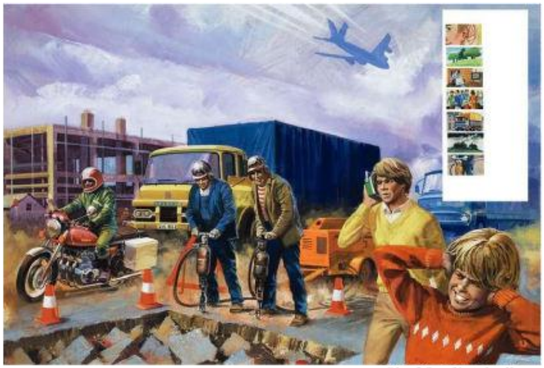
ACOUSTIC FACADE MITIGATION



"Noise Pollution" by Andrew Howat

Noise Pollution

Noise pollution within the urban environment is inescapable and directly correlates to the interrelated issues of the need for proximity, speed, and mechanical advancement. Cars, trains, and airplanes cause a majority of the noise in an urban environment in a range of different scenarios: vehicles on freeways and streets, trains on railways and in stations, plane flight paths, and in airports. The ubiquity of noise in our quotidian environment has been shown to have serious side effects over the course of an individual's life. Studies (citation) have shown that environmental noise can increase daily tension causing stress, and increases the risk of heart disease. Other effects of noise pollution can lead to auditory fatigue and deafness, physical disorder, affect activities requiring concentration, and even affect the value of property.

Sound Theory

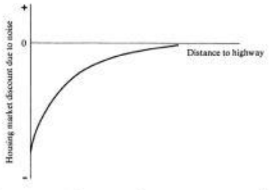
Sound is a complex physical phenomena that iscan be far more difficult to control and predict, than light, particularly with when working with architectural strategies. Sound is a force that uses pressure to act upon molecules, such as air, creating waves. WThe waves that compose audible sounds exist along a specific range of frequency of, 20 Hz to– 20,000 Hz. FWhat frequency measures is the size of a wavelength; the shorter the wavelength the higher pitched the sound.

Sound also can also be measured in terms of Decibels (dB). Decibels measure the intensity of pressure propelling the sound waves. Essentially itThis intensity determines how loud something is and w. With proper instrumentation one can measure the dB levels in the environment.

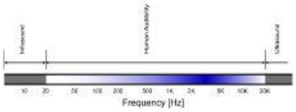
The final metric of sound is a perceptual measurement rather than a physical property of sound. Human hearing is most sensitive at the frequency ranges of 2000 Hz – to 5000 Hz. Several systems of 'weighting' match actual Sound Pressure Levels with human hearing sensitivity to give a rubric that would describe how sound is perceived. The most common weighting is A weighting. The unit is dB(A).

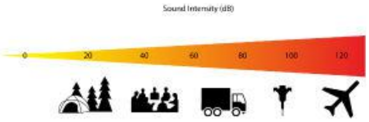
Effects of noise pollution:

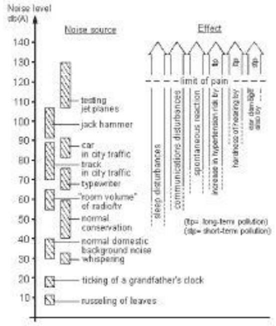
- A decrease in the attention span and the power of concentration
- A reduction of the ability to observe
- Impairment of sleep and relaxation
- Overexcitement of the nervous system
- High blood pressure
- Cardiovascular disease
- Hearing Impairment
- Stess
- Poor Work Performance
- Aggression



Highway noise and property values Jon P. Nelson

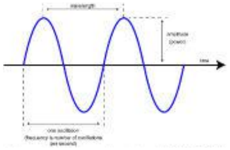






Noises and the Accompanying Typical A-sound

Source: Berlin Environmental Atlas



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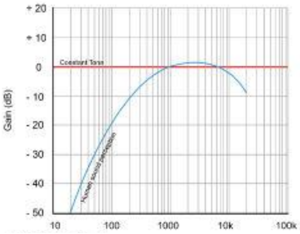
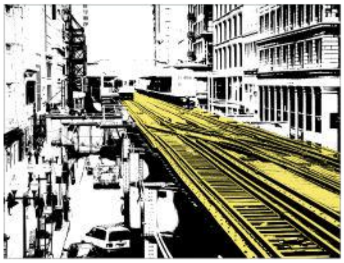


A-Weighting Graph

http://en.wikipedia.org/wiki/A-weighting

Scenario I
Urban street through residential zone

Scenario II
Urban park

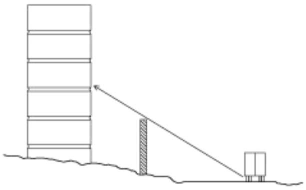


Scenario III
Elevated rail in an urban canyon

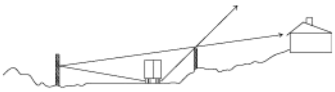
Scenario IV
Highway through mixed use zone

Sound Abatement Walls

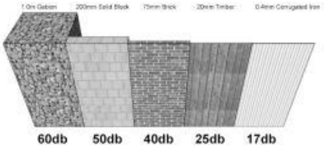
Reflecting surfaces on both sides of the highway can amplify the noise level by up to 6 dB.



Noise barriers can shield only the lowest floors of a building.



Wall barriers may reflect sound from one side of the highway to the other.



The amount of sound that a barrier wall can stop is a funcion of the material and thickness of the wall. For example a 7-5/8 inch solid concrete block wall can only stop 50 dB of noise, the remaining sounds passes through.

Precast concrete noise barriers with colored transparent openings bending over the highway in Barcelona. The shape of the geometry limits noise diffraction on to the buildings.

Source: "Noise Barrier Design" Hans Bendtsen

A sound barrier tunnel on the Croatian A7 motorway near Rijeka. The motorway is approximatly 130 feet away from residential area, most notably a 26 story building.

Source: Croatian Motorway Authority

Steel and glass noise barrier along a highway in Vienna, Austria. Geometry used to break the noise path from the source to the reciever is critical. Optimal effects are obtained if the screen is placed as close as possible to the highway or next to the receiver.

Source: "Noise Barrier Design" Hans Bendtsen

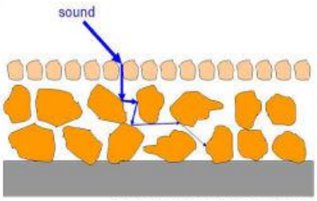
Dutch concrete noise barrier bent at a small angle from the road in order to reflect the noise wpwards to reduce the disturbance of residents on the other side of the highway.

Source: "Noise Barrier Design" Hans Bendtsen

SOUND MITIGATION STRATEGIES

1. Absorption

There are several types of sound absorbers: Porous absorbers, panel or membrane absorbers, and volume absorbers. Of particular relevance to our research are porous absorbers because this can be the by-product of material properties used in the fabrication of architectural surfaces. Specifically, our research will focus on the application of exterior surfaces and it is possible to create porous surfaces through certain techniques of concrete mixture and curing. In the case of porosity the principle at work is that sound enters the voids and bounces against the surfaces of the cells, cause friction, and eventually slow down. With the right mixture, it will be possible to harness the aggregate structure in concrete to mitigate sound.



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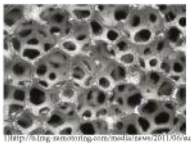
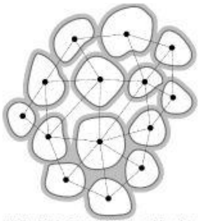
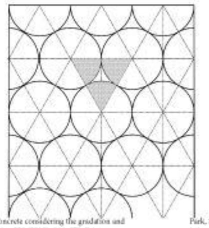



1)http://i.img-zemotoring.com/media/news/2011/06/sumitomo-aluminium-celmet.jpg; 2) http://www.kineticsnoise.com/industrial/images/krp01.jpg; 3) http://www.soundservice.co.uk/acoustic_foam_ss_foam.html 4) http://www.fendtproducts.com/images/products/concrete_masonry_units/sound_cell/12_sc_thumb.gif

Absorbent Porous Concrete

Previous experiments using porous concrete have focused on the variation of mixtures and void ratio in order to determine the effect on acoustical absorption. Some of the tests demonstrated a significant increase in sound absoption was possible aiming at certain target void ratios. This could be modified with water content in the mixture, as well as using certain aggregate sizes.

The range of frequency which the concrete was able to best absorb was within the range of traffic. The tests also indicated that it might be possible to develop mixtures that dealt with very specific frequency ranges. In these particluar tests it was found that the concrete was able to absorb the lower spectrum of frequencies, which incidently is the range within noise from a freeway, train, or subway might create.

H.K. Kim, H.K. Lee "Acoustic absorption modeling of porous concrete considering the gradation and shape of aggregates and void ratio". Journal of Sound and Vibration 329 (2010): 866–879. Print.

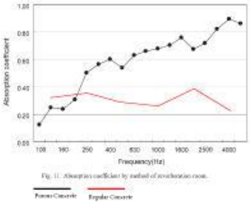
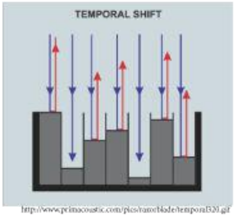


Fig. 11. Absorption coefficient by method of reverberation room.

Park, Seung Bum, Dae Seuk Seo, and Jun Lee. "Studies on the sound absorption characteristics of porous concrete based on the content of recycled aggregate and target void ratio".

2. Diffusion

Sound Diffusion is a type of reflection. However, rather than simply providing a mirrored imitation, in the case of sound diffusion the reflection breaks up one original sound wave into many different waves. Generally diffusion occurs on several types of surfaces, but generally they have a rough or geometrically configured surface. Primitive root diffusers have surfaces that are placed at different distances from the sound source so that the reflections occur with a time delay. Therefore, the reflections are divided and dispersed. Pyramid diffusers have angled surfaces so that when the original wave strikes the surface, the reflections are directed by their angles. Due to the variety of angles, an original wave can be sent in multiple directions.



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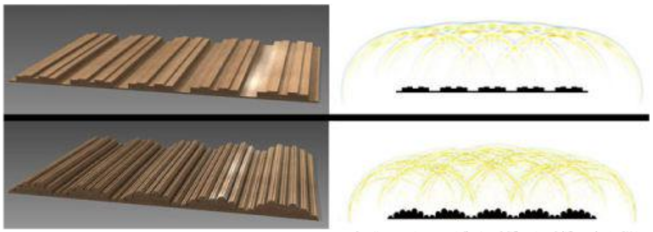


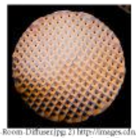
http://arqee.com/wp-content/gallery/sound-diffusers/sound-diffuser-calage1-w700.jpg

Common Types of Diffusers

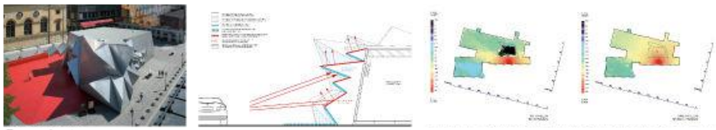








1)http://www.recordingstudiolondon.co.uk/images/lg_images/Control-Room-Diffuser.jpg 2) http://images.cdn.baunetz.de/img/2/2/1/6/7/6dfdba1efcdb7d91.jpeg 3) http://commons.wikimedia.org/wiki/File:Bundesarchiv_Bild_183-C1009-0020-004,_Berlin,_Staatsratsgeb%C3%A4ude,_Empfangshalle,_Foyer.jpg 4) http://produceremplre.com/wp-content/uploads/2013/07/2d-qrd-diffuser.jpg 5) http://i.ebayimg.com/t/1-x-1-WOOD-acoustic-sound-diffuser-panels-BUDGET-LINE-/00/s/NTQwWDUyNQ==/z/46IAAMXQKAtRK5gF/$T2eC16ZHJF0E9nmF$tGeBRKSgFkHG!--60_35.JPG; 6) http://www.danieldavis.com/responsive-acoustic-surfaces/; 7) http://www.responsive-a-s-c.com/wp-content/uploads/2011/04/Texture_003-1024x685.jpg; 8) http://www.acousticsfirst.com/diffusors-quadrapyramid/QuadraPyramid1.png; 9) http://www.acousticsfirst.com/Double-Duty-Diffuser/DoubleDutyDiffuser_Fabric.png

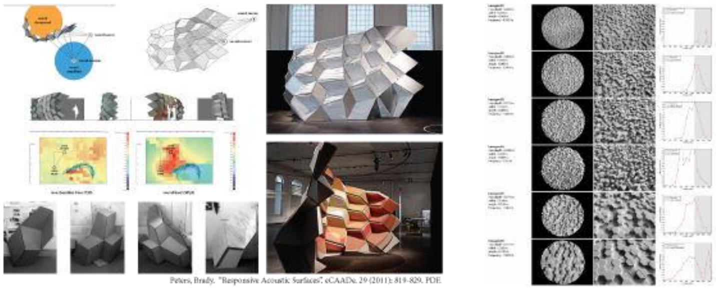


http://www.coop-himmelblau.at/architecture/projects/pavilion-21-mini-opera-space/

Precedents

Our research exist within a context of solutions already undertaken in other arenas of architectural research. Each of these projects investigated the design of gemoetry to alter a soundscape. The first project was a pavilion for small concerts placed in a plaza in Munich. The principles behind the acoustical design are very simple. The geometry is simply designed to scatter sound upwards, while the panels have acoustical absorption built into them.

The second and third projects were explorations by Brady Peters to determine geometricl effects on sound within interior environments. That each project was placed in an interior context it allowed measuring to be relatively precise. What the Pavilion shows us is that it is possible to make an affect with construction in an urban environment; while the research Peters conducted gives us a framework about how to begin testing and planning acoustical surfaces.



Peters, Brady. "Responsive Acoustic Surfaces". eCAADe. 29 (2011): 819-829. PDF.

hexagon wall 01
design frequency - 1000 Hz
scattering coefficient - 0.2

hexagon wall 02
design frequency - 1000 Hz
scattering coefficient - 0.4

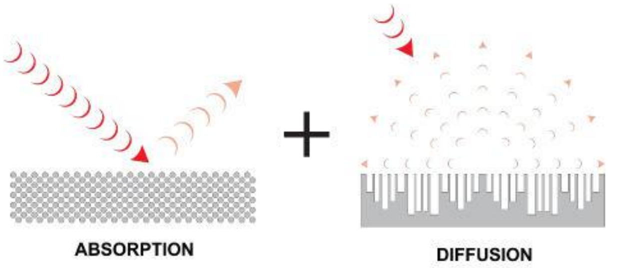
hexagon wall 03
design frequency - 1000 Hz
scattering coefficient - 0.6

hexagon wall 04
design frequency - 1000 Hz
scattering coefficient - 0.8

hexagon wall 05
design frequency - 1000 Hz
scattering coefficient - 1.0

3. Combining Strategies

Noise pollution is a problem in the experience and configuration of every urban context today. Regardless of size, location, economic status or political structure – noise pollution is a by-product of technological advancement, population density, and the speed at which our present lives move. Attempts to mitigate and address sound control has dealt with either two independent strategies of sound absorption – which is typically an interior application, or sound diffusion, which can be either an interior or exterior use. Our research agenda will focus on the exploration of the material properties of concrete to produce sound absorption properties coupled with highly calibrated geometries that will be produced through a precast mold process to produce sound diffusion panels. It is the unique combination of both the absorption and diffusion into a precast panel that will provide new data and opportunities to understand the potential for precast facades and MSE wall panels to provide sound mitigating properties.



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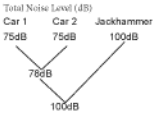
Phase 1: Senario Analysis



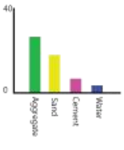
Total Noise Level (dB)

Car 1 75dB
Car 2 75dB
Jackhammer 100dB
78dB
100dB

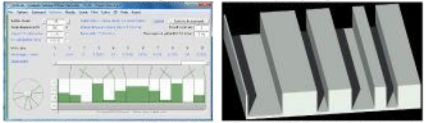
Frequency Ranges for Common Urban Noise Sources

- Motorcycles - 100-400 Hz
- Cars - 700-1300 Hz
- Freight Trucks 100 - 500 Hz
- Jet Engines - 100-500 Hz
- elevated subway - 3000-4000 Hz
- Sirens - 1000 - 3000 Hz

Phase 2: Determining the appropriate mixture for frequency ranges.



Phase 3: Design geometric configuration to deal with frequency ranges



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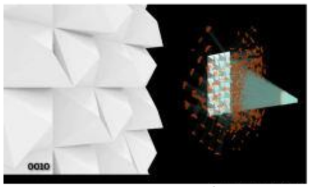

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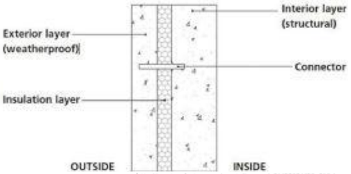
Phase 4: Test digitally



http://assets.selector.com/assets/images/c5/42282/620x310.jpg

Phase 5: Prepare design for fabrication of precast panels.

CONCRETE MIX DESIGN

Nullam placerat hendrerit enim, sed viverra diam venenatis nec. Integer et turpis adipiscing nulla mattis sagittis. Nunc venenatis ac neque a varius. Nam venenatis faucibus diam ac tincidunt. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Phasellus vel risus erat. Maecenas iaculis interdum mauris, id facilisis mauris cursus id.

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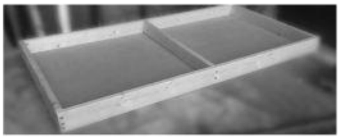
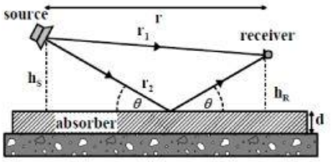
MIXTURE/ MATERIAL	COARSE AGGREGATE				1/4" lightweight aggregate	SAND	CEMENT	w/c ratio	WATER	PEA GRAVEL	SPECIAL	TOTAL WEIGHT LBS
	1"	1/2"	3/8"	#4 and #8 blend								
TP1	42						10	.6	6			
TP2	26					17.5	6.3	.6	3.44			53.24
TP3	26					17.5	6.3	.6	3.44		Exposed aggregated	53.24
TP4							8.2	.6	3.19	41		52.39
TP5		38					7	0.33	2.31			47.31
TP6		17			14		6	0.33	2.30			39.3
TP7				32.5			6	0.33	2.20			40.7
TP8			17	17			6	0.33	2.30			42.3

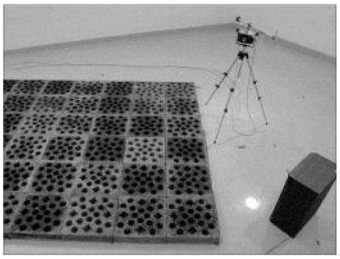


Testing and Digital Simulation

There are several methods of testing the results of our research. We will be working in parallel mediums, one through analogue testing of specimens we pour ourselves; this will give us some data to determin what mixture is ideal for our design, as well as give us data on what absorption we can imput into the digital simulation. The analogue testing was conducted in the facility of an acoustical consultant firm in North Dallas. The single bounce testing method was used to calculated the difference in sound level betwen each concrete panel and a "perfect" reflecting panel. Utilizing the data we collected from the TEF software we were then able to calculate the Absorption coefficents for each speciment. In parallel to the analog testing method we used threshold imagry data analysis to determin the surface porosity of each panel.

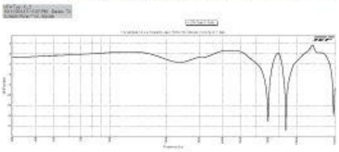


Basic Panel Test

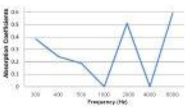


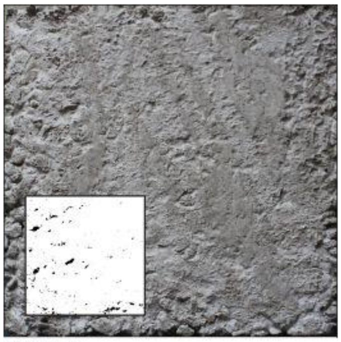
Reverberation Room Seung Bum Park

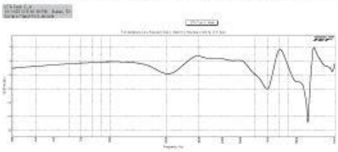
Reverberation Room Brady Peters



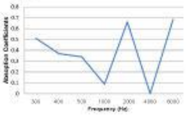
TEST PANEL 1
-target void ratio 25%
-1" crushed stone
-w/c ratio = .6

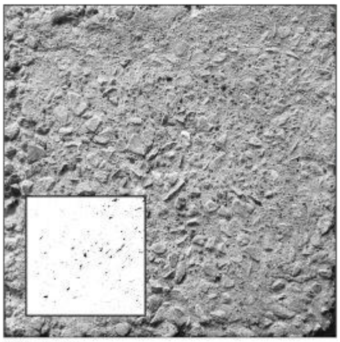


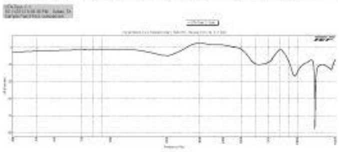




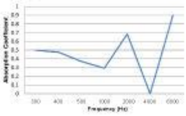
TEST PANEL 2
-1" crushed stone 76%
-sand 24%
-w/c ratio = .6

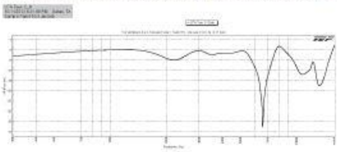




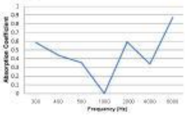


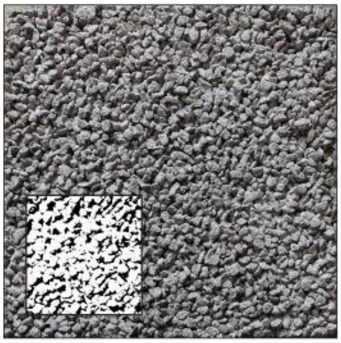
TEST PANEL 3
-same mix as panel 2 but with exposed aggregate

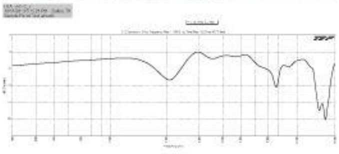




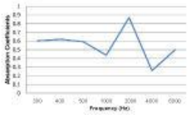
TEST PANEL 4
-target void ratio 25%
-pea gravel
-w/c ratio .6

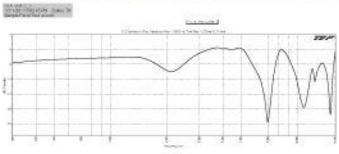




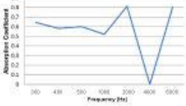


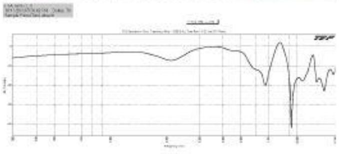
TEST PANEL 5
-target void ratio 25%
-1/2" crushed stone
-w/c ratio = 0.33



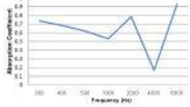


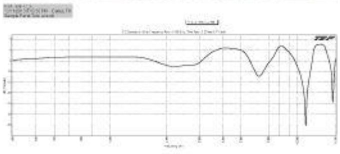
TEST PANEL 6
-target void ratio 25%
-55% 1/2" crushed stone
-45% 1/4" lightweight aggregate
-w/c ratio = 0.33



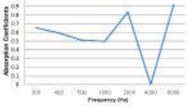


TEST PANEL 7
-target void ratio 25%
-blend of #4 and #8 aggregates
-w/c ratio = 0.33





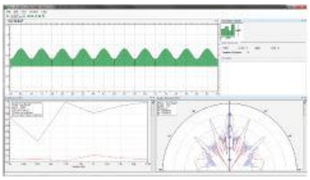
TEST PANEL 8
-target void ratio 25%
-50% blend of #4 and #8 aggregates
-50% 3/8" curshed stone



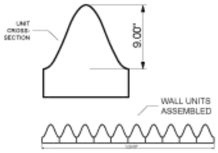
GEOMETRY

DIGITAL SIMULATION

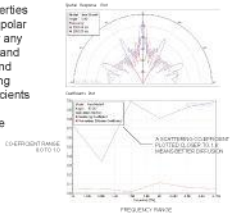
AFMG Reflex is a two-dimensional acoustics simulation software to model the reflection, diffusion, and scattering of a sound wave incident upon a defined geometrical structure. The surface defined by this geometry is also assumed to be perfectly rigid. This means the surface is 100% reflective and does not in any way absorb sound or allow sound to be transmitted through it.



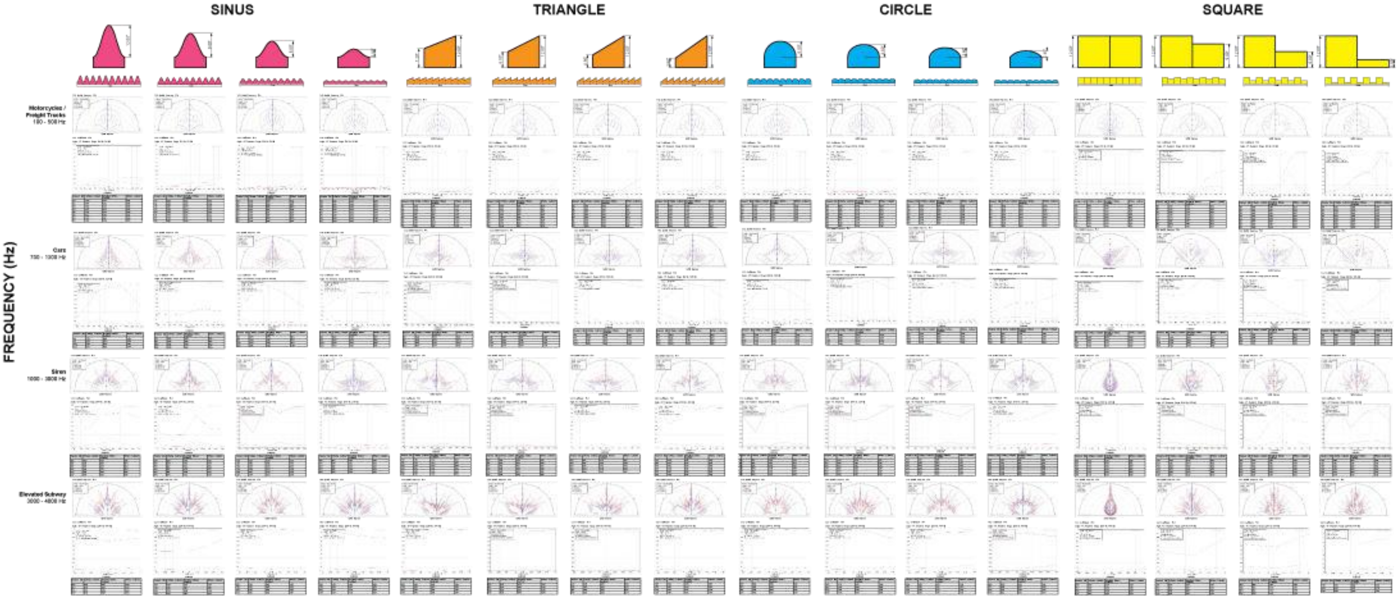
The simulation is based on the Boundary Element Method (BEM) to calculate the reflection, diffusion, and scattering properties of the surface. Our initial simulation into testing takes geometry units of equal widths and various depths configured into 10 ft wall assemblies.



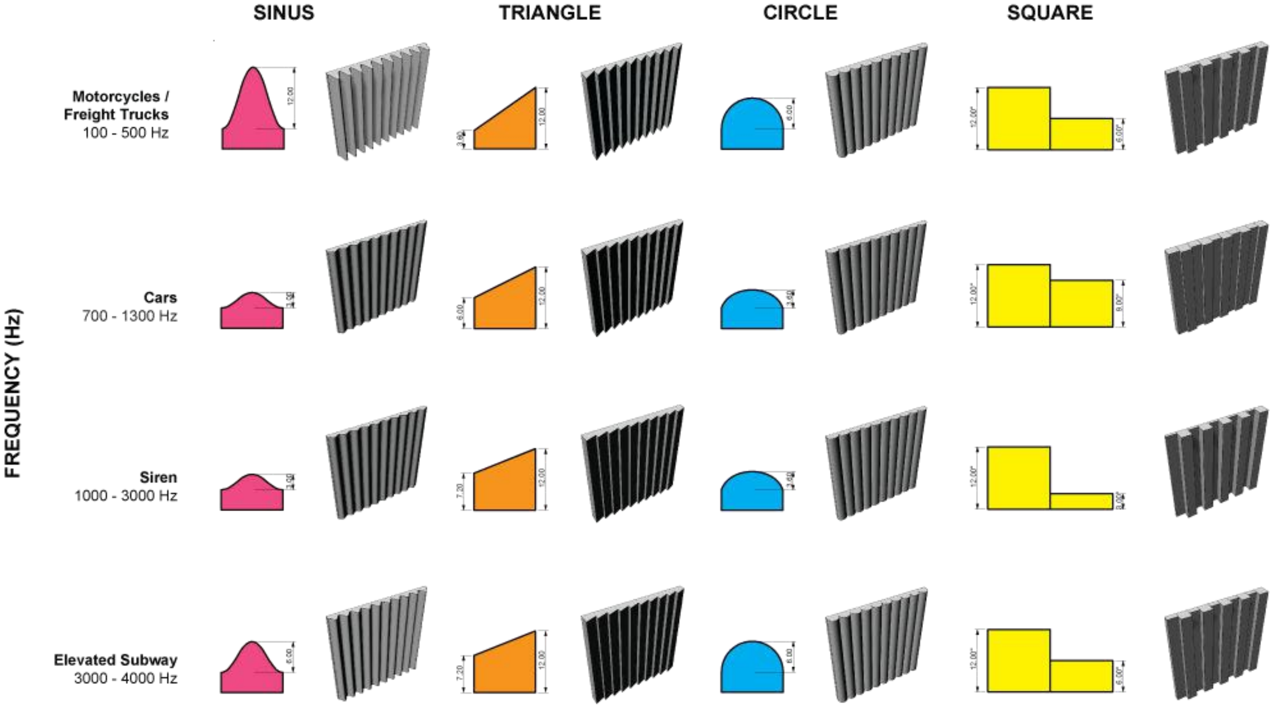
The reflective properties are displayed as a polar response graph for any angle of incidence and frequency of a sound wave. The scattering and diffusion coefficients are displayed as frequency response graphs.



SIMULATION 01



SIMULATION 01 OPTIMUM TYPE PER FREQUENCY RANGE



GEOMETRY PROFILE AND ARTICULATION

Planar Reflectors

The angle of incidence (i) is equal to the angle of reflection (r). For specular reflection to occur, the surface irregularities should be much smaller than wavelength of sound. "A concrete wall with exposed aggregate behaves as a smooth wall, since their irregularities are much smaller than the wavelengths of sound of interest to us."

Reflector profile determined based on specular reflection of geometrical acoustics. The reflectors are designed in such a way that increasingly greater amount of noise is directed to the sky.

LOCATING THE FIRST REFLECTOR

(i) Choose point A as the starting point of the reflector system.

(ii) Join a with source (S).

(iii) Choose points P (approximate height of adjacent building) and U (approximate height of building).

(iv) Join A with P, and bisect angle SAP. Let this bisector be AN.

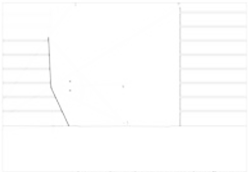
(v)Draw a dashed line (TAB) normal to AN at A. Line TAB represents the slope of the reflector.

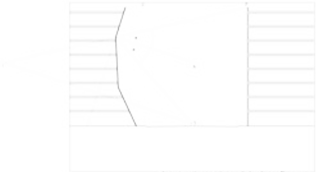
(vi) Locate image I behind line TAB, so that ST=TI, and ST is perpendicular to line TB.

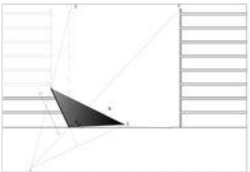
(vii)Join I with U, so that IU intersects the dashed line TAB at B. The reflector is represented by line AB.

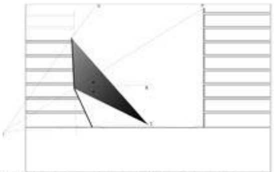
(Source: Architectural acoustics: Principles and Design. Medan Mehta.)

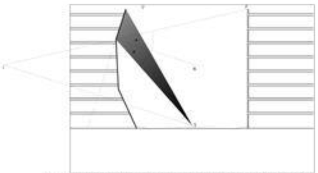

Locating the first reflector

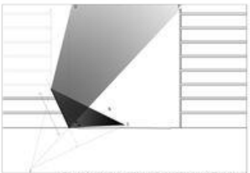

Locating the second reflector

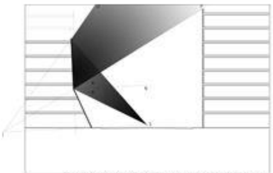

Locating the third reflector

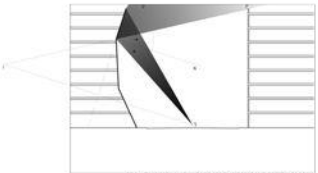

Noise from source to incident on first reflector


Noise from source to incident on second reflector


Noise from source to incident on third reflector


Reflection of noise first reflector


Reflection of noise second reflector


Reflection of noise third reflector

Surface Articulation

A wavelength is the distance between adjacent compression peaks or adjacent rarefaction peaks. So it is simply the distance between two air particles that are in exactly the same vibration situation. Wavelength is calculated by dividing the velocity of sound in air (c) by the frequency of sound (f).

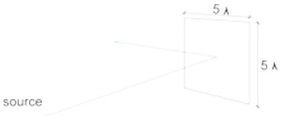
$\lambda = c/f$

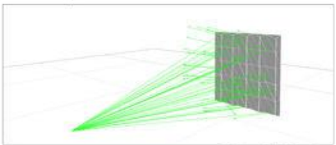
Even though the velocity of sound is 1,130ft/sec, for most practical purposes it is common to regard it as 1,000ft/sec.

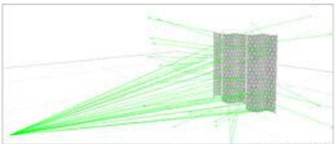
Relationship between frequency and wavelengths of sound.

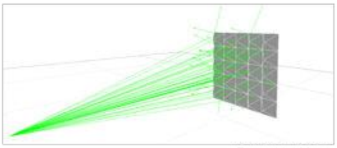
Frequency (f) (Hz)	Wavelength (λ) (ft)
63	18
125	9
250	4.5
500	2.3
1000	1.1
2000	0.6
4000	0.3
8000	0.15

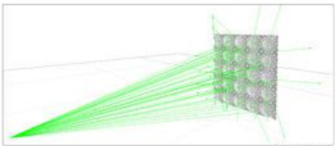
For a surface to act as a reflector both its width and height have to be at least five times bigger then the wavelength. One can then begin to articulate that surface to diffuse the sound in a more controlled order.

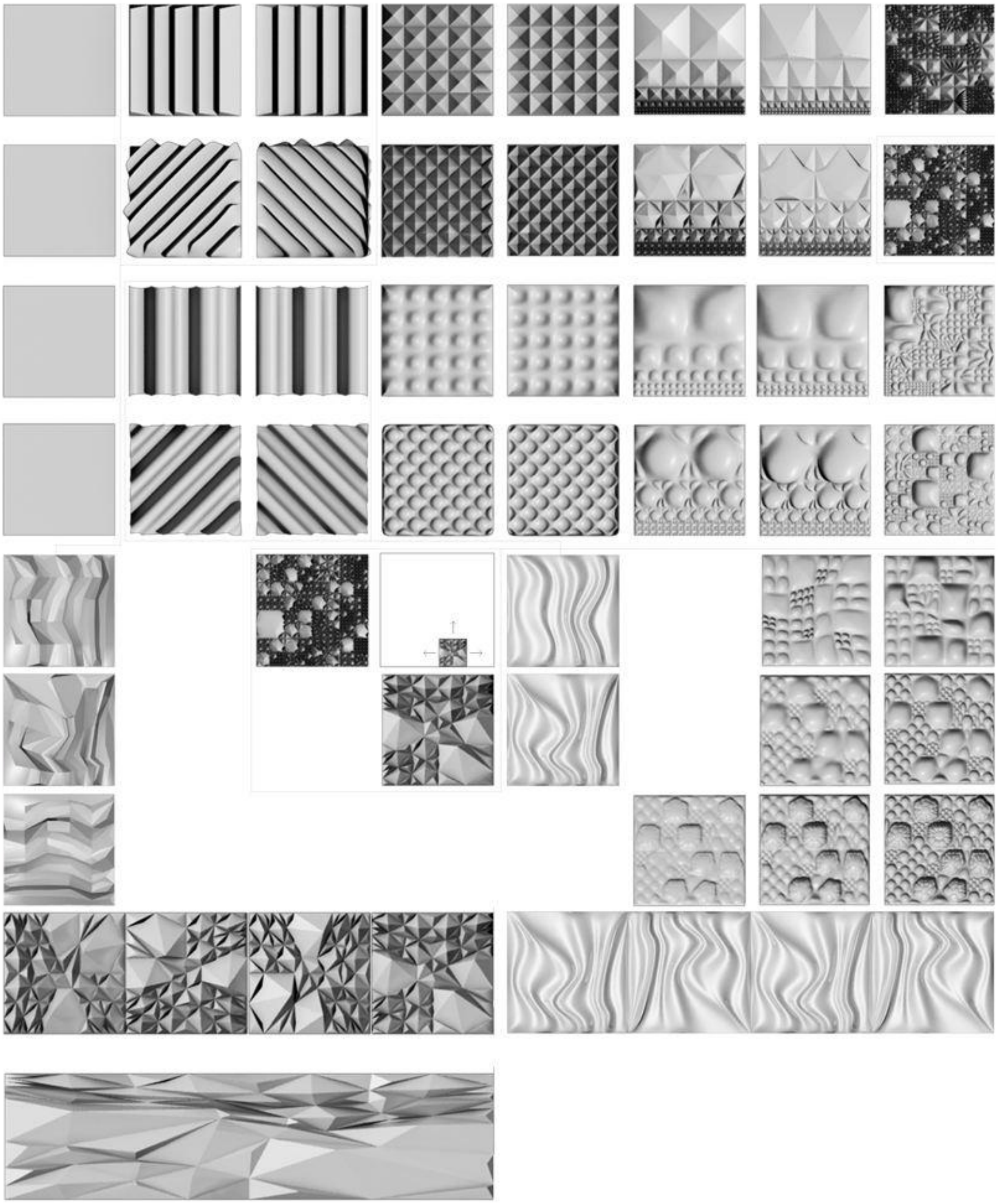



Extruded Triangles

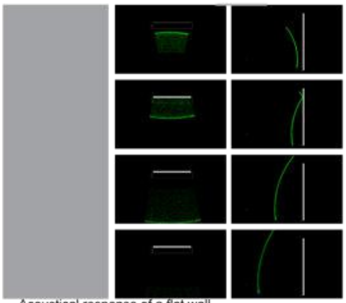

Extruded Sine


Pyramidal Matrix

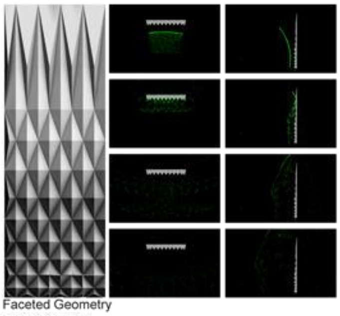

Sine Matrix



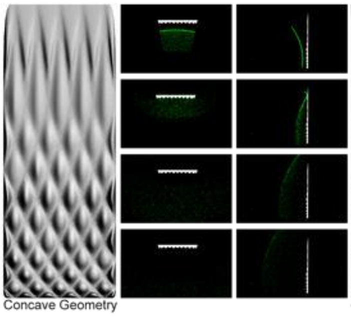
DIGITAL TESTING



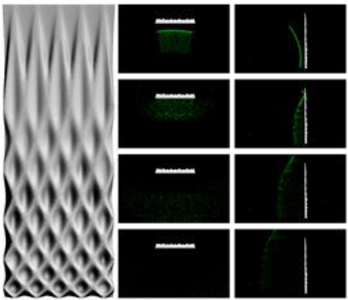
Acoustical response of a flat wall



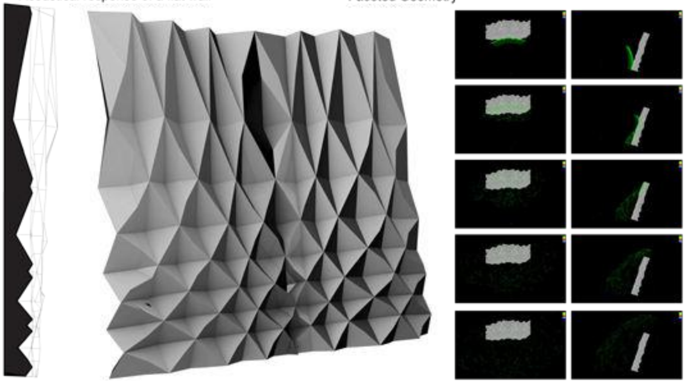
Faceted Geometry

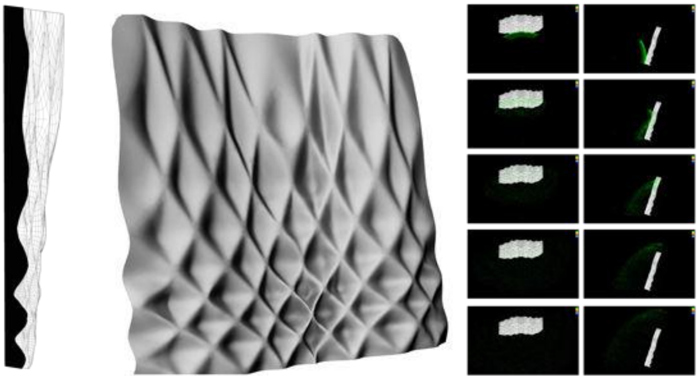


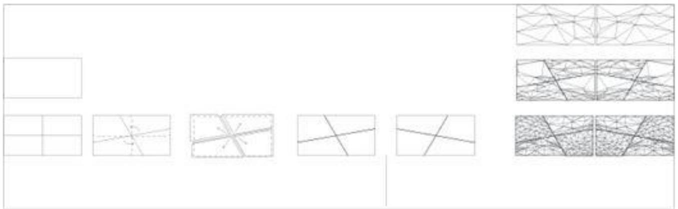
Concave Geometry

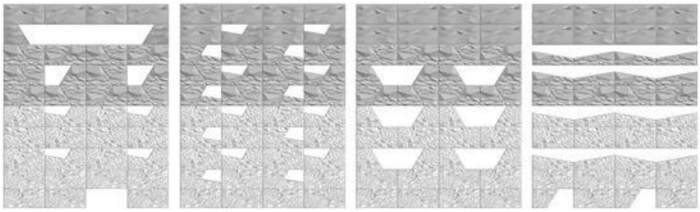


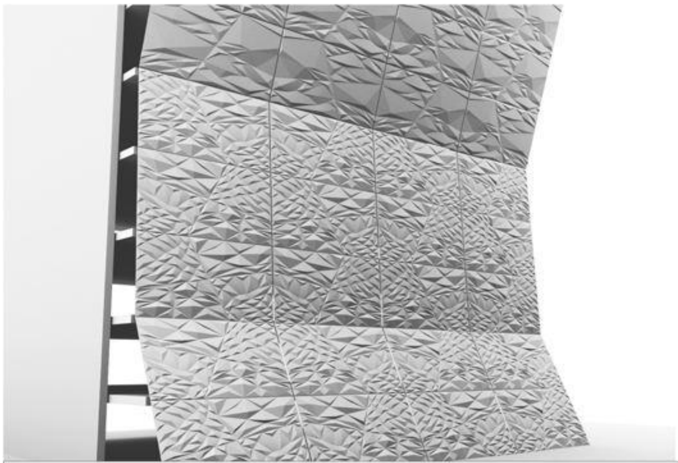
Convex Geometry

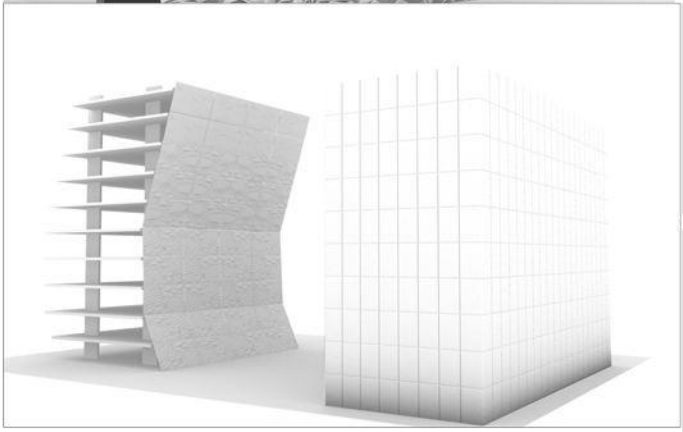


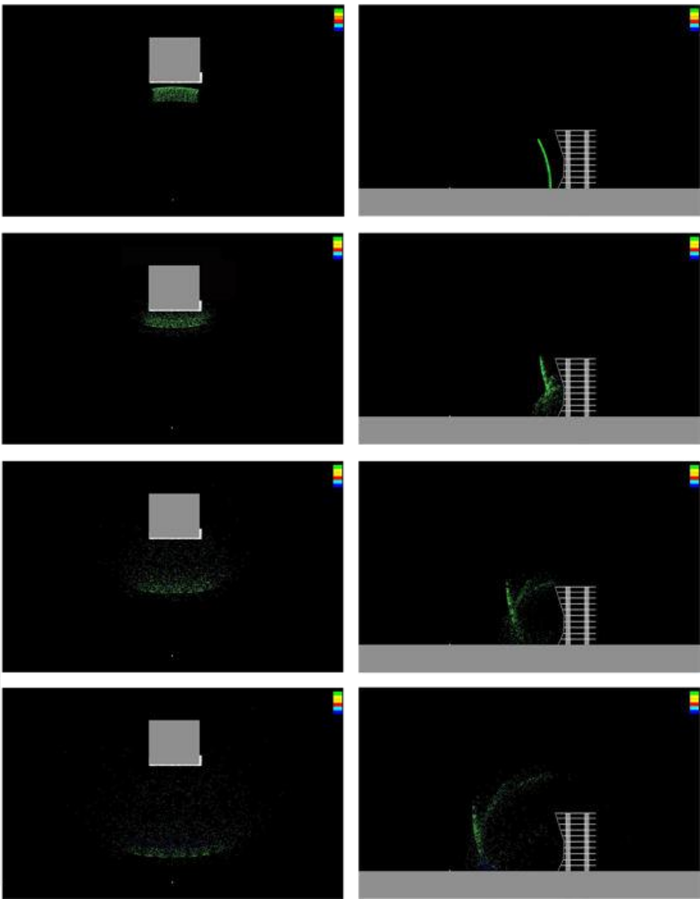








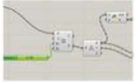




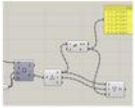
GEOMETRIC APPLICATION

Sinuous

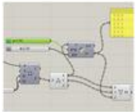
01 Rectangular grid and python component generated
a = math.sin(y)



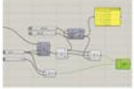
02 Passing x through the python script component and into the z input of the construct pt component constructs a set of points on the grid in a sinuous configuration, although still only an extrusion in one dimension.



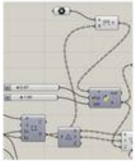
03 The Y and Z inputs on the Python Component are re-labeled amp (amplitude) and per (period), and the python component script is edited to
a = amp * math.sin(x/per)



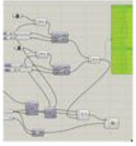
04 Adding one to the amount of the initial grid input, and using the sum for the u and v input of the mesh from pts component renders a faceted sinus surface



05 The X pt deconstructed position used as the python script driver is replaced with an inserted reference pt used as an attractor. These measurements against all the surface points and attractor pt along with the amplitude and period parameters are now used to manipulate the geometry.

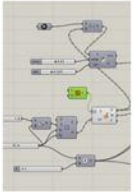


06 Copying over a second pt / distance / and python component set and multiplying both with each other increases manipulation control to the surface further.

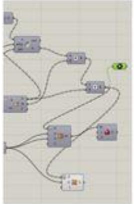


07 Set multiple curves with a loft component, and then evaluate the reparameterized lofted surface using the grid points output as uv coordinates.

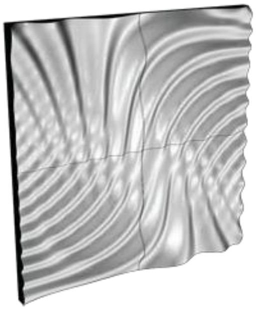
08 A division component is added to get a cell size between 0 and 1 for the reparameterized surface



09 The evaluated surface points are then moved in the direction of the normal by a factor of the python script output. The result of this is then added to the evaluated surface points output, and a fluid surface with gradual transitions of varying geometrical depth sizes is generated

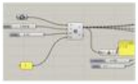


10 Combining this script with earlier digital simulation in AMFG Reflex produced a panel type refined to mitigate the frequency range categories from the previous study

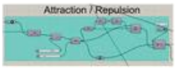


Faceted

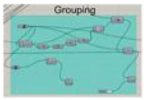
01 Triangulated grid generated

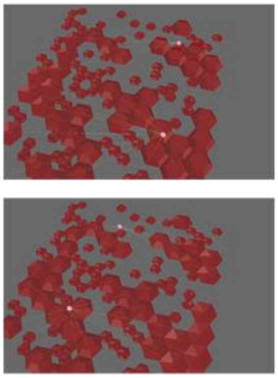


02 Point attractors inserted to manipulate various areas of grid acting as sound points of origin

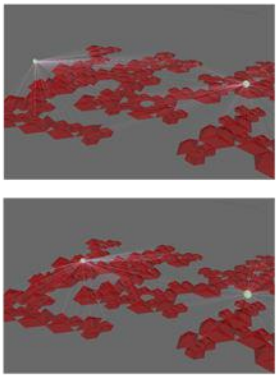


03 Grouping determines geometry type and porosity amount within the defined grid





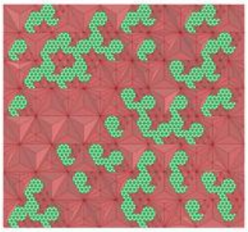
HEXAGONAL GEOMETRY VARIATION



PYRAMID GEOMETRY VARIATION

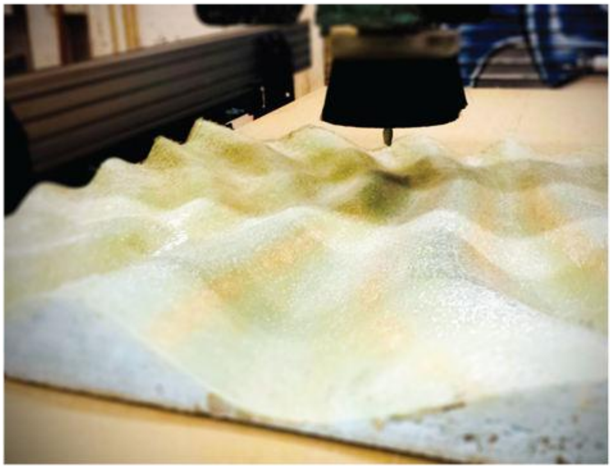
04 Two types of porosity were examined. An aperture type where a fixed geometry's exterior face would vary in diameter, and a porosity application where a geometry type's surface would increase or decrease in a fractal manner

APERTURE TYPE

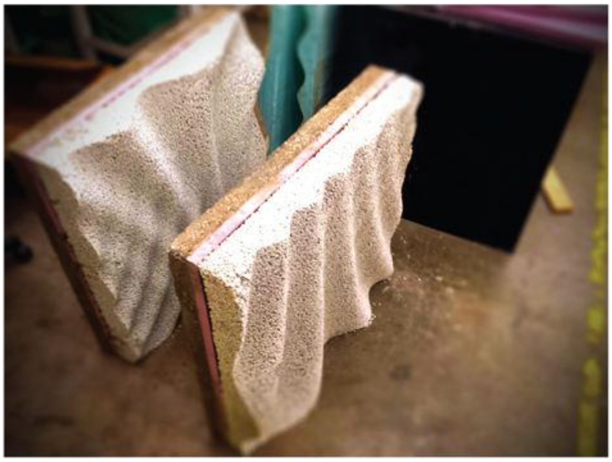


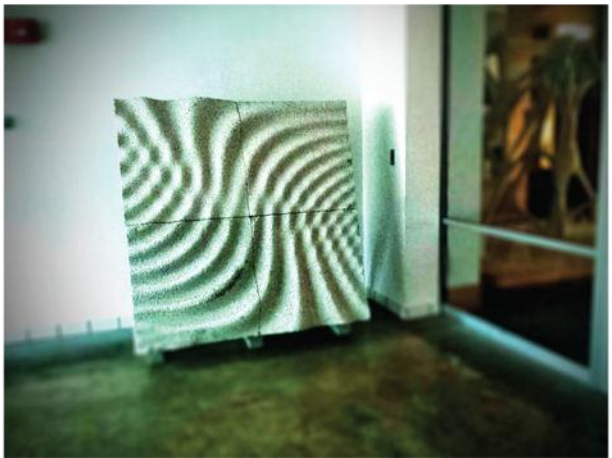
FRACTAL TYPE

PROCESS



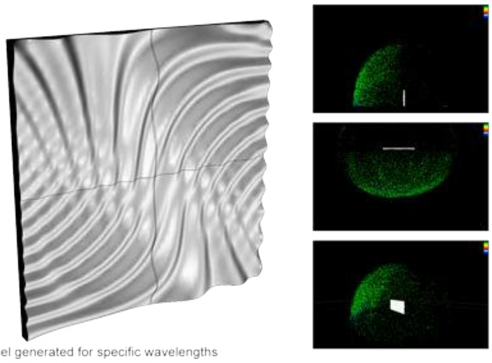




ARCHITECTURAL APPLICATIONS

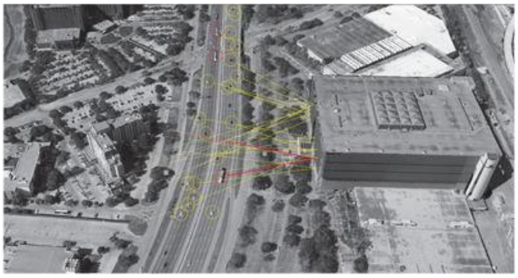
Proposed sound barrier wall along highway



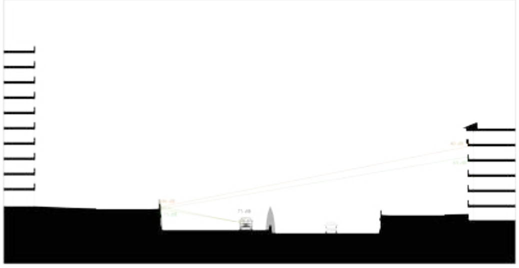
Panel generated for specific wavelengths

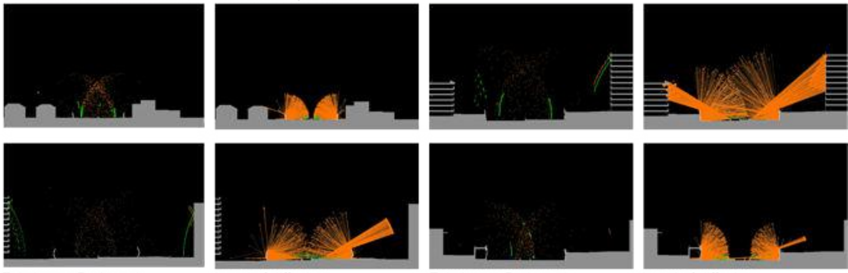
Contextual Projections

A possible scenario where the panel might be used is along freeways as barrier walls. With some basic calculations and the results from our initial testing we found that it in a very generic scenario that the absorptive qualities of the concrete along with the diffusive properties of the panel would significantly reduce the level of noise that reached nearby buildings. Normally sound from a freeway will decrease 3 dB for every doubling of distance. With the panel in place 61% of the sound is absorbed, and the rest is diffused into the atmosphere. Inevitably some of the sound will reach the buildings, but it is significantly less than what the sound level would be without it.



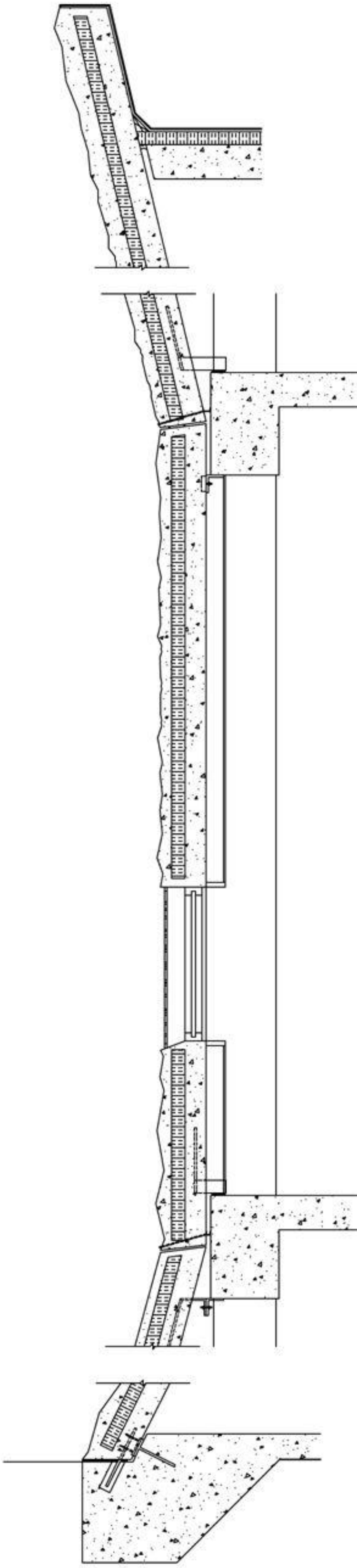
Urban Corridors as the main source of noise pollution





Existing vs Projected Level of diffusion Existing vs Projected Level of diffusion

ARCHITECTURAL APPLICATION



Building Facade

The most important areas to regulate noise are at the street level. The building's facade adapts itself to mitigating sound at the pedestrian level and as its elevation moves upwards sound mitigation becomes less critical. Our prototype suggests that at higher floors more porosity can be incorporated to allow views and let light into the building. Furthermore, the porosity of the concrete is determined by the amount of noise that needs to be absorbed and the height of the building. Based on the analysis we have determined that for our prototype the ideal concrete porosity on the first floor of the building facade would be 25%, while at the top floor conventional concrete with a porosity of 3% would not effect the noise pollution at the street level.