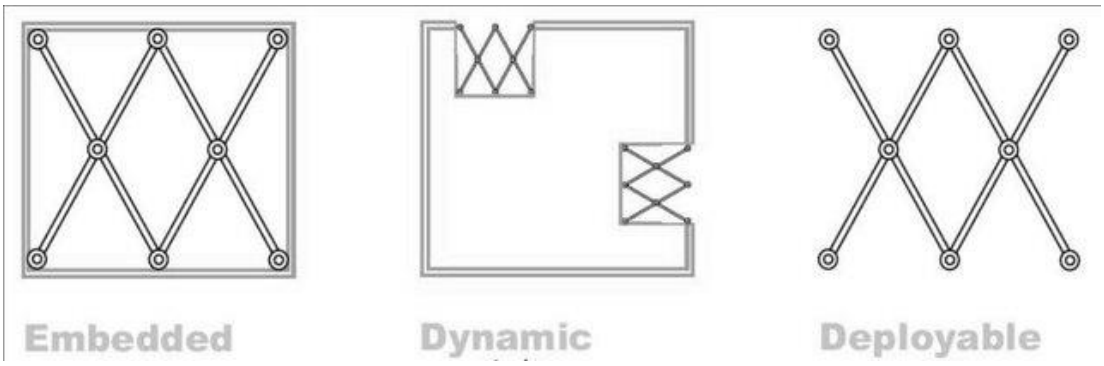


Figure 10. The diagram illustrates the various typologies of kinetic structures (Fox, 1999)

According to Michael Fox (Fox & Yeh, 2000) he categorized the control systems for kinetics into six distinct types based on their varying levels of complexity:

1. Internal controls: These controls lack a physical mechanism, such as mechanical hinges, to directly manipulate their movement.
2. Direct control: They are manipulated directly by an external energy source.
3. Indirect control: Their operation relies on a sensor feedback system.
4. Responsive indirect control: Their functioning is contingent upon multiple feedback sensors.
5. Ubiquitous responsive indirect control: These controls possess predictive capabilities through a network of controls equipped with predictive algorithms.
6. Heuristic, responsive indirect control: These controls operate based on algorithmically mediated networks that have the ability to learn and adapt.

Embedded kinetic structures:

Michael A. Fox (2000) defines embedded kinetic structures as systems that are integrated within a larger architectural entity, occupying a fixed position. These structures primarily serve the purpose of controlling the overall architectural system, adapting it in response to various factors, particularly environmental conditions such as seismic activity and wind fluctuations. Embedded kinetic structures are considered the most advanced among the three categories and are invariably coupled with computational control mechanisms (Fouad, 2012). An example of how embedded structure mechanism works can be seen in figure 11. In the stadium of Qiuhong, China, in which the stadium features a mobile roof composed of eight petals, with each petal rotating on a single hinge simultaneously. Below the petals, there is a circular truss with an inverted triangle shape that provides support. Each petal is capable of movement through a combination of a hinges and three rails, creating a cantilever beam structure. This design ensures sufficient strength even in the face of strong winds, such as during a typhoon (Shome et al., 2022).

Figure 11. An example of embedded kinetic structures, Qi Zhong Stadium (URL 2)

Deployable kinetic structures:

According to Michael A. Fox (2000), deployable kinetic structures are temporary structures that can be easily transported. Unlike embedded kinetic structures, which are fixed in place, deployable structures are designed to be constructed and deconstructed in a reversible manner, providing mobility rather than motion within a fixed framework. These structures are commonly employed in exhibit design, pavilion construction, and stage design, where the ability to swiftly assemble and disassemble is essential. Unlike embedded kinetic structures, deployable kinetic structures are seldom integrated with computational control systems (Fouad, 2012). An example of how deployable structure mechanism works can be seen in figure 12. The deployable bridge comprises of eight modules, with each module consisting of two fixed trapezoidal steel frames positioned on either side of a deck section at the base. These modules are interconnected by hinges at the bottom and pinned rigid struts at the top, linking the trapezoidal frames. The movement of the structures is facilitated by hydraulic rams connected to these pinned struts. When the hydraulic rams extend, the modules fold, resulting in the bridge's curved shape.

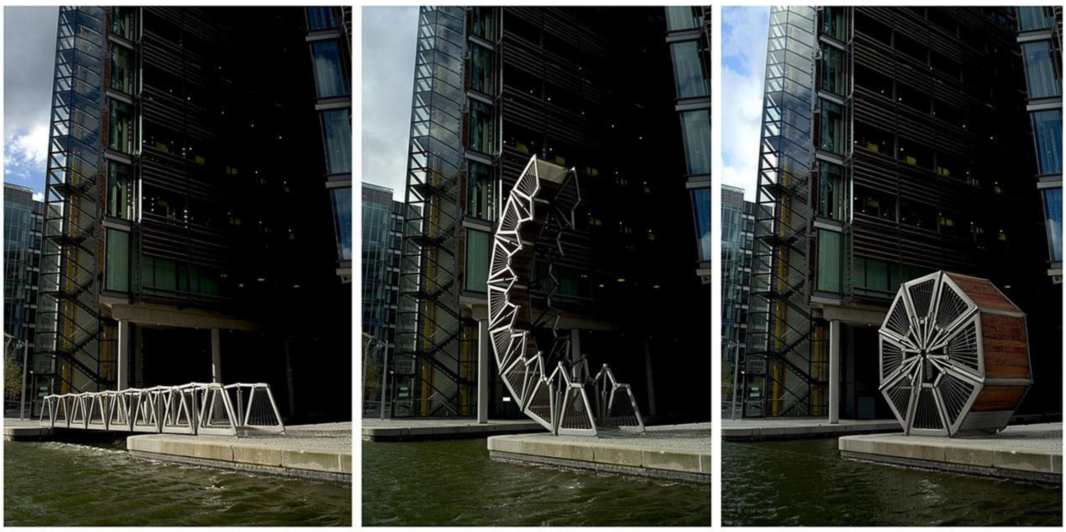


Figure 12. An example of Deployable kinetic structures and how they operate. Rolling bridge, Paddington Basin, London, UK (URL 3)

In its deployed state, the top of the frames and the struts serve as handrails, with the rams integrated into them. When packed, the bridge completely folds back onto itself, forming a circular shape on one side of the bridge.

Dynamic kinetic structures:

According to Fox and Kemp (2009), dynamic kinetic structures are integrated within a larger architectural context but function independently in terms of control. These systems encompass a wide range of elements, both small and large, such as doors, windows, movable partitions, furniture, and ceilings. It is common to find dynamic kinetic systems coexisting with embedded kinetic systems within a building. With advancements in technology, these systems are progressively becoming more automated and intelligent (Fouad, 2012).

An example of how dynamic structure mechanism works can be seen in figure 13. The building is encompassed by a mobile curtain that adjusts according to the building's evolving usage and provides glimpses of the stage on the balcony as well as views towards Pudong. Developed in partnership with local engineers from Tongji University, the facade takes the form of a curtain structured along three tracks. It is composed of multiple layers of 675 individual tassels made from magnesium alloy, reminiscent of traditional Chinese bridal headdresses. These tassels vary in length from approximately 2 meters to 16 meters, enabling the curtain to rotate independently along each track. As a result, the tassels overlap, creating diverse visual effects and degrees of opacity (Foster & Heatherwick, 2017).

Figure 13. An example of Dynamic kinetic structures Bund Finance Centre / Foster + Partners + Heatherwick Studio, SHANGHAI, China (Foster & Heatherwick, 2017)

Thus, after going through and introducing each system the following system is the research’s aim and focus, because of its movable elements on the façade, which makes it the most related of all the systems to the topic’s adaptive façade. Dynamic kinetic systems can be further classified as follows:

1. Mobile systems: These systems can be physically relocated within an architectural space.
2. Transformable systems: These systems have the ability to change their shape and adapt to different spatial configurations, often employed for space-saving or utilitarian purposes.
3. Incremental kinetic systems: Similar to LEGO pieces, these systems can be added to or removed from a building (Fox & Kemp, 2009).

2.3 Approaches of Adaptive Façade Design

A dynamic facade is characterized by its ability to adjust and react to changes in environmental conditions. Its application can enhance the quality of daylight and improve thermal heat performance within interior spaces. This adaptation relies on movements that impact the physical structure or material properties of the building facade, while ensuring the overall structural integrity is not compromised (Sharaidin, 2014). The fundamental movements involved are shifting, rotating, and scaling. By combining different types of motions, such as directional twisting, more intricate and complex movements can be achieved (Waseef & Nashaat, 2017). Responsive kinetic facades rely on advanced technologies and methodologies.

Adaptive facades offer the potential for substantial reductions in building energy consumption and CO2 emissions, while simultaneously enhancing the indoor environment's quality.

A wide array of adaptive facade concepts, encompassing various materials, components, and systems (Loonen et al., 2015). The facade of a building serves as the primary visible component that defines the building's aesthetic appearance. Additionally, it plays a crucial role in providing a physical barrier and serving as an interface between the interior and exterior of the structure. Moreover, the interface’s physical barrier protects the user from various environmental factors that poses a risk to the wellbeing and comfort, these factors can be categorized as noise, daylighting vs. artificial lighting, natural ventilation, thermal control, moisture control, and visual comfort. The design of integrated adaptive facade systems is a dynamic process, primarily assessed based on how well they meet specific objectives. In contrast to conventional shading systems like roller shades with fixed functions or venetian blinds with limited adjustments, adaptive facades offer performance-based functions that enable potential innovations (e.g., various configurations) and adaptations according to user preferences since they are not restricted to predefined settings (Tabadkani, A. et al., 2021).

Kinetic movements:

Kinetic facades utilize changes in geometry to generate motion, which impacts the physical structure of the facade without causing harm to the building. These facades can undergo four types of movement, as illustrated in Figure 14: translation, rotation, scaling, and material deformation.

1. Translation involves motion in a specific direction
2. Rotation occurs around different axes
3. Scaling encompasses contraction or expansion

4. Material deformation relies on changes in material properties, such as elasticity.

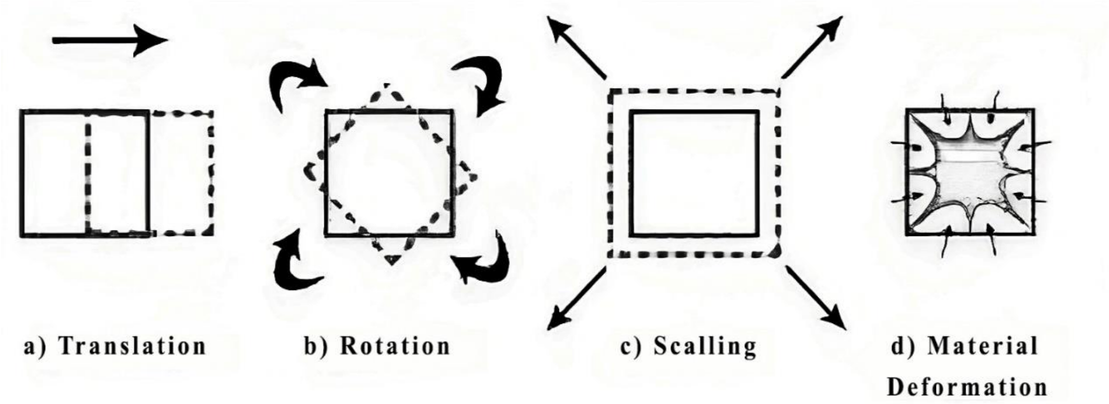


Figure 14. Different geometric transitions are employed in kinetic systems, Designing kinetics for architectural facades (Moloney, 2011)

By combining sensors such as the one seen in Figure 15, with processing software, more comprehensive information can be obtained, particularly when tracking bodily movements with sound being generated. This information proves valuable in understanding individual users' behaviors within a building. Various tools such as webcams, optical input devices, sound/text input devices, and traditional means of gathering information are employed to capture data (Waseef & Nashaat, 2017).

They comprise four primary elements, as outlined by Costa Maia et al. (2015) and depicted in Figure 15:

1. Sensors are utilized to detect and measure the environmental factors.
2. The collected data is processed by a logical unit, which then generates an appropriate response.
3. Actuators are responsible for reacting to the prevailing environmental conditions.

4. The transfer of information among all components is facilitated by a wired or wireless communication system, commonly known as the management system.

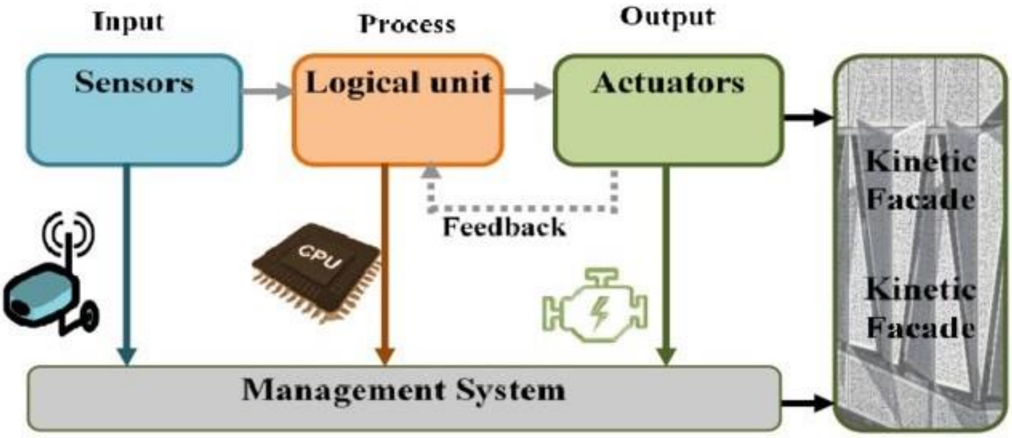


Figure 15. Kinetic façade idea, Responsive Kinetic Facades (Nashaat, 2017)

The management of kinetic motion is influenced by factors such as design and construction methods, the functionality and upkeep of the kinetic elements, as well as the interaction between humans and the environment. Sensors are devices designed to collect data from the physical environment, including light, motion, temperature, and more. Over time, sensors have evolved significantly, from basic models like an infrared beam that detects motion to more advanced versions capable of discerning color, motion direction, voice and facial features, and gain, among other characteristics. A closed-loop control system tends to be highly precise due to the fact that the feedback mechanism continuously upholds its level of accuracy. On the down side of closed is that the closed-loop control system exhibits a delayed response, primarily because feedback is a contributing factor unlike the open-loop control system offers rapid response times since it operates without the need for output measurement and feedback (Saini, 2023).

Designing and constructing facades that can interact and adapt to the environment's conditions is highly crucial. These facades, including the kinetic facade, Figure 16 shows how facades have the ability to automatically modify their shape, position, or openings based on environmental factors like temperature, humidity, wind, and more (Wigginton & Harris et al., 2013).

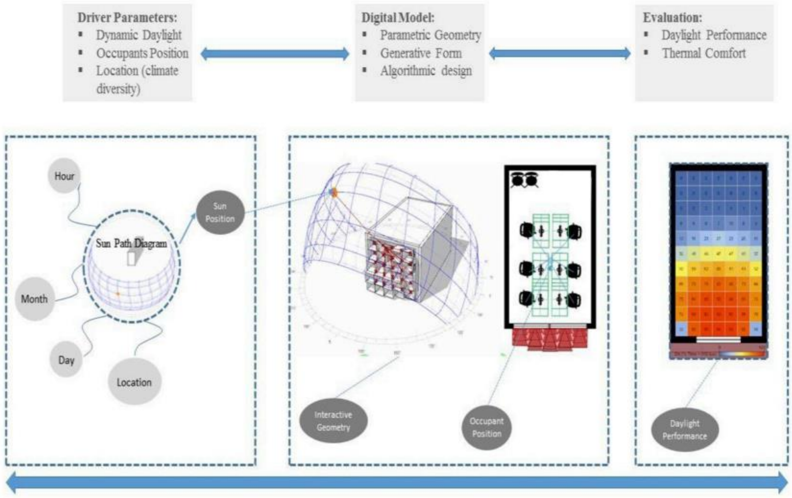


Figure 16. A systematic process using algorithms for creating digital models and assessing parametric variables (Hosseini, 2019)

Most kinetic facades such as the one seen in Figure 17, in the literature generally discuss visual comfort, shading element, and sustainability as well as energy efficiency. In the past, dynamic kinetic facades have been utilized to manage four key factors that impact the environment: regulating solar heat, controlling daylight, managing ventilation, and generating energy (Kensek & Hansanuwat, 2011).

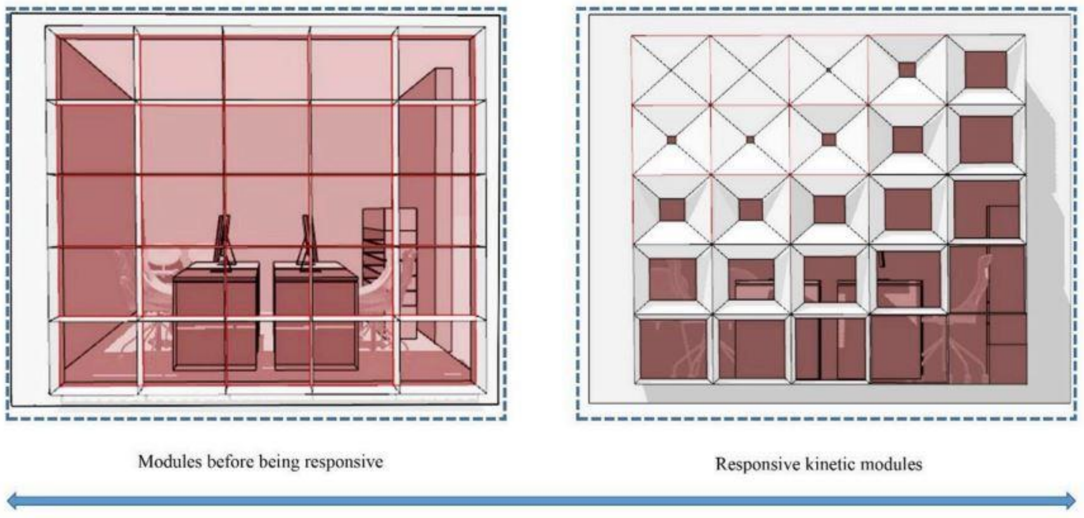


Figure 17. Interactive building façade that responds to the occupants' position (Hosseini et al., 2019)

Kinetic façades offer a significant benefit by reducing the reliance on energy to ensure user comfort in buildings. Well-designed kinetic façades enable the optimal utilization of natural daylight while preventing excessive heat buildup (Seyrek & Widera et al. 2021). While the existing literature discusses ventilation control in the context of adaptive kinetic façades (AKF). By incorporating movable elements, the facade can change its shape, position, or transparency, creating an ever-changing exterior appearance while also providing functional benefits such as shading, ventilation control, and energy optimization.

Moreover, the exploration of kinetic elements and architectural skins in buildings is being increasingly utilized as a resolution for environmental design challenges, though the use of these kinetic elements hasn’t been explored in the literature or there is any constructed examples of it in the regards of acoustics, the main use of these elements is usually thermal comfort, visual aesthetics, and energy gain. This involves transforming facades and elements into dynamic entities that adapt and harmonize with their surroundings (Mahmoud & Elghazi, 2016).

2.4 Chapter Summary

In order to improve the building's acoustics concerning its façade, it is essential to comprehend the noise-related concerns and their origins. The study provided fundamental insights into noise pollution, its potential health impacts on occupants, and the significance of building design in addressing these issues. Subsequently, the research focused on addressing noise pollution concerning the building's façade. It shed light on external noise sources, particularly traffic-related noises, and their detrimental effects. To effectively tackle the noise issue, it becomes essential to examine how kinetic façade elements can respond adaptively to environmental factors, specifically in relation to the aforementioned external noise sources.

Chapter 3

SIMULATION TOOLS FOR DESIGNING FAÇADE AND MEASURING NOISE

Building Information Modeling (BIM) is an innovative technology and methodology that has rapidly revolutionized the entire lifecycle of buildings, including their conception, design, construction, and operation (Hardin, 2009). BIM, also known as building information modeling, is a visual representation of buildings in a three-dimensional model. It encompasses various details about a building, such as its geometry, properties, names, and specific functional characteristics of its components (Migilinskas et al., 2013).

3.1 BIM Interpretation and Principle

BIM holds significant potential in the examination and assessment of energy usage within current structures. Its impact on estimate precision is noteworthy. By functioning as a tool for precise building information estimation, BIM facilitates the anticipation of energy efficiency outcomes resulting from retrofit measures. This is achieved through the creation of models representing existing buildings, suggesting alternative approaches, Examining, and comparing the performance of these options, and simulating improvements (Tobias & Vavaroutsos, 2012; Ma et al., 2012).

3.1.1 Autodesk Revit as a Facilitator of 3D Structures

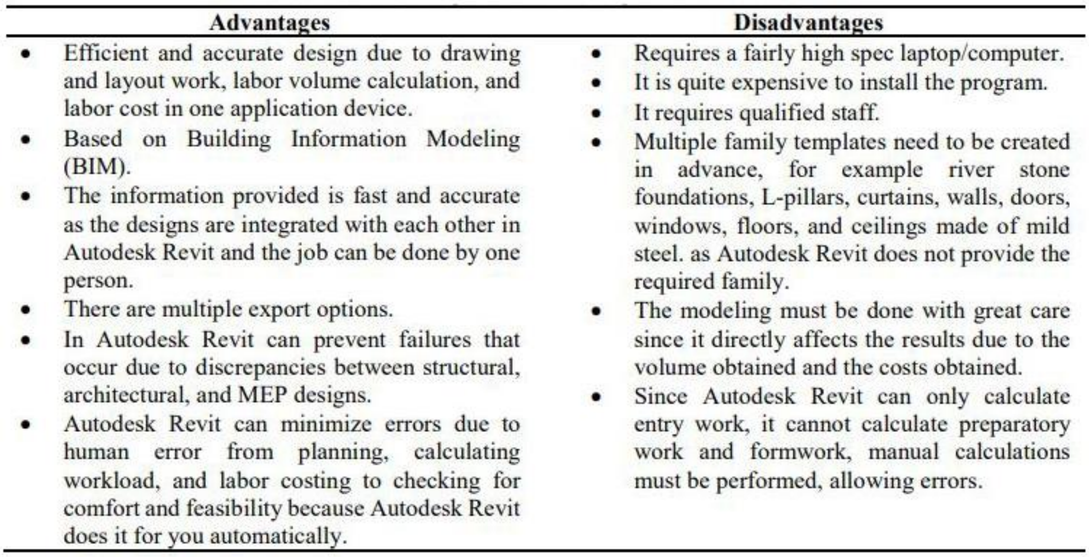
Autodesk Revit is a software developed by Autodesk, specifically designed for Building Information Modeling (BIM). Widely utilized in the architecture, engineering, and construction (AEC) industries, it facilitates the design, planning, and management of building projects (Yuvita & Budiwirawan, 2022). BIM entails creating digital representations of a building's physical and functional aspects, enabling effective collaboration, visualization, and simulation of the construction and operation processes.

A prominent feature of Revit is its parametric modeling, “parametric modeling” in this instance means, where interconnected elements automatically adapt when modifications are made. For instance, altering the size of a wall triggers automatic adjustments in related elements like doors and windows, streamlining the process and minimizing errors (Stine, 2011). BIM has emerged as a leading approach for integrating various software applications, including Revit, which is employed for modeling the case study.

3.1.2 Advantages and disadvantages of Autodesk Revit

Autodesk Revit possesses impressive capabilities in multiple modeling aspects, which can be viewed as both advantages and disadvantages. However, the advantages of Revit outweigh its disadvantages due to its remarkable precision and error indicators, which promptly detect and highlight any illogical or inaccurate commands in the modeling process more can be seen in Table 2.

Table 2: Advantages and disadvantages of Revit 3D modelling software (Yuvita, 2022)



Advantages	Disadvantages
• Efficient and accurate design due to drawing and layout work, labor volume calculation, and labor cost in one application device. • Based on Building Information Modeling (BIM). • The information provided is fast and accurate as the designs are integrated with each other in Autodesk Revit and the job can be done by one person. • There are multiple export options. • In Autodesk Revit can prevent failures that occur due to discrepancies between structural, architectural, and MEP designs. • Autodesk Revit can minimize errors due to human error from planning, calculating workload, and labor costing to checking for comfort and feasibility because Autodesk Revit does it for you automatically.	• Requires a fairly high spec laptop/computer. • It is quite expensive to install the program. • It requires qualified staff. • Multiple family templates need to be created in advance, for example river stone foundations, L-pillars, curtains, walls, doors, windows, floors, and ceilings made of mild steel. as Autodesk Revit does not provide the required family. • The modeling must be done with great care since it directly affects the results due to the volume obtained and the costs obtained. • Since Autodesk Revit can only calculate entry work, it cannot calculate preparatory work and formwork, manual calculations must be performed, allowing errors.

Although Autodesk Revit offers building performance analysis capabilities, such as acoustic analysis and simulations, another important disadvantage to note that the dedicated simulation tool Ecotect acoustic software, previously used, has been discontinued by Autodesk. Consequently, Autodesk Revit lacks built-in tools specifically dedicated to acoustic simulations.

3.2 Rhinoceros & Grasshopper Software Principles Overview

Rhinoceros has gained popularity as a preferred modeling software in numerous North American architecture schools and certain practices, particularly those emphasizing formal design aspects (McNeel 2010). The graphical algorithm editor known as Grasshopper, integrated into Rhinoceros, facilitates the rapid generation of parametric forms, even for designers without formal scripting experience (Day, 2010). Moreover, the plug-in Grasshopper operates as a visual programming language and environment integrated into the Rhinoceros 3D computer-aided design (CAD) software (Wikipedia, Grasshopper 3D, 2023). The functionality of the Grasshopper plugin involves connecting certain parts of geometry, whether already existing or newly generated in Rhinoceros, to a visual algorithm editor as can be seen in Figure 18. As a result, these geometries are shown in the Rhinoceros viewport, and any modifications to the sequences of scripted graphical transformations immediately trigger visual updates (Lagios et al., 2010). Thus, simulating a kinetic facade involves modeling the individual components, their motion, and their interaction to predict the overall behavior of the system.

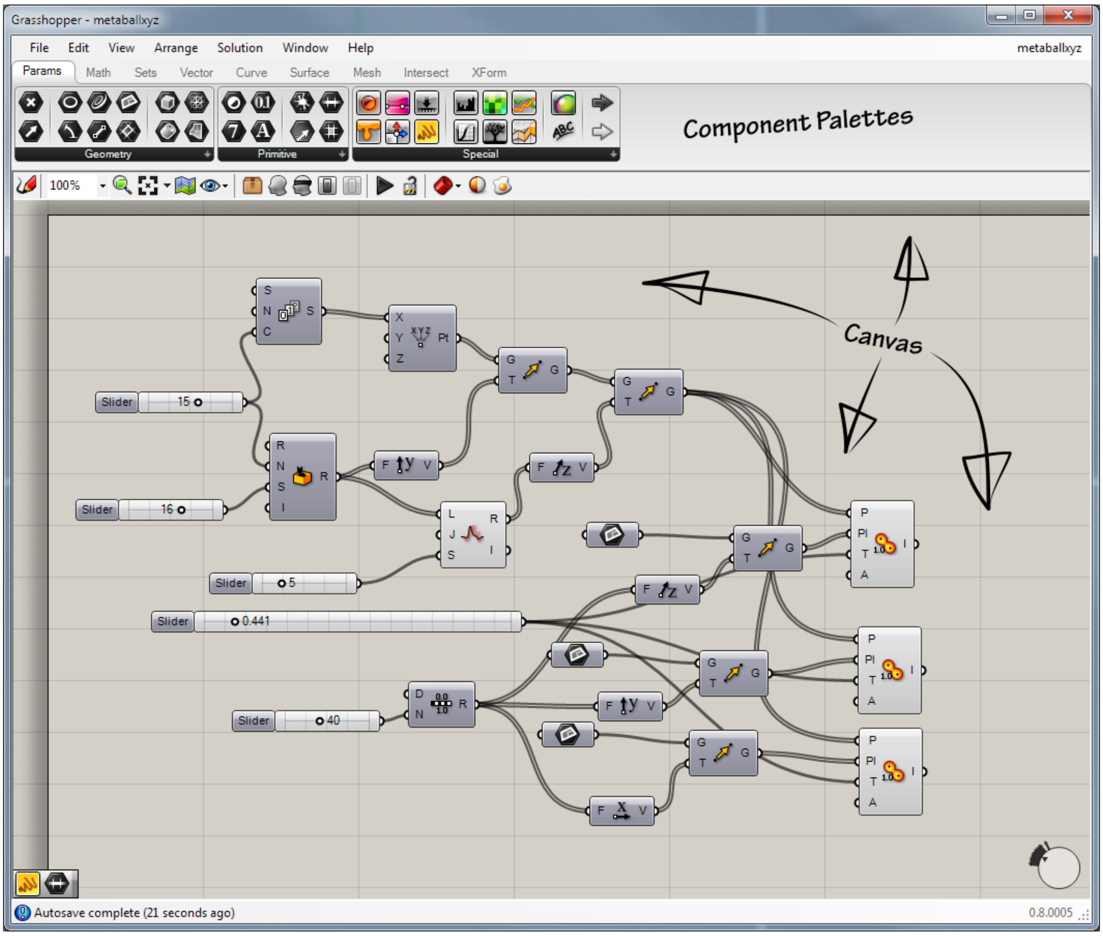


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Figure 18. visual algorithm editor (Wikipedia, Grasshopper 3D, 2023)

The Use of physics-based simulations or scripting to simulate the behavior of each movable component. The purpose is to gain insights into how kinetic facades perform in response to environmental conditions. Before predicting the performance of these elements, they must be translated into conceptual models as part of the process (Sharaidin et al., 2012).

3.3 Pachyderm Acoustic Simulation Tool

Pachyderm Acoustic Simulation consists of a series of acoustics simulation algorithms, providing the capability to forecast noise, visualize sound propagation, and conduct critical listening in designed environments. Pachyderm is an innovative software that falls under the domain of building acoustics, and it has demonstrated potential in simulating, analyzing, and enhancing acoustic performance within buildings. In conclusion, this chapter illustrates how the process, as depicted in Figure 19, and the capabilities of the software tools can contribute to achieving the research paper's objectives. Moreover, in detail, Figure 19 illustrates the progression of the software, including Autodesk Revit, which efficiently transformed 2D drawings into precise 3D models. Grasshopper was employed to design the facades through an algorithm editor (scripts), and the ultimate stage involved simulating the impact of these proposed facades on indoor acoustic comfort.

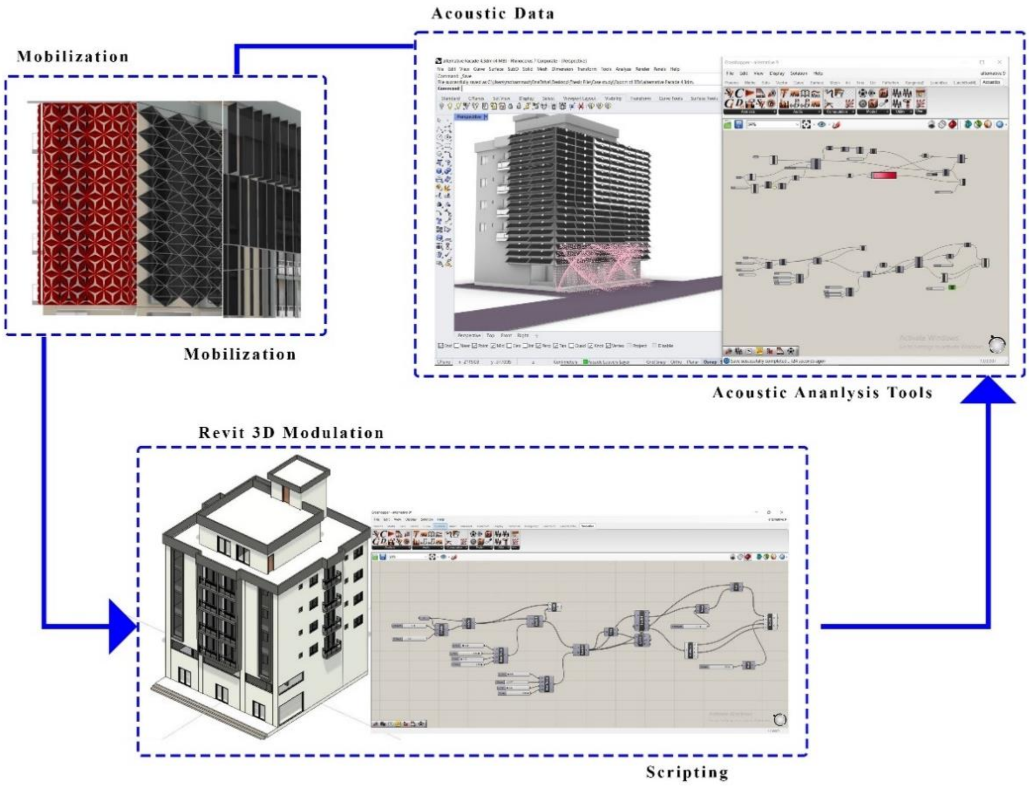


Figure 19. Process of the 3D modelling and simulation software (Author, 2023)

Chapter 4

CASE STUDY OF A RESIDENTIAL BUILDING IN TRNC

4.1 Introduction to the Method of Data Collection

The case study was examined by retrieving data from a field study. Various 3D platforms were utilized step by step to attain the required data. Autodesk Revit 2023, along with the digital blueprints from Autodesk AutoCAD, was employed to create necessary drawings like plans, sections, elevations, and 3D representations. This process aimed to ensure the accuracy of the drawings and minimize errors during the export of the final 3D model for simulation. Additionally, to achieve precise simulation results, it was crucial to maintain consistent units in all 3D models across platforms, as indicated in the literature. The author utilized Rhino and Grasshopper software to design different kinetic facades such as a Diamond Façade Form, Horizontal Louvers, and Vertical Louvers. The Diamond façade has a form that is used on a smaller scale in the interior to insulate sound as well as get rid of standing waves and flutter echoes. Horizontal and Vertical louvres come into play when noise is generated by a large air-moving machine within a confined space, such as a building or a sizable plant room. These louvres serve a dual purpose: they aid in ventilation while also addressing noise concerns. Acoustic louvres can seamlessly integrate into a building's design, serving as both a weatherproof barrier and an architectural element (Noise Control Engineering, 2023). Subsequently, the façade elements were simulated within

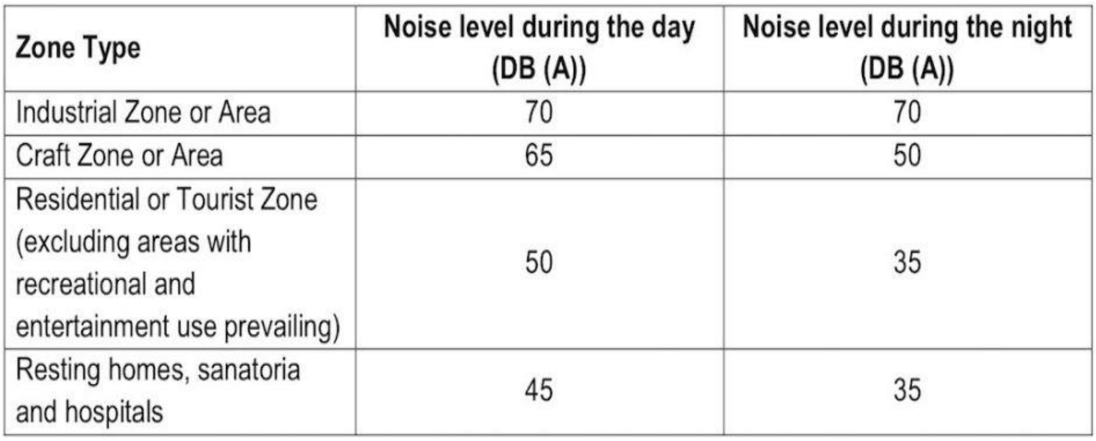
Grasshopper using the "Pachyderm" acoustics plug-in, considering noise and its impact on the kinetic facades' performance.

4.2 Context’s Data Reports

Cyprus is situated in West Asia (35.1149° Latitude, 33.9192° Longitude) Figure 20 from a geographical perspective. It is considered as the third largest and third-most populous island in the Mediterranean. Despite being a crowded small city with a population of forty-one thousand, Famagusta, situated in the North East of Cyprus. The extent of noise pollution in Famagusta lacks specific information in the literature. However, a publication by Ferk, (2017), which focuses on noise pollution in the South side Specifically “Nicosia”, provides guidelines on noise limitations during day and night at different locations, as depicted in Table 3.

Figure 20. Location of the field study, Famagusta Cyprus (URL 2)

Table 3: Guidelines on noise limitations during day and night at different locations (Ferk, 2017)



Zone Type	Noise level during the day (DB (A))	Noise level during the night (DB (A))
Industrial Zone or Area	70	70
Craft Zone or Area	65	50
Residential or Tourist Zone (excluding areas with recreational and entertainment use prevailing)	50	35
Resting homes, sanatoria and hospitals	45	35

4.3 Cihangir Residential Building

The Cihangir building, a residential structure, was designed by MUST Group, an architectural firm led by architect Mustaffa Saqqa. The building is located alongside the primary road known as Salamis Street in the city of Famagusta. As can be seen in Figure 21 and 22, the building's layout and form have a square plan approach with an area of 1450 m2. The buildings consist of five floor plans in total, one floor has a commercial function on the ground floor and the other four are residential function.

Figure 21. An aerial view of the case study's location (URL 5)

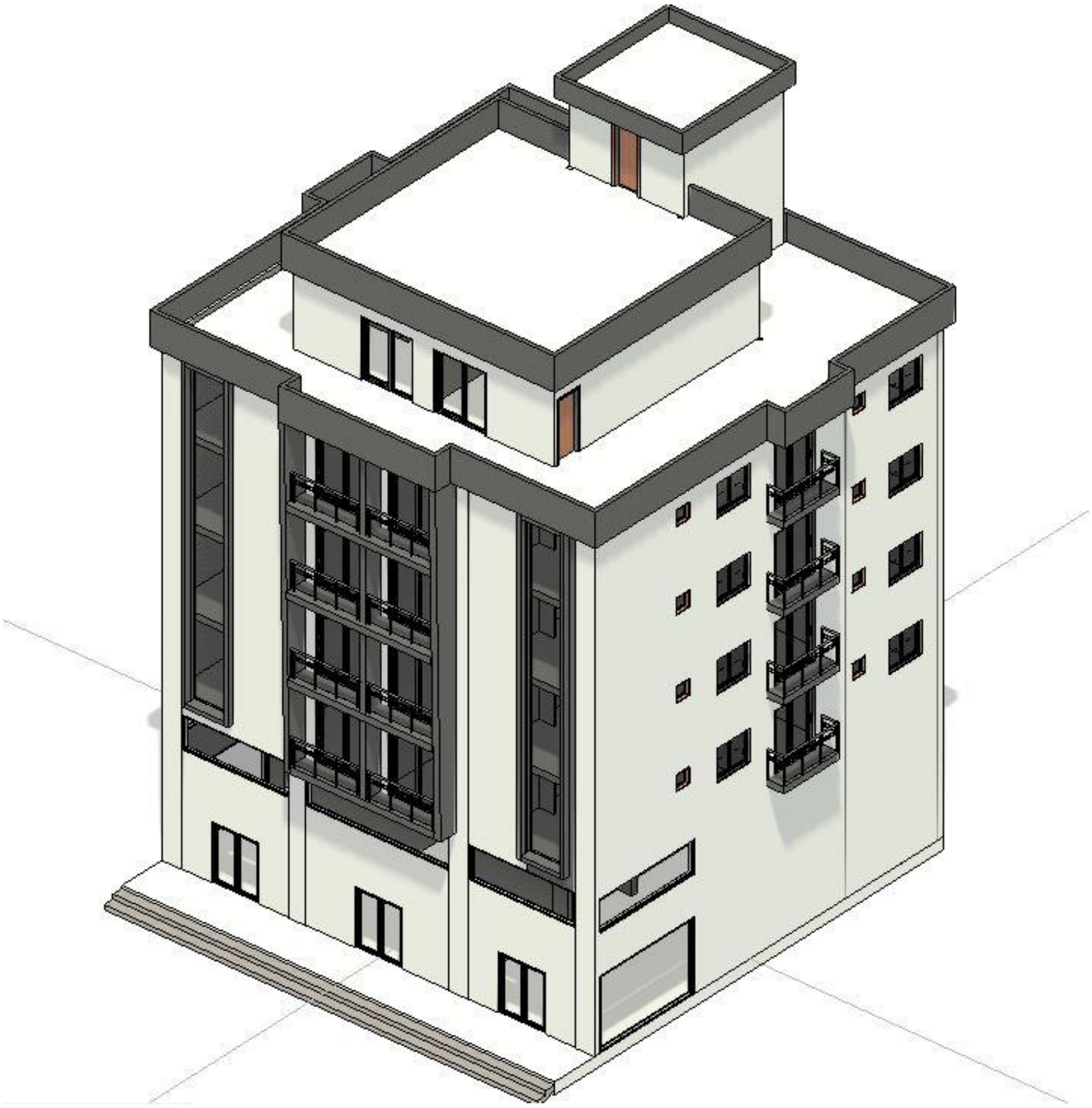


Figure 22. Cihangir Residential building’s 3D module (Author, 2023)

The ground floor plan of 238 m2 consists of three shops at the south side of the plan, two shops share the same plan layout of a kitchenette and a WC with a mezzanine floor. The shop in the middle has a mezzanine floor, WC, and a basement floor as depicted in Figure 23. Figure 24 shows the four floors sharing the same typical floor plan, used for residential functions consisting of bedrooms, kitchen, bathrooms, and living rooms. Finally in Figure 25, on the fifth floor there’s a pent house consisting of two units.

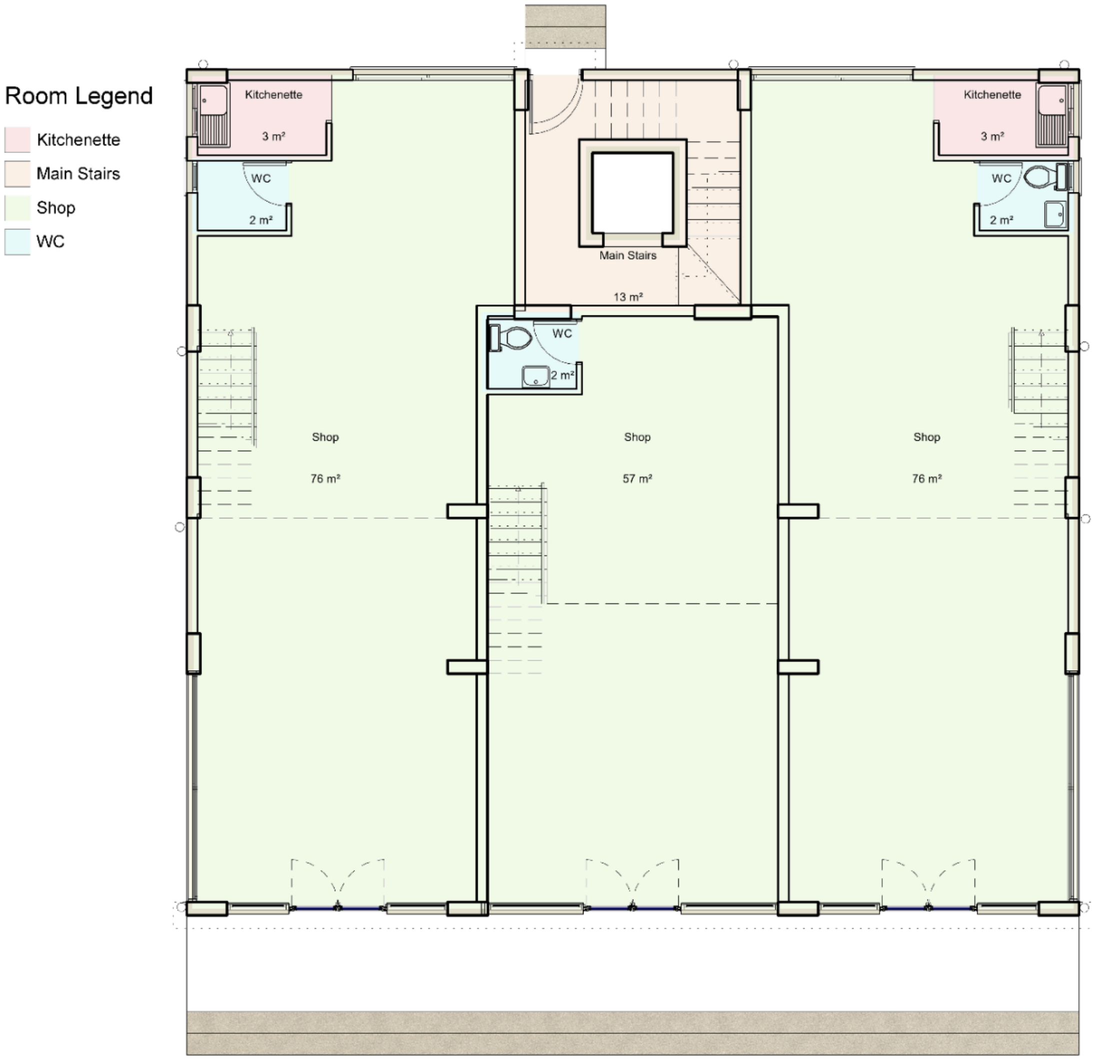


Figure 23. Ground Floor Plan of Cihangir residential building on level +0.45 (Author. 2023)

Figure 24. Typical Floor Plan of Cihangir residential building on level +5.85, +8.91, +11.97, +15.03 (Author. 2023)

Figure 25. Pent House Floor Plan of Cihangir residential building on level +18.09 (Author. 2023)

4.4 Analysis by Field Examination of Cihangir Building

To gather precise data aligning with the study's objectives, field research was conducted on the building. Pictures were captured to illustrate the deficiencies in the façade design of the structure. These efforts aimed to fulfill the study's aims and targets effectively.

Table 4: Table of building field photos and observed data based on the façade orientation (Author, 2023)

Orientation	**Field Photos**	**Observed Data**
South Elevation		- No double glazing of the windows and the sliding balcony doors - Lack of trees or any type of vegetation for natural insulation - Most of the functions are oriented on this side of the façade - Parking and most of the vehicular transportation are located on this of the façade
West Elevation		- No double glazing of the windows and the sliding balcony doors - The HVAC outer-unit are directly installed on the walls - Lack of trees or any type of vegetation for natural insulation - Parking and most of the vehicular transportation are located on the side of the building

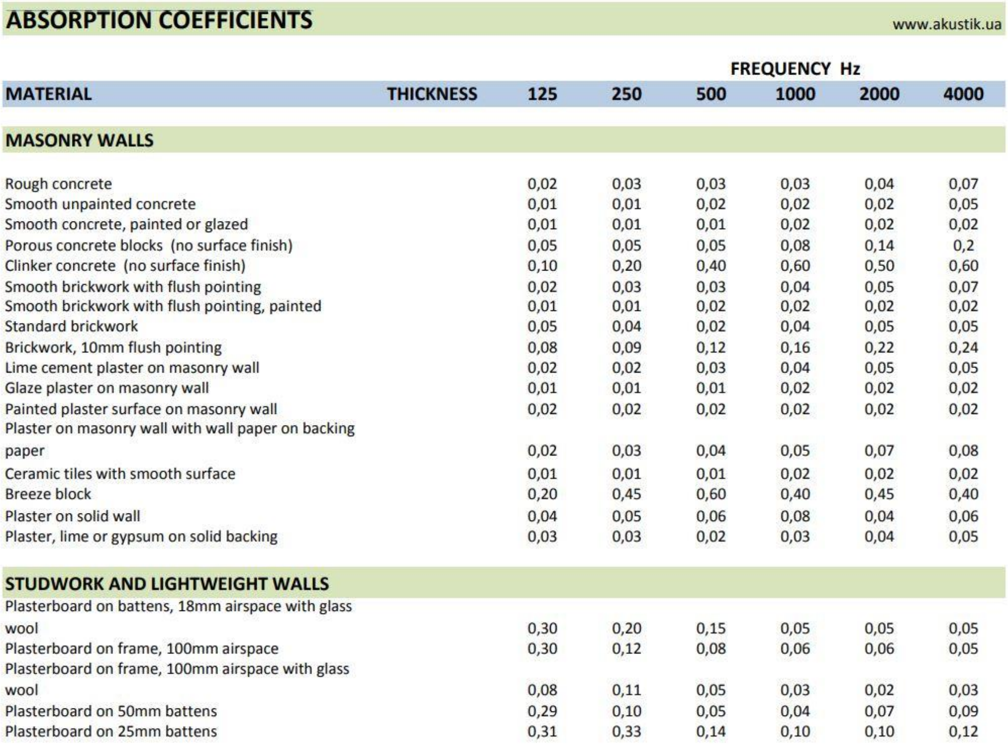
East Elevation		- No double glazing of the windows and the sliding balcony doors - The HVAC outer-unit are directly installed on the walls - Neighboring building facing directly with the façade - Less traffic noise sources
North Elevation		- Least used façade in the building - Least usage of openings - Façade located on the back closed off side of the building - Least noise polluted area of the building

4.5 Simulation Assessment of Cihangir Building

Given that the building is already constructed, the study will focus on analyzing the South areas facing the main street at the front side of the building, as this location is most susceptible to noise pollution. The simulation will be carried out on the first-floor plan at level +5.85 m, which represents consistent characteristics throughout the building. Conducting the simulation on this floor will yield comparable results due to its similarity to other areas.

The choice of the front façade for the research is justified by several factors. Firstly, the architectural elements in this building, particularly the balcony sliding doors, lack adequate sound insulation properties, with only one set of glazing. Additionally, the wall materials consist of concrete and plaster without any sound insulation properties, causing it to reflect and transmit noise to the interior of the building. These deficiencies make the front façade an ideal focus for the study's investigation into noise insulation solutions. Moreover, the materials used in the simulation have used an absorbent coefficient, based on a list of octave band frequencies of each material and its respective absorbent coefficients as can be seen in Figure 26.

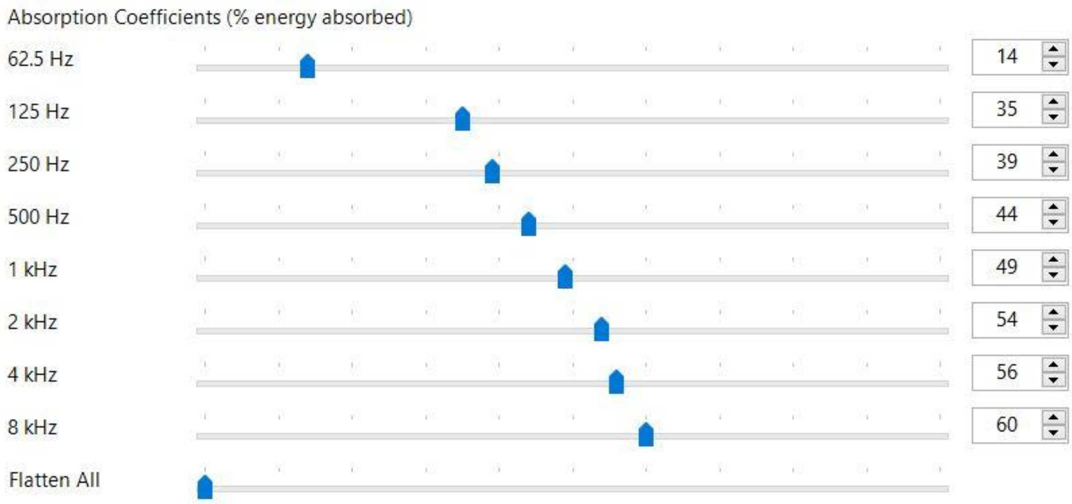
These absorbent coefficients have been used solely on the walls and other architectural elements of the building but not the proposed facades, the facades have a different material or absorbent coefficient which is that of metal material. In Figure 27 it shows the octave band frequencies and their respective metal absorption coefficients used in the simulation in the data input for the Diamond Façade Form, Vertical and Horizontal Louvers.



ABSORPTION COEFFICIENTS www.akustik.ua

		FREQUENCY Hz					
MATERIAL	**THICKNESS**	**125**	**250**	**500**	**1000**	**2000**	**4000**
MASONRY WALLS							
Rough concrete		0,02	0,03	0,03	0,03	0,04	0,07
Smooth unpainted concrete		0,01	0,01	0,02	0,02	0,02	0,05
Smooth concrete, painted or glazed		0,01	0,01	0,01	0,02	0,02	0,02
Porous concrete blocks (no surface finish)		0,05	0,05	0,05	0,08	0,14	0,2
Clinker concrete (no surface finish)		0,10	0,20	0,40	0,60	0,50	0,60
Smooth brickwork with flush pointing		0,02	0,03	0,03	0,04	0,05	0,07
Smooth brickwork with flush pointing, painted		0,01	0,01	0,02	0,02	0,02	0,02
Standard brickwork		0,05	0,04	0,02	0,04	0,05	0,05
Brickwork, 10mm flush pointing		0,08	0,09	0,12	0,16	0,22	0,24
Lime cement plaster on masonry wall		0,02	0,02	0,03	0,04	0,05	0,05
Glaze plaster on masonry wall		0,01	0,01	0,01	0,02	0,02	0,02
Painted plaster surface on masonry wall		0,02	0,02	0,02	0,02	0,02	0,02
Plaster on masonry wall with wall paper on backing paper		0,02	0,03	0,04	0,05	0,07	0,08
Ceramic tiles with smooth surface		0,01	0,01	0,01	0,02	0,02	0,02
Breeze block		0,20	0,45	0,60	0,40	0,45	0,40
Plaster on solid wall		0,04	0,05	0,06	0,08	0,04	0,06
Plaster, lime or gypsum on solid backing		0,03	0,03	0,02	0,03	0,04	0,05
STUDWORK AND LIGHTWEIGHT WALLS							
Plasterboard on battens, 18mm airspace with glass wool		0,30	0,20	0,15	0,05	0,05	0,05
Plasterboard on frame, 100mm airspace		0,30	0,12	0,08	0,06	0,06	0,05
Plasterboard on frame, 100mm airspace with glass wool		0,08	0,11	0,05	0,03	0,02	0,03
Plasterboard on 50mm battens		0,29	0,10	0,05	0,04	0,07	0,09
Plasterboard on 25mm battens		0,31	0,33	0,14	0,10	0,10	0,12

Figure 26. Absorption coefficients of various materials (URL 3)



Absorption Coefficients (% energy absorbed)

62.5 Hz 14

125 Hz 35

250 Hz 39

500 Hz 44

1 kHz 49

2 kHz 54

4 kHz 56

8 kHz 60

Flatten All

Figure 27. Absorption coefficients for the materials used in the simulation in the data input for the Diamond Façade Form and the Horizontal Vertical Louvers (Author, 2023)

4.6 Sound Pressure Level (SPL) Simulation of Cihangir Building

The research conducted Sound Pressure Level simulation on the case study without any façade as an initial phase to determine the existing conditions of the building's acoustics. Moreover, the research conducted a simulation with a source of sound as in impulse response, scattering 5000 ray tracing of sound at the building in a scattering direction can be seen in Figure 28. Thus, the SPL is then measured accordingly when the aforementioned rays hit the existing building's façade, by which some of the sound is reflected and some is transmitted to the indoor space. Thus, on the decibel scale, according to (Svantek Academy, 2023) an audible sound span from 0 dB, which marks the threshold of hearing, all the way up to over 130 dB, signifying the threshold of pain. While a doubling of sound pressure equates to a 6 dB increase, it typically requires a 10 dB increment for the sound to be perceived as subjectively twice as loud. Human ears can detect the smallest audible change, which amounts to approximately 3 dB. Sound pressure level (SPL) can be characterized subjectively using the decibel (dB) scale. Noise levels ranging from 0 to 40 dB are generally considered quiet to very quiet, whereas the 60 to 80 dB range is commonly described as noisy. A sound pressure level of 100 dB is typically perceived as very noisy, while anything exceeding 120 dB becomes intolerable. Furthermore, after simulating with Pachyderm acoustic simulation tool the results of the measurements gave a result of a > 100 dB on different Octave band frequencies resulting in annoyance levels of sound, as can be seen in Figure 29 and Table 5.

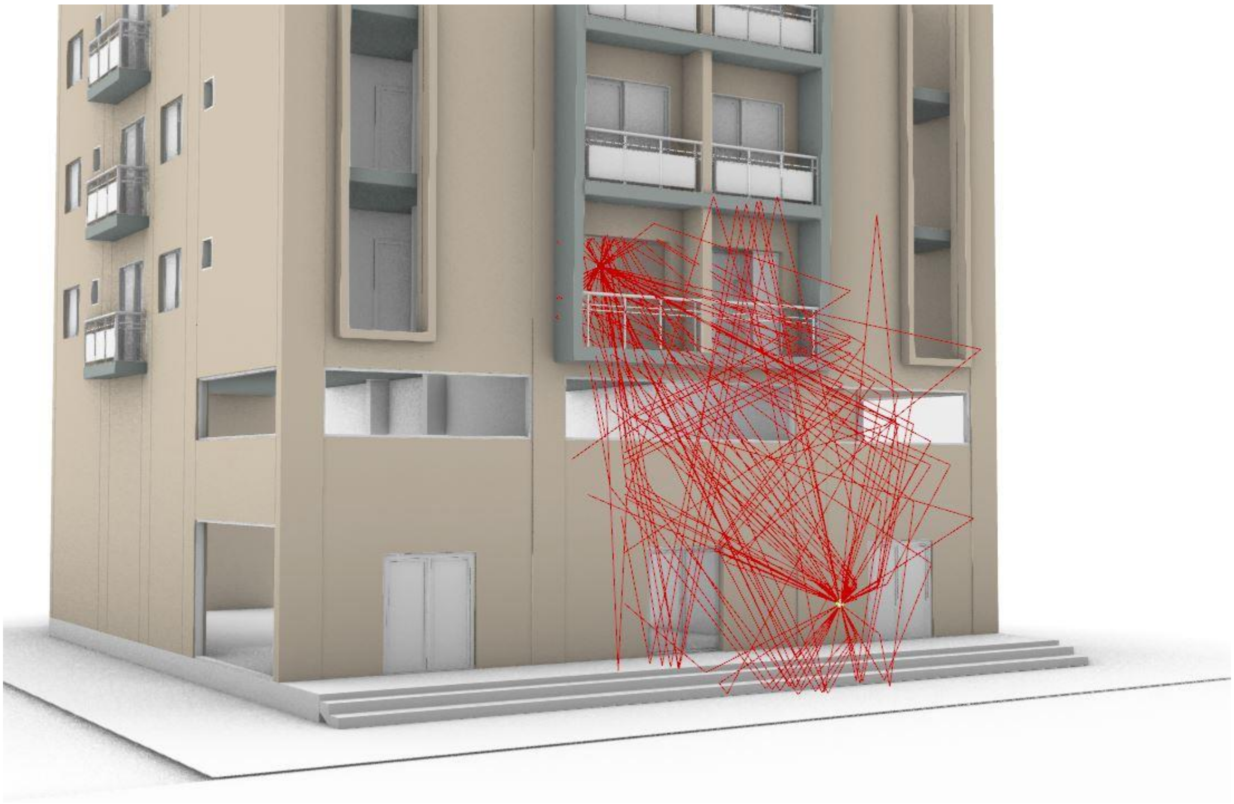
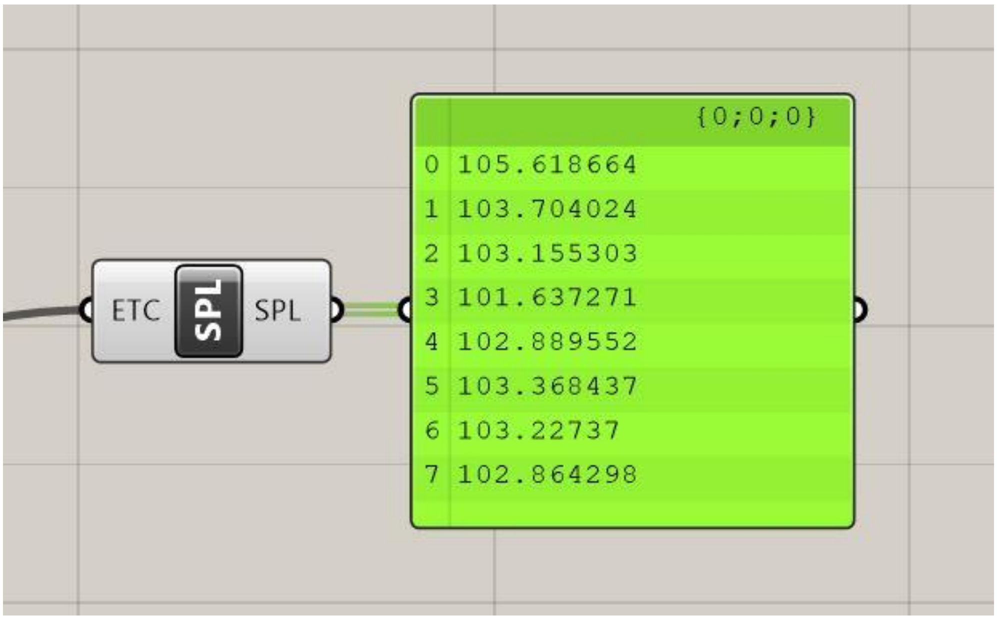


Figure 28. Pachyderm depiction of Sound Pressure level emitted sound of 5000 rays traced from a sound source on the ground level to a receiver in the first-floor level (Author, 2023)



```
{0;0;0}
0 105.618664
1 103.704024
2 103.155303
3 101.637271
4 102.889552
5 103.368437
6 103.22737
7 102.864298
```

Figure 29. Sound Pressure Level results (Author, 2023)

Table 5: list of simulation results of Octave Band frequencies and their respective SPL without façade elements (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	105 dB
2	125 Hz	103 dB
3	250 Hz	103 dB
4	500 Hz	101 dB
5	1 kHz	102 dB
6	2 kHz	103 dB
7	4 kHz	103 dB
8	8kHz	102 dB

In addition to giving numerical data Pachyderm can animate and visualize the simulation results, as visualized in Figure 30 shows a simulation of particles of sound causing a sound transmission by hitting the existing building’s façade.

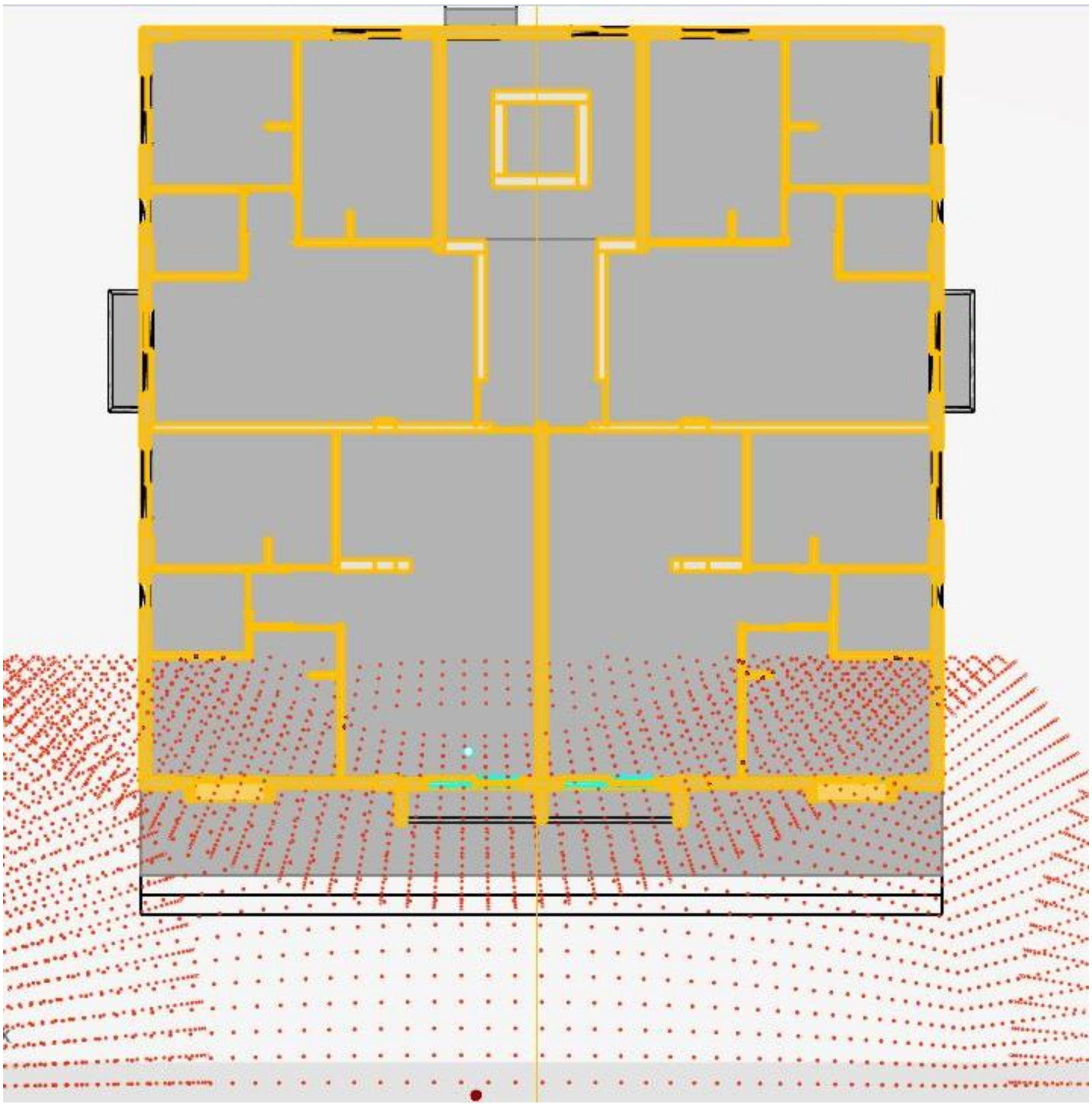


Figure 30. Pachyderm simulation of sound particles bouncing (Author, 2023)

4.7 Simulation Assessment of Diamond Form Façade Elements

In the simulation of the Diamond Form Façade Elements, the elements experience a form of kinetic movement described as “scaling” in which the elements will contract and expand, and the simulation will be conducted at different domains where the said expansion and contraction will occur, as can be seen in Figure 31, Figure 32, and Figure 33. Furthermore, the simulations will be conducted on the aforementioned elements to firstly measure the Speech Transmission Index (STI) which quantifies sound transmission objectively, focusing on the physical process of sound blending. In simpler terms, it helps us gauge how easy or challenging it is to understand speech by comparing the original sound wave to what reaches the ears. STI values fall within a range of 0 to 1. When the sound reaching the ears contains a significant amount of reflected sound, meaning it differs significantly from the original, the STI value approaches 0 (indicating poor intelligibility). Conversely, when the transmitted sound closely resembles the original, with fewer reflections, the STI value approaches 1 (indicating good intelligibility). Typically, a minimum STI value of 0.6 is required for human speech to be intelligible (Dorfaki, 2021). Secondly, a simulation of the sound pressure level will be conducted to show if the façade elements have insulated the building and the levels have minimized the annoyance effect that was perceived in the simulation without the façade elements. Overall, the simulations of both measurements work together to show how the façade elements reacted to the sounds ray traced when they are reflected and transmitted to the indoors of the building.

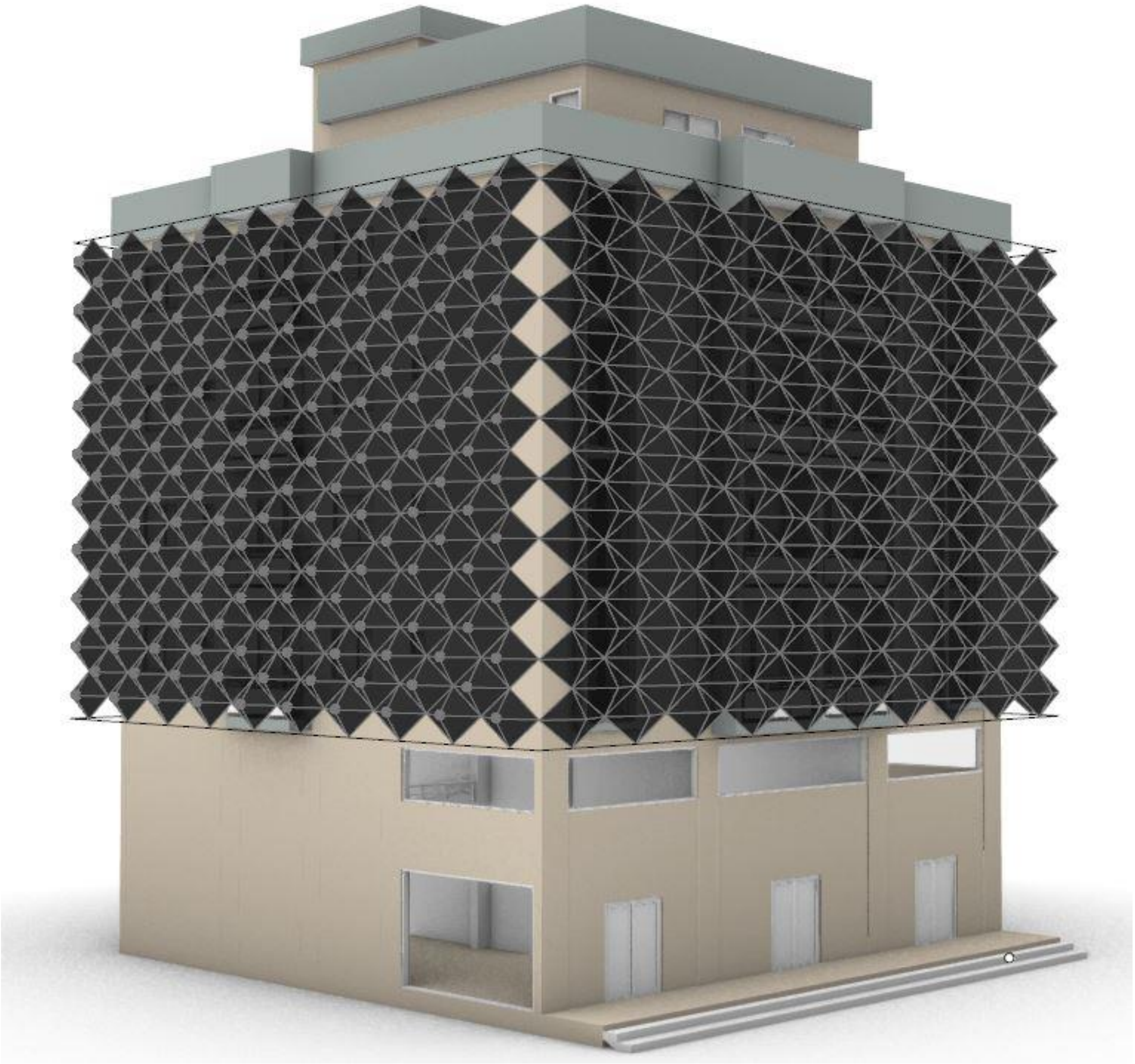


Figure 31. 3D visualization of the Diamond form façade elements surrounding the building fully contracted (Author, 2023)

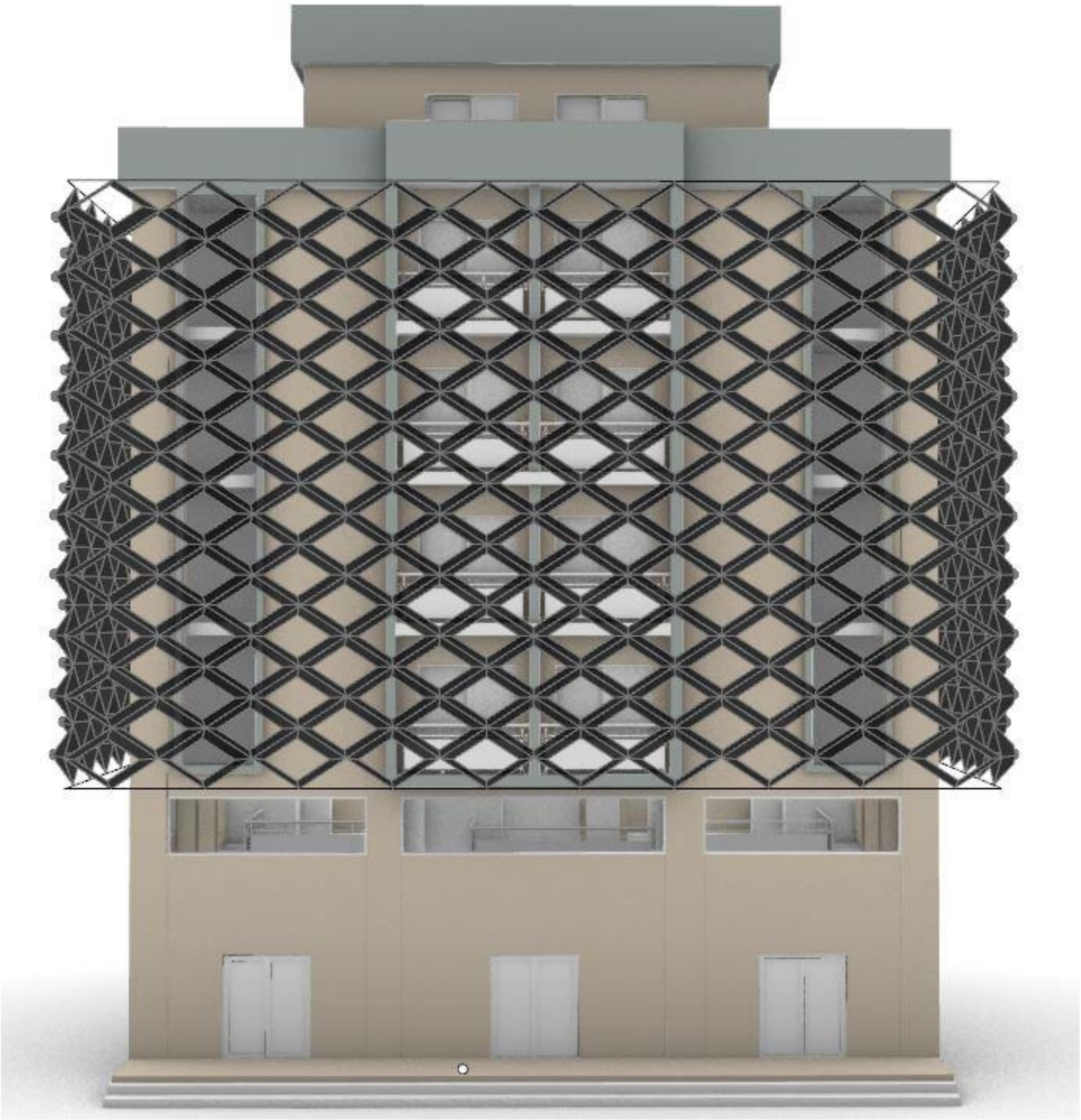


Figure 32. 3D visualization of the Diamond form façade elements surrounding the building fully expanded (Author, 2023)

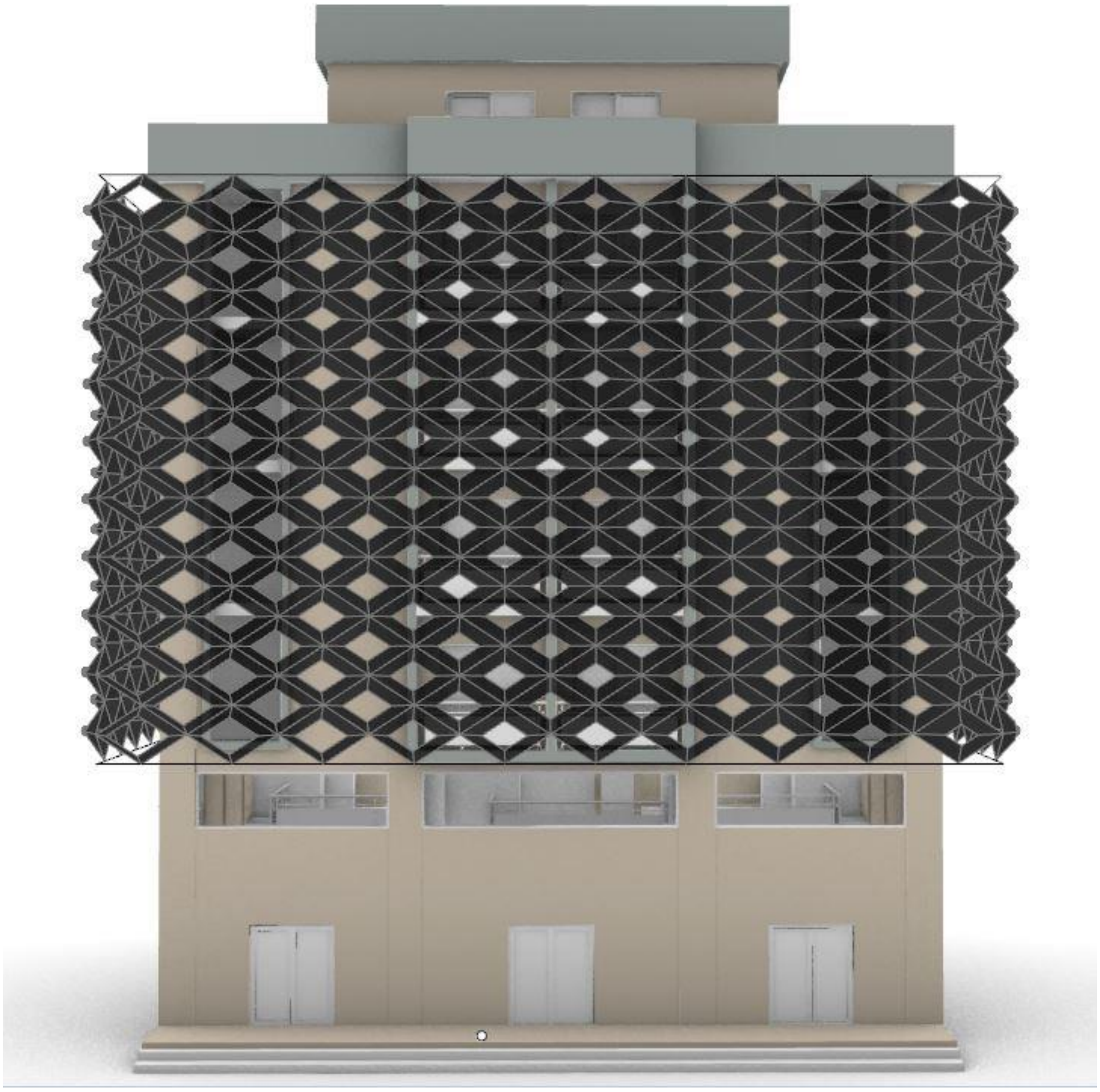
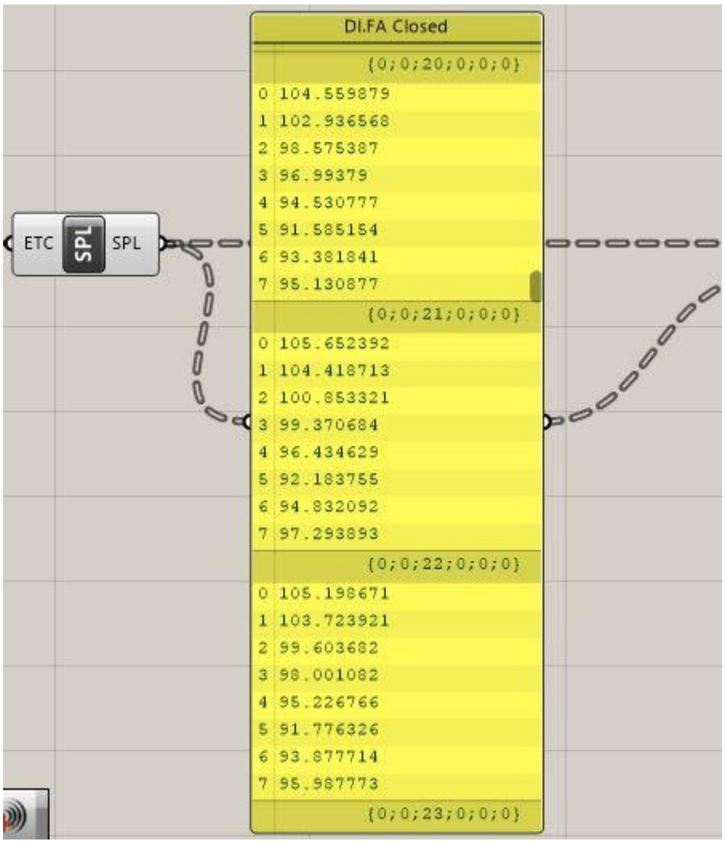


Figure 33. 3D visualization of the Diamond form façade elements when scaling expanding elements on the left and contracting elements on the right (Author, 2023)

4.8 Sound Pressure Level (SPL) & Speech Transmission Index (STI) Simulation of Diamond Form Elements

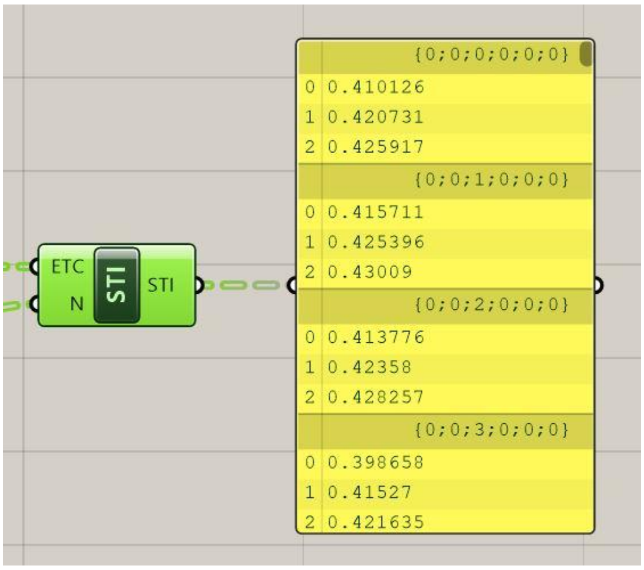
The simulation has been conducted on several stages on kinetic movements as mentioned earlier "scaling" in which the façade elements were simulated when in total expansion state, total contraction state, and in both contraction and expansion states.

Based on the simulations done the results showed that the sound reflected of the Diamond Form elements leading to a decrease in the SPL and an increase in STI for in which an increase towards a factor of 1 is better for speech intelligibility in the indoor area, these results can be seen in Figures 34, 35, 36, 37, 38, 39 and Tables 6, 7, 8.



```
DI.FA Closed
{0;0;20;0;0;0}
0 104.559879
1 102.936568
2 98.575387
3 96.99379
4 94.530777
5 91.585154
6 93.381841
7 95.130877
{0;0;21;0;0;0}
0 105.652392
1 104.418713
2 100.853321
3 99.370684
4 96.434629
5 92.183755
6 94.832092
7 97.293893
{0;0;22;0;0;0}
0 105.198671
1 103.723921
2 99.603682
3 98.001082
4 95.226766
5 91.776326
6 93.877714
7 95.987773
{0;0;23;0;0;0}
```

Figure 34. Sound Pressure Level results of Diamond Façade Form when in total contraction state shown in a numerical chart (Author, 2023)



```
{0;0;0;0;0;0}
0 0.410126
1 0.420731
2 0.425917
{0;0;1;0;0;0}
0 0.415711
1 0.425396
2 0.43009
{0;0;2;0;0;0}
0 0.413776
1 0.42358
2 0.428257
{0;0;3;0;0;0}
0 0.398658
1 0.41527
2 0.421635
```

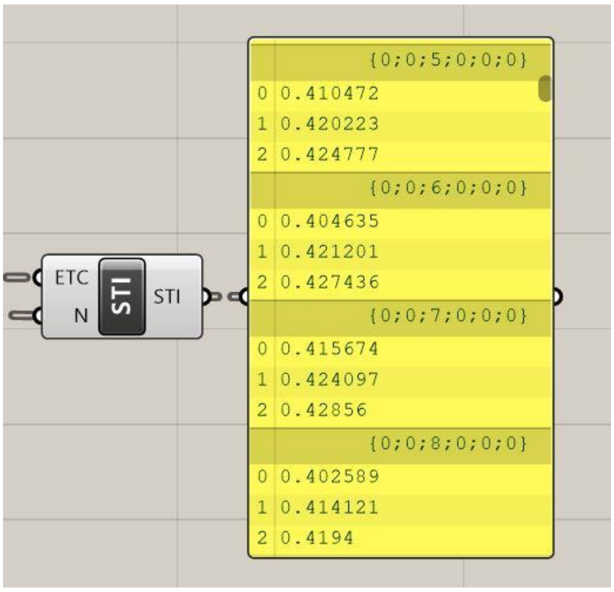
Figure 35. Speech Transmission Index results of Diamond Façade Form when in total contraction state shown in a numerical chart (Author, 2023)

Table 6: list of simulation results of Octave Band frequencies and their respective SPL with Diamond façade elements when in total contraction state (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	104 dB
2	125 Hz	102 dB
3	250 Hz	98 dB
4	500 Hz	96 dB
5	1 kHz	94 dB
6	2 kHz	91 dB
7	4 kHz	93 dB
8	8kHz	95 dB

```
DI.FA SPL left OP Right Closed
        {0;0;5;0;0;0}
0 105.259848
1 103.841396
2 99.838831
3 98.157431
4 95.133535
5 91.643004
6 93.722545
7 95.966087
        {0;0;6;0;0;0}
0 104.86041
1 103.244724
2 98.89474
3 97.382122
4 94.885679
5 91.70911
6 93.662047
7 95.529322
        {0;0;7;0;0;0}
0 105.396992
1 104.036555
2 100.278648
3 98.757046
4 95.911102
5 91.973558
6 94.406157
```

Figure 36. Sound Pressure Level results of Diamond Façade Form when the elements are expanding on the left and contracting on the right (Author, 2023)



```
        {0;0;5;0;0;0}
0 0.410472
1 0.420223
2 0.424777
        {0;0;6;0;0;0}
0 0.404635
1 0.421201
2 0.427436
        {0;0;7;0;0;0}
0 0.415674
1 0.424097
2 0.42856
        {0;0;8;0;0;0}
0 0.402589
1 0.414121
2 0.4194
```

Figure 37. Speech Transmission Index results of Diamond Façade Form when the elements are expanding on the left and contracting on the right (Author, 2023)

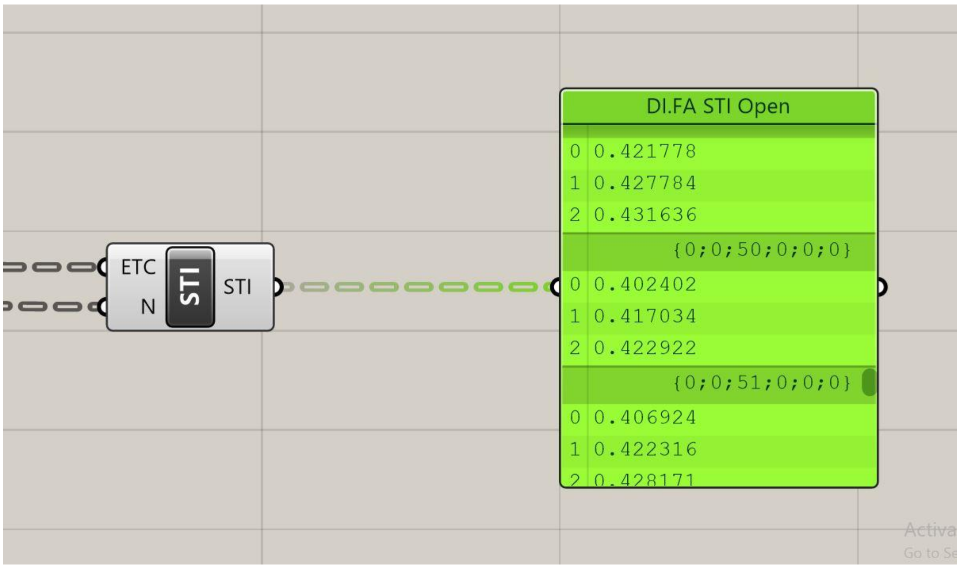
Table 7: list of simulation results of Octave Band frequencies and their respective SPL with Diamond façade elements when the elements are expanding on the left and contracting on the right (Author, 2023)

Number of Frequency	Octave Band Frequency (Hz)	Sound Pressure Level (SPL)
1	62.5 Hz	104 dB
2	125 Hz	103 dB
3	250 Hz	98 dB
4	500 Hz	97 dB
5	1 kHz	94 dB
6	2 kHz	91 dB
7	4 kHz	93 dB
8	8kHz	95 dB

DI.FA SPL Open

```
{0;0;3;0;0;0}
0 105.083248
1 103.537043
2 99.242214
3 97.592083
4 94.918755
5 91.683629
6 93.658054
7 95.624864
{0;0;4;0;0;0}
0 104.57993
1 103.209871
2 99.564652
3 98.181424
4 95.618687
5 91.952831
6 94.24646
7 96.335992
{0;0;5;0;0;0}
0 105.475609
1 104.223191
2 100.436967
3 98.865309
4 95.889987
5 91.939504
6 94.36427
```

Figure 38. Sound Pressure Level results of Diamond Façade Form when the elements are in total Expansion (Author, 2023)



DI.FA STI Open

```
0 0.421778
1 0.427784
2 0.431636
{0;0;50;0;0;0}
0 0.402402
1 0.417034
2 0.422922
{0;0;51;0;0;0}
0 0.406924
1 0.422316
2 0.428171
```

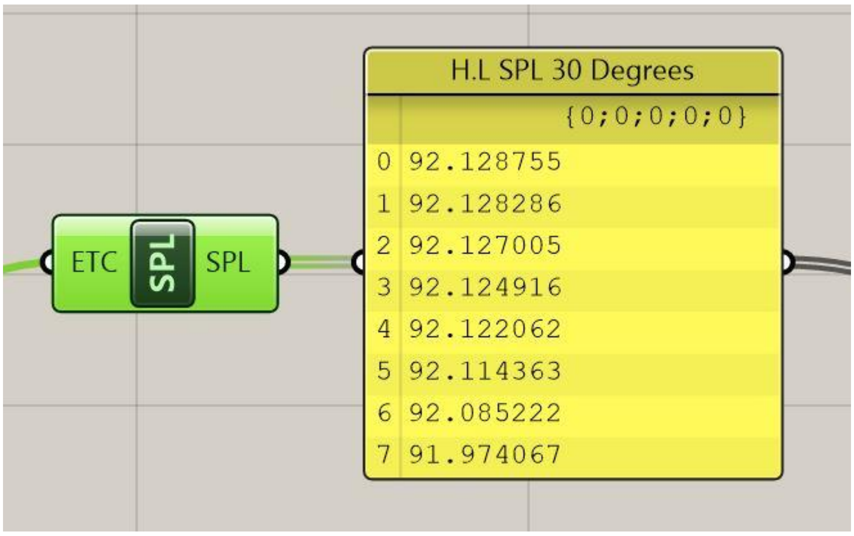
Figure 39. Speech Transmission Index results of Diamond Façade Form when the elements are in total Expansion (Author, 2023)

Table 8: list of simulation results of Octave Band frequencies and their respective SPL with Diamond façade elements when the elements are in total expansion (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	105 dB
2	125 Hz	103 dB
3	250 Hz	99 dB
4	500 Hz	97 dB
5	1 kHz	94 dB
6	2 kHz	91 dB
7	4 kHz	93 dB
8	8kHz	95 dB

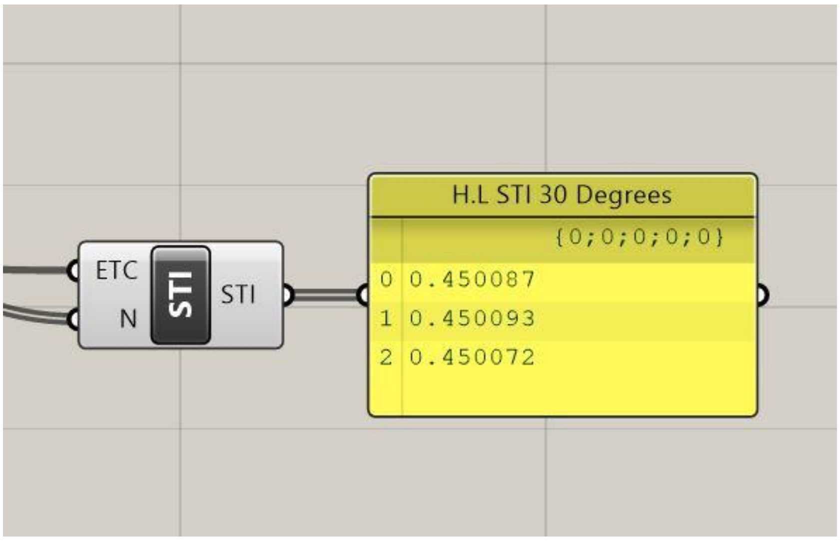
4.9 Sound Pressure Level (SPL) & Speech Transmission Index (STI) Simulation of Horizontal Louver Elements

The simulation has been conducted on several stages on kinetic movements "Translation" which involves motion in a specific direction in which the façade elements were simulated when translation at different angles such as 30°, 60°, 90°. The simulations done have shown that the results of sound reflected or bouncing of the Horizontal Louvers leading to a significant decrease in the SPL and some of the transmitted sound that resulted from the reflection didn't have a great effect and an increase in STI was experienced as a result, for which an increase towards a factor of 1 is better for speech intelligibility in the indoor area, these results can be seen in Figures 40, 41, 42, 43, 44, 45, 46, 47, 48, 49 and Tables 9, 10, 11.



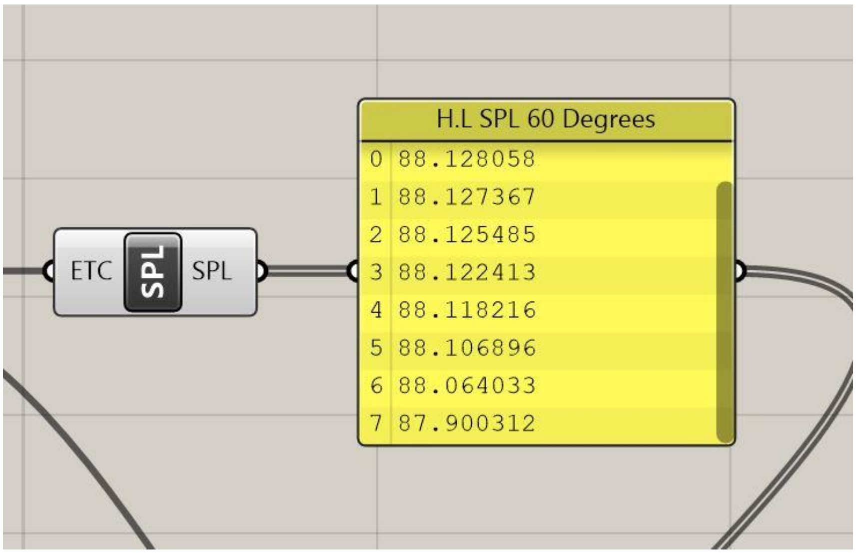
```
{0;0;0;0;0}
0 92.128755
1 92.128286
2 92.127005
3 92.124916
4 92.122062
5 92.114363
6 92.085222
7 91.974067
```

Figure 40. Sound Pressure Level results of Horizontal Louvers at 30° (Author, 2023)



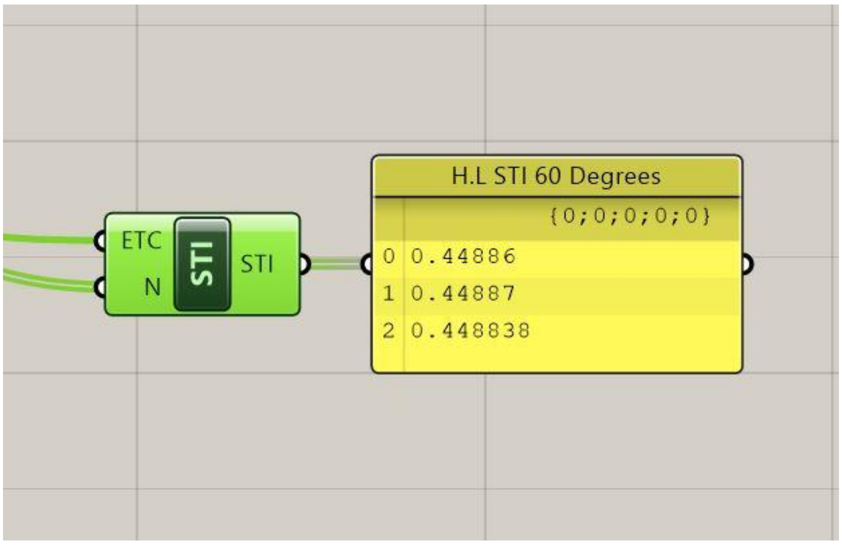
```
{0;0;0;0;0}
0 0.450087
1 0.450093
2 0.450072
```

Figure 41. Speech Transmission Index results of Horizontal Louvers at 30° (Author, 2023)



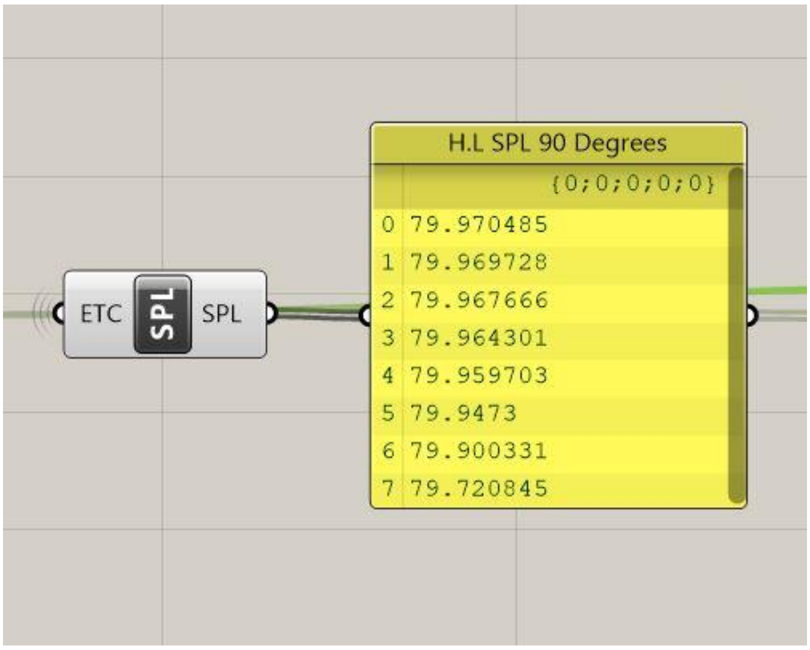
```
H.L SPL 60 Degrees
0 88.128058
1 88.127367
2 88.125485
3 88.122413
4 88.118216
5 88.106896
6 88.064033
7 87.900312
```

Figure 42. Sound Pressure Level results of Horizontal Louvers at 60° (Author, 2023)



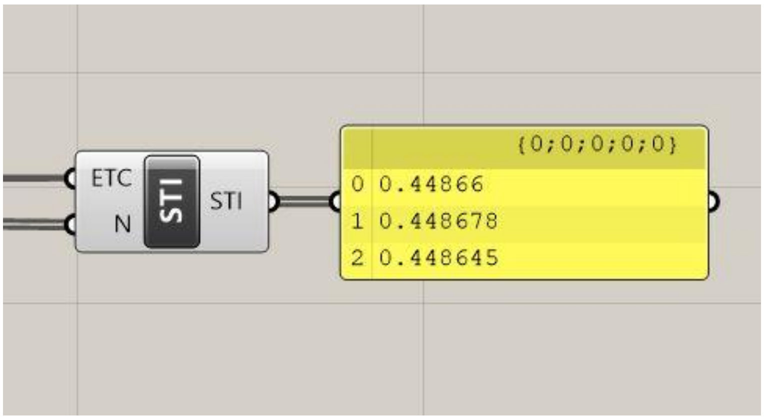
```
H.L STI 60 Degrees
            {0;0;0;0;0}
0 0.44886
1 0.44887
2 0.448838
```

Figure 43. Speech Transmission Index results of Horizontal Louvers at 60° (Author, 2023)



```
{0;0;0;0;0}
0 79.970485
1 79.969728
2 79.967666
3 79.964301
4 79.959703
5 79.9473
6 79.900331
7 79.720845
```

Figure 44. Sound Pressure Level results of Horizontal Louvers at 90° (Author, 2023)



```
{0;0;0;0;0}
0 0.44866
1 0.448678
2 0.448645
```

Figure 45. Speech Transmission Index results of Horizontal Louvers at 90° (Author, 2023)

Table 9: list of simulation results of Octave Band frequencies and their respective SPL with Horizontal Louvers at 30° (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	92 dB
2	125 Hz	92 dB
3	250 Hz	92 dB
4	500 Hz	92 dB
5	1 kHz	92 dB
6	2 kHz	92 dB
7	4 kHz	92 dB
8	8kHz	91 dB

Table 10: list of simulation results of Octave Band frequencies and their respective SPL with Horizontal Louvers at 60° (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	88 dB
2	125 Hz	88 dB
3	250 Hz	88 dB
4	500 Hz	88 dB
5	1 kHz	88 dB
6	2 kHz	88 dB
7	4 kHz	88 dB
8	8kHz	87 dB

Table 11: list of simulation results of Octave Band frequencies and their respective SPL with Horizontal Louvers at 90° (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	79 dB
2	125 Hz	79 dB
3	250 Hz	79 dB
4	500 Hz	79 dB
5	1 kHz	79 dB
6	2 kHz	79 dB
7	4 kHz	79 dB
8	8kHz	79 dB

What has been observed that during the impulse response that has scattered the rays, some of the Horizontal Louver elements give less SPL and some give more, and that is caused due to the movement of the elements at certain angles as can be seen in the results of each angle in the tables.

Figure 46. 3D visualization of the Horizontal Louver elements surrounding the building (Author, 2023)

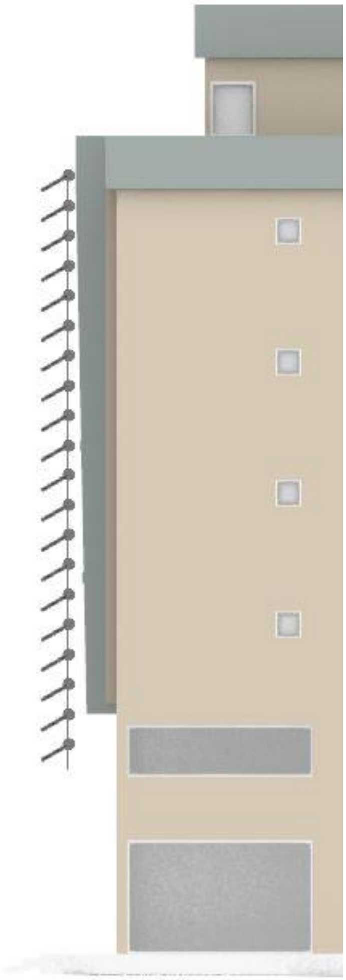


Figure 47. A side view of the Horizontal Louver on a 30° angle (Author, 2023)

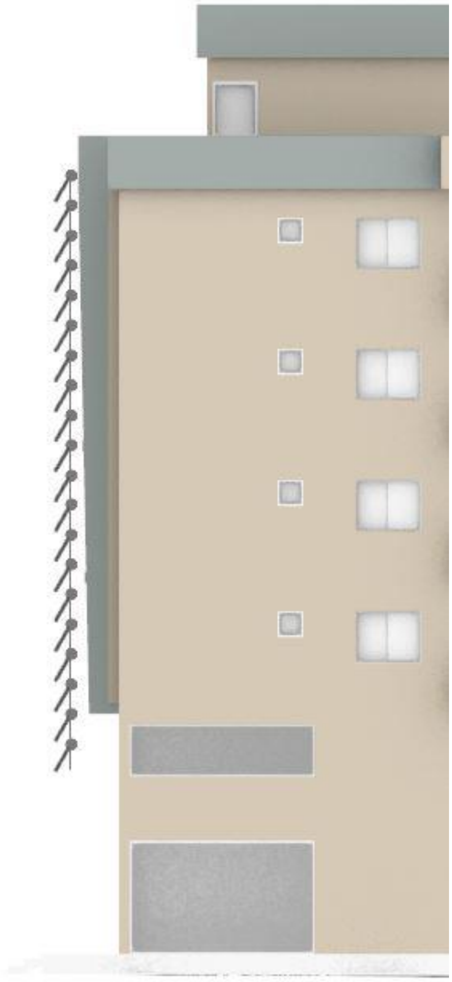


Figure 48. A side view of the Horizontal Louver on a 60° angle (Author, 2023)

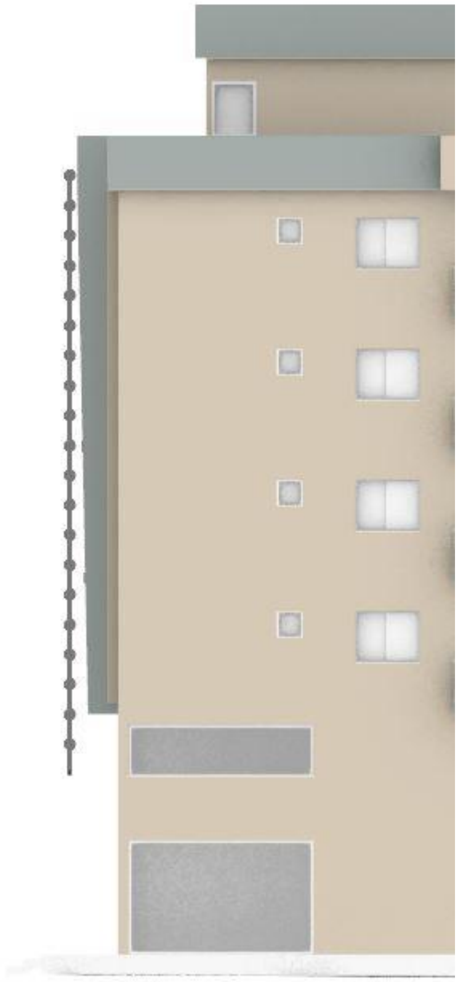
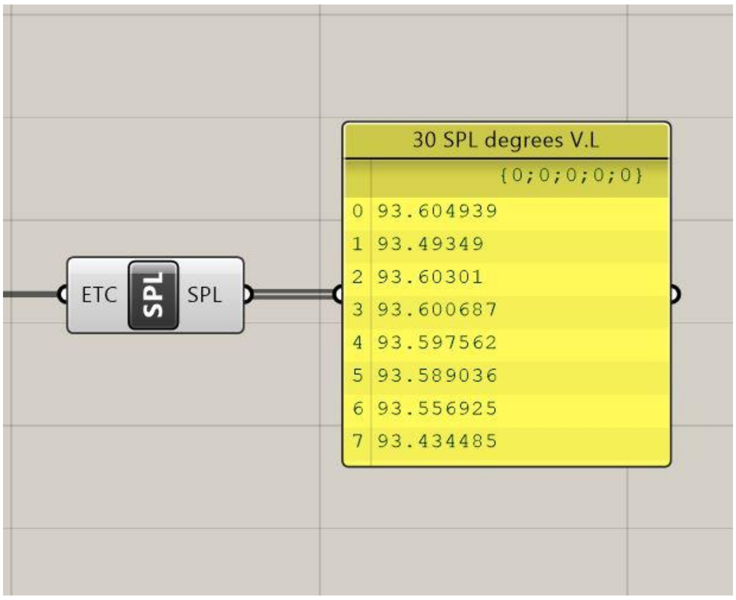


Figure 49. A side view of the Horizontal Louver on a 90° angle (Author, 2023)

4.10 Sound Pressure Level (SPL) & Speech Transmission Index (STI) Simulation of Vertical Louver Elements

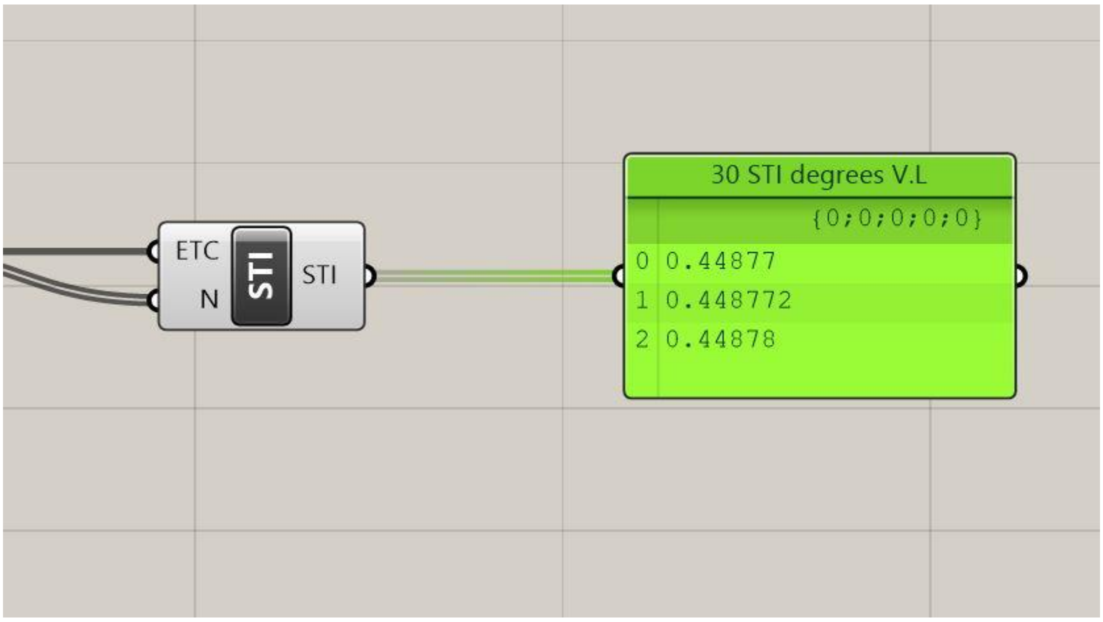
The simulation that has been conducted on Vertical Louver Elements has the same conceptual kinetic movement and has been conducted similarly as the Horizontal louver elements on several stages. Then the façade elements were simulated when translation kinetic movement was at different angles such as 30°, 60°, 90°. The simulations done have shown that the results of sound reflected or bouncing of the Vertical Louvers leading to a significant decrease in the SPL and some of the transmitted sound that resulted from the reflection didn’t have a great effect and an increase in STI was experienced as a result, for which an increase towards a factor of 1 is better for speech intelligibility in the indoor area, these results can be seen in Figures 50, 51, 52, 53, 54, 55, 56, 57, 58 and Tables 12, 13, 14.

The measurements of both SPL and STI were done to show how the sound reacts on the exterior when bouncing of the Façade elements, in which from the results it shows that the sound got reflected and dispersed in various directions, and the STI in which the sound transmitted shows how it reacts on the indoors of the space in which it didn’t affect it because of the insulation or the bouncing and reflection of the façade elements.



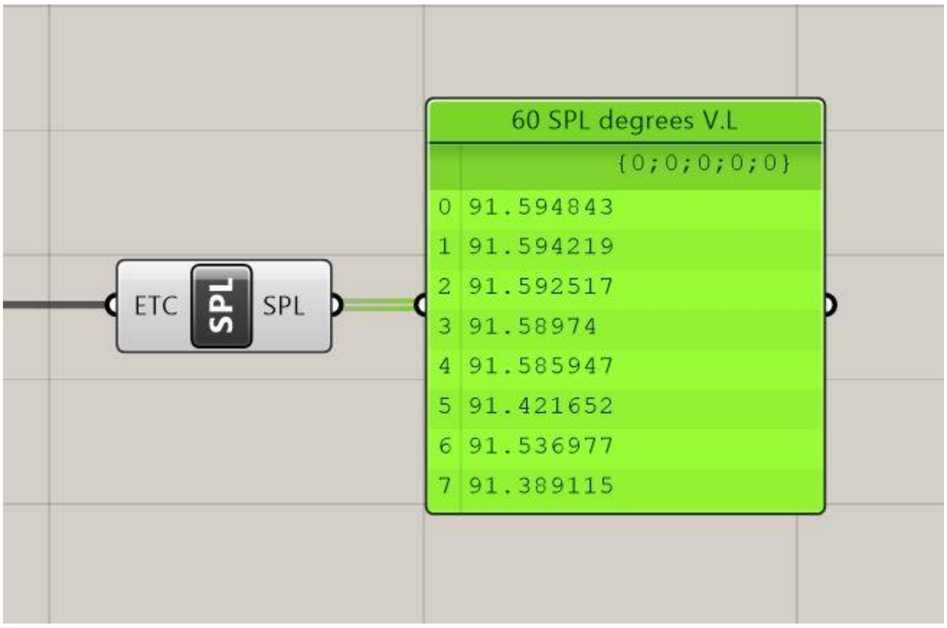
```
30 SPL degrees V.L
{0;0;0;0;0}
0 93.604939
1 93.49349
2 93.60301
3 93.600687
4 93.597562
5 93.589036
6 93.556925
7 93.434485
```

Figure 50. Sound Pressure Level results of Vertical Louvers at 30° (Author, 2023)



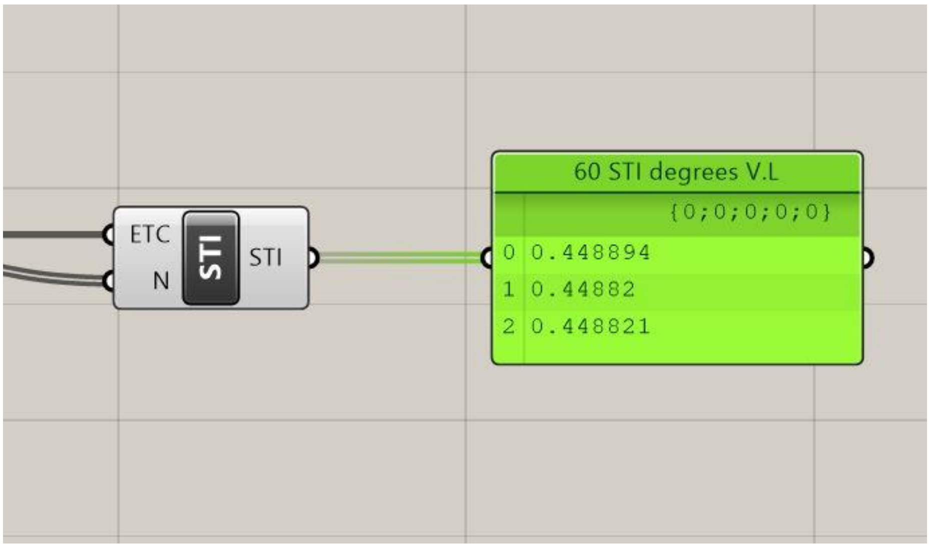
```
30 STI degrees V.L
{0;0;0;0;0}
0 0.44877
1 0.448772
2 0.44878
```

Figure 51. Speech Transmission Index results of Vertical Louvers at 30° (Author, 2023)



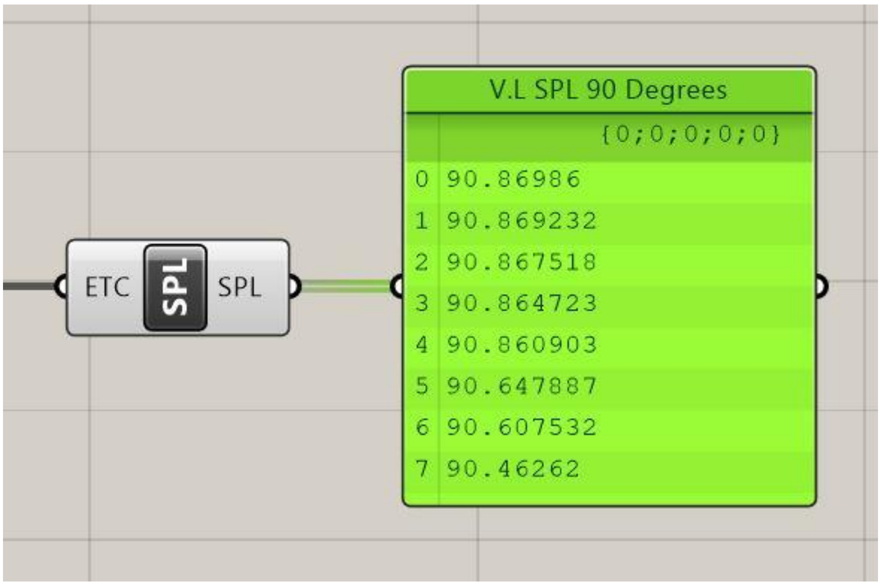
```
60 SPL degrees V.L
{0;0;0;0;0}
0 91.594843
1 91.594219
2 91.592517
3 91.58974
4 91.585947
5 91.421652
6 91.536977
7 91.389115
```

Figure 52. Sound Pressure Level results of Vertical Louvers at 60° (Author, 2023)



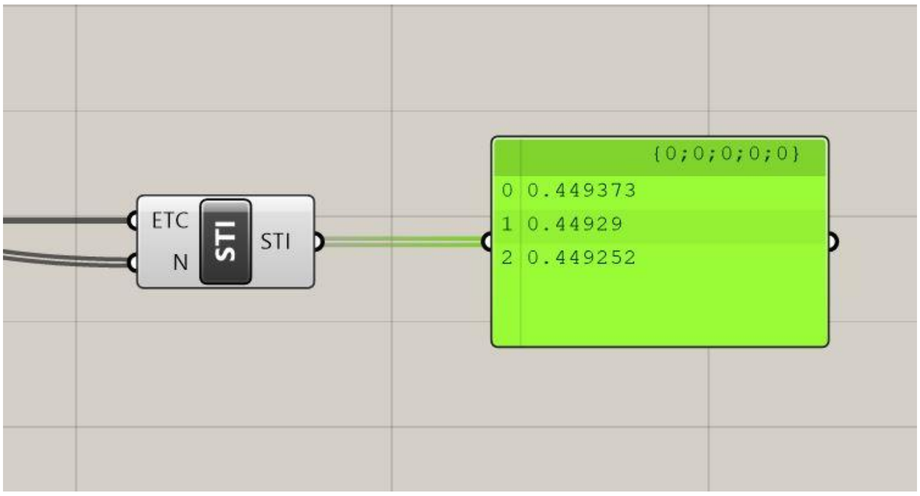
```
60 STI degrees V.L
{0;0;0;0;0}
0 0.448894
1 0.44882
2 0.448821
```

Figure 53. Speech Transmission Index results of Vertical Louvers at 60° (Author, 2023)



```
V.L SPL 90 Degrees
{0;0;0;0;0}
0 90.86986
1 90.869232
2 90.867518
3 90.864723
4 90.860903
5 90.647887
6 90.607532
7 90.46262
```

Figure 54. Sound Pressure Level results of Vertical Louvers at 90° (Author, 2023)



```
{0;0;0;0;0}
0 0.449373
1 0.44929
2 0.449252
```

Figure 55. Speech Transmission Index results of Vertical Louvers at 90° (Author, 2023)

Table 12: list of simulation results of Octave Band frequencies and their respective SPL with Vertical Louvers at 30° (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	93 dB
2	125 Hz	93 dB
3	250 Hz	93 dB
4	500 Hz	93 dB
5	1 kHz	93 dB
6	2 kHz	93 dB
7	4 kHz	93 dB
8	8kHz	93 dB

Table 13: list of simulation results of Octave Band frequencies and their respective SPL with Vertical Louvers at 60° (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	91 dB
2	125 Hz	91 dB
3	250 Hz	91 dB
4	500 Hz	91 dB
5	1 kHz	91 dB
6	2 kHz	91 dB
7	4 kHz	91 dB
8	8kHz	91 dB

Table 14: list of simulation results of Octave Band frequencies and their respective SPL with Vertical Louvers at 90° (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	90 dB
2	125 Hz	90 dB
3	250 Hz	90 dB
4	500 Hz	90 dB
5	1 kHz	90 dB
6	2 kHz	90 dB
7	4 kHz	90 dB
8	8kHz	90 dB

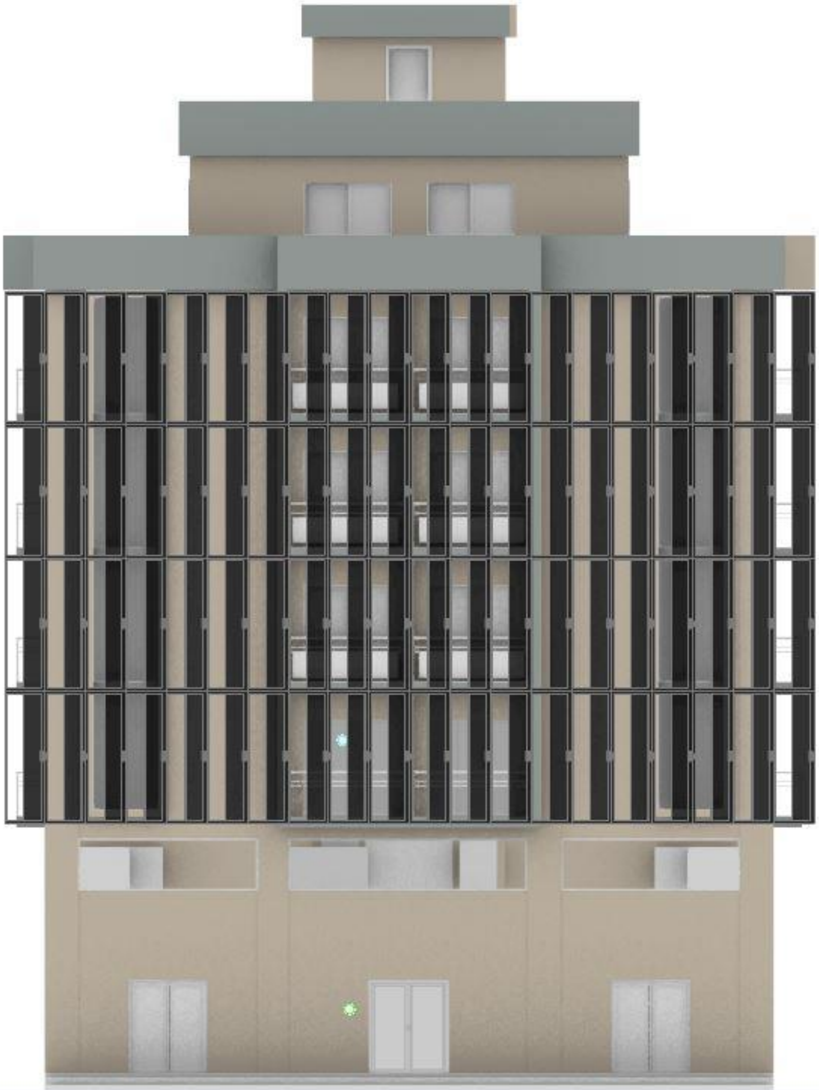


Figure 56. A front view of the Vertical Louver on a 30° angle (Author, 2023)

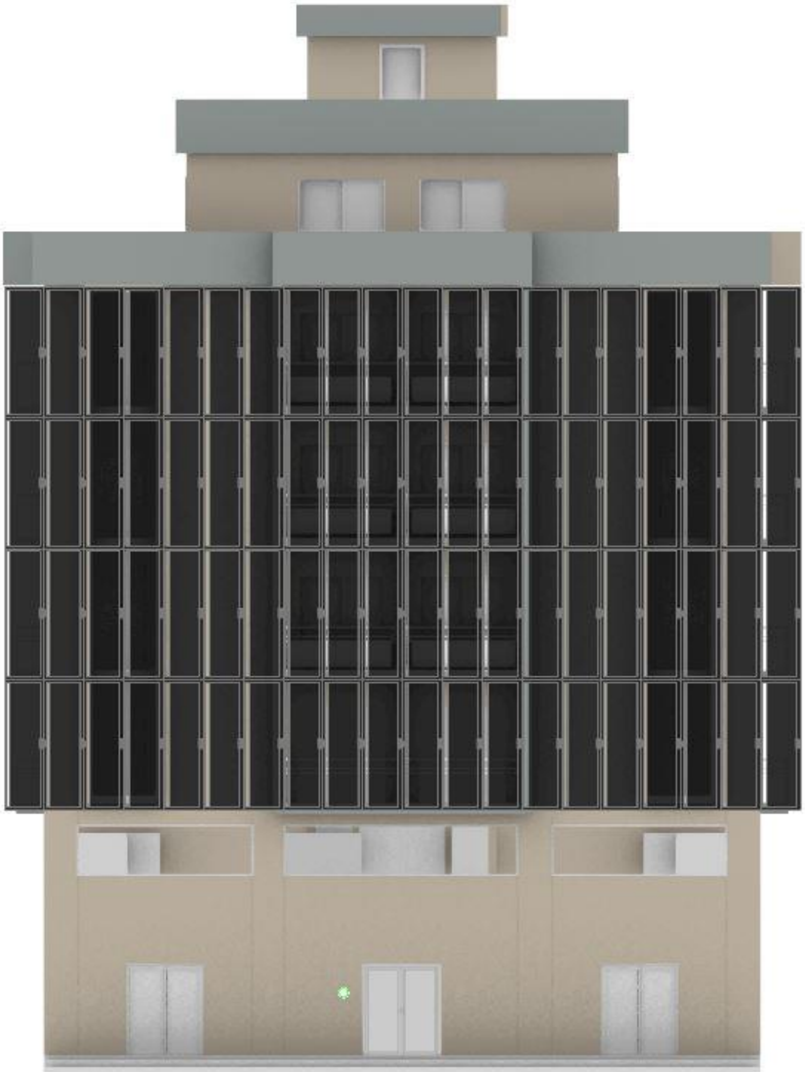


Figure 57. A front view of the Vertical Louver on a 60° angle (Author, 2023)

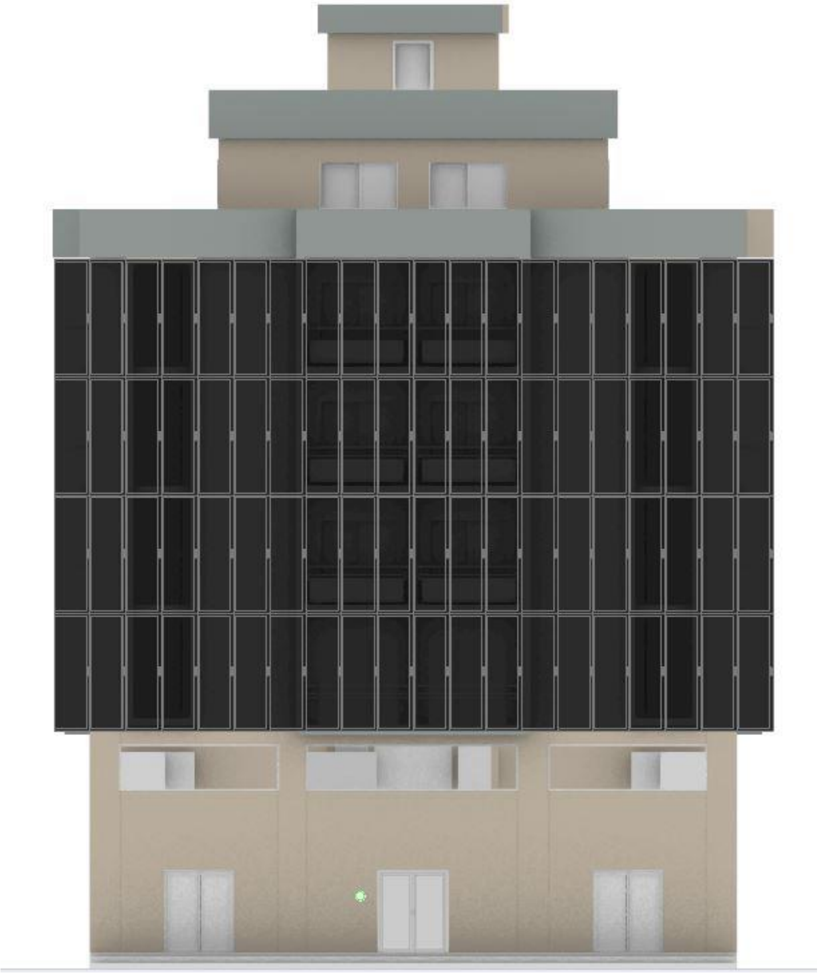


Figure 58. A front view of the Vertical Louver on a 90° angle (Author, 2023)

4.11 Chapter Summary

The integration of the literature review and the chapter on software tools aims to optimize the performance of a residential building in Famagusta, TRNC, through the implementation of Adaptive façade solutions. The workflow begins with gathering environmental and building data, which is then utilized to create precise 3D visualizations by importing the data into the Autodesk Revit 2023 program. Moreover, then the module was imported in Rhinoceros which then with the aid of a plug-in Grasshopper the adaptive facades were designed accordingly in addition to their movement in certain degrees with the aid of closed loop systems in which Environmental data is collected through sensors, processed by a logical unit, and acted upon by actuators, with communication facilitated by a management system. The façade elements were designed accurately on the existing building. Finally, Pachyderm has been utilized as an acoustic simulation by inputting relative data such as material on every architectural element with their respective absorption coefficients. The simulation was applied first on the existing building to understand the existing conditions acoustically, then another simulation was done on three different façade proposals, the Diamond Façade element, Vertical and the Horizontal Louver, all are adaptive façade designs. The initial simulation without the adaptive façade elements showed that the building is lacking in acoustical standards, in which the sound pressure level (SPL) exceeded the standard when an impulse response of scattering rays was introduced. However, the results overall showed that between the proposed adaptive façades the Horizontal Louvers had the best insulation properties in which the sound propagated from the noise source bounced and or reflected off the façade elements and in return the speech transmission index (STI) was not affected, and the measurement results of the simulation showed an increase in intelligibility of sound and speech in the indoor area.

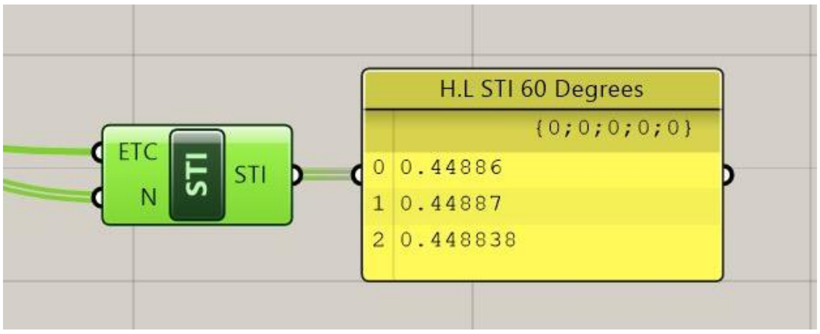
Chapter 5

CONCLUSION

The significance of noise pollution and acoustic considerations is paramount in enhancing building design and minimizing the impact on users. Therefore, it is crucial to investigate how kinetic façade elements can effectively optimize building performance in relation to noise pollution. To achieve this, the research delved into the literature, explaining the definition of sound and noise, as well as the properties of sound, its propagation, and its potential negative effects on human health over time. Additionally, the research focused on external noise sources, particularly traffic-related noises, and their adverse consequences. To address these issues, the study proposed various façade concepts and their approaches to create solutions for optimizing indoor building acoustics. The research showcased diverse façade approaches with conceptual mechanisms such as designing with the adaptive façade approach, this method shows a potential of implementing its technology into the issue of façades and where the movement of these façade elements was determined by environmental factors. Therefore, the simulation results indicated a deficiency in addressing acoustic factors. Through the application of simulations on diverse adaptive facades like Diamond Form Elements, Horizontal and Vertical Louver panels, the findings demonstrated a favorable shift from prior results. Specifically, the sound pressure levels when simulated the results showed how Horizontal Louver elements proposed façade solution interacted with the noise source by being reflected of the said façade elements and there was no effect and an increase in the speech transmission index as can be seen in Table 15 and in Figure 59 which shows an increase towards 0.6 which is better intelligibility and clarity of sound in the indoor space of the building.

Table 15: list of simulation results of Octave Band frequencies and their respective SPL with Horizontal Louvers at 60° (Author, 2023)

Number of Frequency	**Octave Band Frequency (Hz)**	**Sound Pressure Level (SPL)**
1	62.5 Hz	88 dB
2	125 Hz	88 dB
3	250 Hz	88 dB
4	500 Hz	88 dB
5	1 kHz	88 dB
6	2 kHz	88 dB
7	4 kHz	88 dB
8	8kHz	87 dB



```
{0;0;0;0;0}
0 0.44886
1 0.44887
2 0.448838
```

Figure 59. Speech Transmission Index results of Horizontal Louvers at 60° (Author, 2023)

REFERENCES

Arsenault, P. J. (2016). Acoustical Control in Buildings. Retrieved from https://continuingeducation.bnpmedia.com/courses/certainteed-insulation/acoustical-control-in-buildings/1/#:~:text=Sound%20Transmission,is%20transmitted%20directly%20through%20it.

Al-Obaidi, K. M., Ismail, M. A., Hussein, H., & Rahman, A. M. A. (2017). Biomimetic building skins: An adaptive approach. *Renewable and Sustainable Energy Reviews*, *79*, 1472-1491.

Basner, M., Babisch, W., Davis, P. A., Brink, M., Clark, C., Janssen, S., & Stansfeld, P. S. (2014). Auditory and non-auditory effects of noise on health. *Lancet*, *383*(9925), 1325. https://doi.org/10.1016/S0140-6736(13)61613-X

Bhatia, R. (2014). Noise Pollution: Managing the Challenge of Urban Sounds. Earth Journalism Network. https://earthjournalism.net/resources/noise-pollution-managing-the-challenge-of-urban-sounds

Badarnah, L. (2016). Water management lessons from nature for applications to buildings. *Procedia engineering*, *145*, 1432-1439.

Babisch, W. (2002). The noise/stress concept, risk assessment and research needs. *Noise and health*, *4*(16), 1.

Brodoceanu, D., Bauer, C. T., Kroner, E., Arzt, E., & Kraus, T. (2016). Hierarchical bioinspired adhesive surfaces—a review. *Bioinspiration & biomimetics, 11*(5), 051001.

Britannica, T. Editors of Encyclopaedia (2013, May 14). sound intensity. Encyclopedia Britannica. https://www.britannica.com/science/sound-intensity

Basnet, M. (2023). How does sound travel? [Article]. Retrieved from https://www.researchgate.net/publication/370047158_How_does_sound_travel/citations#fullTextFileContent

Chen, F., Wong, L., & Hu, Y. (2014). Effects of lexical tone contour on Mandarin sentence intelligibility. Journal of Speech, Language, and Hearing Research, 57, 338. https://doi.org/10.1044/1092-4388(2013/12-0324)

Chandrappa, R., & Das, D. B. (2021). Noise Pollution. In Environmental Health - Theory and Practice. Springer, Cham. https://doi.org/10.1007/978-3-030-64484-0_7

Costa Maia, S., Teicher, H., & Meyboom, A. (2015). Infrastructure as social catalyst: Electric vehicle station planning and deployment. Technological Forecasting and Social Change. https://doi.org/10.1016/j.techfore.2015.09.020

Chepesiuk, R. (2005). Decibel hell: the effects of living in a noisy world.

Cantuaria, M. L., Waldorff, F. B., Wermuth, L., Pedersen, E. R., Poulsen, A. H., Thacher, J. D., ... & Sørensen, M. (2021). Residential exposure to transportation noise in Denmark and incidence of dementia: national cohort study. *bmj*, *374*.

Charpentier, V., Hannequart, P., Adriaenssens, S., Baverel, O., Viglino, E., & Eisenman, S. (2017). Kinematic amplification strategies in plants and engineering. *Smart Materials and Structures*, *26*(6), 063002.

Dorfaki, R. (2021). What is Speech Transmission Index (STI) in sound calculation for PAGA system design? Retrieved from https://www.linkedin.com/pulse/what-speech-transmission-index-sti-sound-calculation-paga-dorfaki/

Day, M. 2000-2010. Rhino Grasshopper, AEC Magazine, X3DMedia, http://aecmag.com.

Ephraime, E. E. (2002). The Decaying City: The Prevailing Instruments of Decay Governments' Inaction and Public Attitudinal Posturing. In Faworaja, A., et al. (Eds.), The Decaying City: Architect's Dilemma and Responsibilities (pp. 16-24)

Elmokadem, A., Ekram, M., Waseef, A., & Nashaat, B. (2018). Kinetic Architecture: Concepts, History and Applications. International Journal of Science and Research (IJSR), 7(4), Retrieved from www.ijsr.net.

Fox, M., & Kemp, M. (2009). Interactive Architecture. Princeton Architectural Press.

Ferk, H. J. (2017). Protection against Noise: Technical Assistance for Reforming the Cyprus Planning & Building Legislation Framework. Retrieved from http://www.moi.gov.cy/MOI/moiup/moi.nsf/all/9CAF33FDE6CAD8F7C225858C002C5F37/$file/2nd%20mission%20-%20Protection%20Against%20Noise.pdf

Fouad, S. M. A. E. (2012). Design methodology: kinetic architecture. Architectural Engineering, Alexandria University.

Fox, m. Yeh, b. (1999) Intelligent kinetic systems. Kinetic design group, massachustts, institute of technology (mit), department of architecture.

Foster, N., & Heatherwick, T. (2017, October 13). Bund Finance Centre. ArchDaily. https://www.archdaily.com/881511/bund-finance-centre-foster-plus-partners-plus-heatherwick-studio

Fox, M. A., & Yeh, B. P. (2000). Intelligent kinetic systems in architecture. In P. Nixon, G. Lacey, & S. Dobson (Eds.), Managing interactions in smart environments. Springer, London.

Foster, N., Heatherwick, T., & ArchDaily. (2017, October 13). Bund Finance Centre. Retrieved July 9, 2023, from https://www.archdaily.com/881511/bund-finance-centre-foster-plus-partners-plus-heatherwick-studio

Fink, D. (2019). A new definition of noise: noise is unwanted and/or harmful sound. Noise is the new 'secondhand smoke'. Proc. Mtgs. Acoust, 39(1), 050002. https://doi.org/10.1121/2.0001186

Fu QJ, Zeng FG, Shannon RV, Soli SD (1998) Importance of tonal envelope cues in Chinese speech recognition. J Acoust Soc Am 104:505–510. https://doi.org/10.1121/1.423251

Grasshopper 3D. (2023, June 12). In *Wikipedia*. https://en.wikipedia.org/wiki/Grasshopper_3D

Hawkins, B. S. (2023). How do sound waves work? Retrieved from https://www.popsci.com/reviews/what-are-sound-waves/

Hosseini, S. M., Mohammadi, M., Rosemann, A., Schröder, T., & Lichtenberg, J. (2019). A morphological approach for kinetic façade design process to improve visual and thermal comfort: Review. *Building and Environment*, *153*, 186-204. https://doi.org/10.1016/j.buildenv.2019.02.040

Harris, T. (2021, February 12). How Hearing Works. Retrieved from https://health.howstuffworks.com/mental-health/human-nature/perception/hearing.htm

ISO/TS 15666, Acoustics – Assessment of noise annoyance by means of social and socio-acoustic surveys, (2003) Irwin, M. R., & Vitiello, M. V. (2019). Implications of sleep disturbance and inflammation for Alzheimer's disease dementia. *The Lancet Neurology, 18*(3), 296-306.

Kronenburg, R. (2013). Architecture in motion: The history and development of portable building. Routledge, London.

Kensek, K., & Hansanuwat, R. (2011). Environment control systems for sustainable design: a methodology for testing, simulating, and comparing kinetic facade systems. *Journal of Creative Sustainable Architecture & Built Environment*, *1*(11), 27-46.

Knippers, J., & Speck, T. (2012). Design and construction principles in nature and architecture. *Bioinspiration & biomimetics*, *7*(1), 015002.

Körner, A., Born, L., Mader, A., Sachse, R., Saffarian, S., Westermeier, A. S., ... & Knippers, J. (2017). Flectofold—a biomimetic compliant shading device for complex free form facades. *Smart Materials and Structures*, *27*(1), 017001.

Lagios, K., Niemasz, J., & Reinhart, C. F. (2010). Animated Building Performance Simulation (ABPS) - Linking Rhinoceros/Grasshopper with Radiance/Daysim. Proceedings of SimBuild 2010, New York City, August 2010. (Accepted for Publication).

Loonen, R.C.G.M., Rico-Martinez, J.M., Favoino, F., Brzezicki, M., Menezo, C., La Ferla, G., Aelenei, L. (2015). Design for façade adaptability: Towards a unified and systematic characterization. In Proceedings of the 10th Conference on Advanced Building Skins, Bern, Switzerland, pp. 1284–1294. Retrieved from https://research.tue.nl/en/publications/design-for-fa%C3%A7ade-adaptability-towards-a-unified-and-systematic-c.

Libart USA, (2018). Kinetic Architectural Systems. Engineeringcenter. Retrieved from as a PDF https://engineeringcenter.bnpmedia.com/pdf/courses/L665C1971.pdf

Lim, J., Kweon, K., Kim, W., Cho, S. W., Park, J., & Sim, C. S. (2018). Negative Impact of Noise and Noise Sensitivity on Mental Health in Childhood. *Noise & Health*, *20*(96), 199-211. https://doi.org/10.4103/nah.NAH_9_18

Li, S., & Wang, K. W. (2016). Plant-inspired adaptive structures and materials for morphing and actuation: a review. *Bioinspiration & biomimetics*, *12*(1), 011001.

Lopez, M., Rubio, R., Martín, S., Croxford, B., & Jackson, R. (2015). Active materials for adaptive architectural envelopes based on plant adaptation principles. *Journal of Facade Design and Engineering*, *3*(1), 27-38.

Ma, Z., Cooper, P., Daly, D., & Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings*, *55*, 889-902. https://doi.org/10.1016/j.enbuild.2012.08.018

McNeel, R. 2010. Grasshopper - Generative Modeling with Rhino, McNeel North America, Seattle, USA. (http://www.grasshopper3d.com/).

Moloney, J. (2011), Designing kinetics for architectural facades: state change, taylor & francis, new york.

M. Wigginton, J. Harris (2013). Intelligent Skins. http://doi:10.4324/9780080495446

Mahmoud, A. H. A., & Elghazi, Y. (2016). Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns. *Solar Energy*, *126*, 111-127. https://doi.org/10.1016/j.solener.2015.12.039

Migilinskas, D., Popov, V., Juocevicius, V., & Ustinovichius, L. (2013). The Benefits, Obstacles and Problems of Practical Bim Implementation. *Procedia Engineering*, *57*, 767-774. https://doi.org/10.1016/j.proeng.2013.04.097

Minakawa, E. N., Wada, K., & Nagai, Y. (2019). Sleep disturbance as a potential modifiable risk factor for Alzheimer’s disease. *International journal of molecular sciences*, *20*(4), 803.

Nady, R. (2017). Dynamic Facades Environmental Control Systems for Sustainable Design. Renewable Energy and Sustainable Development (RESD), 3(1), 118-127. DOI: 10.21622/resd.2017.03.1.118.

Nađ, B. (2023). Noise. Well with Nature/EEA. https://www.eea.europa.eu/en/topics/in-depth/noise?activeAccordion=

Nashaat, B., & Waseef, A. (2017, April). Responsive Kinetic Facades: An Effective Solution for Enhancing Indoor Environmental Quality in Buildings. Paper presented at The First Memaryat International Conference (MIC 2017): Architecture of the Future: Challenges and Visions, Saudi Arabia.

National Institute for Occupational Safety and Health. (2018). Noise & Hearing Loss Prevention. CDC. Retrieved May 2, 2022, from https://www.cdc.gov/niosh/topics/noise/default.html

Noise Control Act of 1972, P.L. 92-574, 86 Stat. 1234, 42 U.S.C. § 4901 - 42 U.S.C. § 4918. (Noise Pollution, n.d.)

Noise Control Engineering. (2023). Acoustic Louvres. Retrieved from https://noisecontrolengineering.com.au/acoustic-louvres/

OpenStax. (2016). University Physics, Volume 1: 17.1 Sound Waves. https://openstax.org/books/university-physics-volume-1/pages/17-1-sound-waves

Ogunsote, O., & Ganiyu, S. (2010). A study of sources and control of environmental noise pollution on a typical street in Akure, Nigeria. Conference Paper.

Ogunsote, O. O. (2010). Environmental Control – Acoustics and Noise Control. Unpublished Lecture Notes, Department of Architecture, Federal University of Technology, Akure.

Öhrström, E., Skånberg, A., Svensson, H., & Gidlöf-Gunnarsson, A. (2006). Effects of road traffic noise and the benefit of access to quietness. *Journal of sound and vibration*, *295*(1-2), 40-59.

Pohl, G., Nachtigall, W., Pohl, G., & Nachtigall, W. (2015). Biomimetics for buildings. *Biomimetics for Architecture & Design: Nature-Analogies-Technology*, 25-52.

Rieper, A. (2012). The Architectural Manipulation of Sound (Doctoral dissertation). Victoria University of Wellington, School of Architecture.

Radwan, G. A., & Osama, N. (2016). Biomimicry, an approach, for energy effecient building skin design. *Procedia Environmental Sciences*, *34*, 178-189.

Rivière, M., Derr, J., & Douady, S. (2017). Motions of leaves and stems, from growth to potential use. *Physical biology*, *14*(5), 051001.

Shravage, P. (2015). Silence through Science. Alfa Acoustics. https://www.alfaacoustics.com/Sound-Transmission-Loss.html#

Support Technology Pty. Ltd. (2018). SUPPORT TECHNOLOGY Your IT and AV Specialists. Rooms Acoustics.

Shome, A., Singh, R., & Baldota, S. (2022). Kinetic structures - what are kinetic structures, embedded and dynamic kinetic structures.

Sharaidin, K. (2014). Kinetic facades: towards design for environmental performance [RMIT University]. https://researchrepository.rmit.edu.au/esploro/outputs/doctoral/Kinetic-facades-towards-design-for-environmental/9921863888001341#file-0

Stine, D. J. (2011). Commercial Design Using Revit Architecture 2012. United States: SDC Publications.

Saini, M. K. (2023). Difference between Open Loop and Closed Loop Control Systems. Retrieved from https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system

Stewart, J. (2011). Why Noise Matters. New York: Earthscan.

Siham, H., Abed Hassan, S., & Abrahem, S. (2022). Interactive Architecture: Concepts, Objectives, Applications Review. Lab: Susan Abed Hassan's Lab. DOI: 10.13140/RG.2.2.27902.46402.

Sharaidin, K., Burry, J., & Salim, F. (2012). Integration of digital simulation tools with parametric designs to evaluate kinetic façades for daylight performance. In *Digital Physicality-Proceedings of the 30th eCAADe Conference* (Vol. 2, pp. 701-709). Czech Technical University in Prague, Faculty of Architecture Prague, Czech Republic.

Selander, J., Bluhm, G., Theorell, T., Pershagen, G., Babisch, W., Seiffert, I., ... & Järup, L. (2009). Saliva cortisol and exposure to aircraft noise in six European countries. *Environmental health perspectives*, *117*(11), 1713-1717.

Seyrek, C. I., Widera, B., & Woźniczka, A. (2021). Sustainability-Related Parameters and Decision Support Tools for Kinetic Green Façades. *Sustainability*, *13*(18), 10313. https://doi.org/10.3390/su131810313

Svantek Academy. (2023). Pascal to dB Sound Pressure Level (SPL). Retrieved from https://svantek.com/academy/sound-pressure-level-spl/#:~:text=Sound%20pressure%20level%20(SPL)%20can,than%20120%20dB%20is%20intolerable.

Tabadkani, A., Roetzel, A., Li, H. X., & Tsangrassoulis, A. (2021). Design approaches and typologies of adaptive facades: A review. *Automation in Construction*, *121*, 103450. https://doi.org/10.1016/j.autcon.2020.103450

The Constructor. (2021). Noise Control in Buildings Through Architectural Acoustic Design. Retrieved from https://theconstructor.org/building/noise-control-in-buildings-acoustic/14640/

Tobias, L., & Vavaroutsos, G. (2012). *Retrofitting buildings to be green and energy-efficient: optimizing building performance, tenant satisfaction, and financial return*. Urban Land Institute.

Vreede, P. (2018). Diffusion vs Absorption. Retrieved from https://www.linkedin.com/pulse/diffusion-vs-absorption-pieter-vreede/

World Health Organization. (2018). Environmental Noise Guidelines for the European Region; p. 160.

Wang, J, Beltrán, LO and Kim, J. 2012. “From Static to Kinetic: A Review of Acclimated Kinetic Building Envelopes.” In World Renewable Energy Forum, WREF 2012, Including World Renewable Energy Congress XII and Colorado Renewable Energy Society (CRES) Annual Conference

Waseef, A., & Nashaat, B. (2017). Towards a new classification for responsive kinetic facades. https://www.researchgate.net/publication/331803253_TOWARDS_A_NEW_CLASSIFICATION_FOR_RESPONSIVE_KINETIC_FACADES

Yuvita, R. L., & Budiwirawan, A. (2022). Analysis of the Advantages and Disadvantages of Using Autodesk Revit for the Dean Building of the Faculty of Education, Universitas Negeri Semarang. Jurnal Teknik Sipil & Perencanaan, 24(2), 91-98. DOI: 10.15294/jtsp. v24i2.36613.

Yu, Y., Mayeda, E. R., Paul, K. C., Lee, E., Jerrett, M., Su, J., ... & Ritz, B. (2020). Traffic-related noise exposure and late-life dementia and cognitive impairment in Mexican Americans. *Epidemiology (Cambridge, Mass.), 31*(6), 771.

URL 1: https://www.pasco.com/products/guides/sound-waves

URL 2: https://www.orangesmile.com/extreme/en/magnificent-stadiums/qi-zhong-stadium.htm

URL 3: https://www.heatherwick.com/project/rolling-bridge/

URL 4: http://www.maphill.com/cyprus/location-maps/physical-map/

URL 5: https://www.google.com/maps/search/cihangir+apartment+famagusta+north+cyprus/@35.1388947,33.9173152,174m/data=!3m1!1e3?entry=ttu

URL 6: https://www.acoustic.ua/st/web_absorption_data_eng.pdf