OPEN-PLAN OFFICE SPACES AND THEIR ACOUSTIC CHALLENGES

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ACKNOWLEDGEMENTS

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KEY ACOUSTICAL TERMS

Absorption: "The conversion of acoustic energy to heat or another form of energy (as a result of friction) within the structure of sound-absorbing materials (Yerges, 187)."

Decibel (dB): Measurement of the intensity of a sound ("Building Acoustics").

Diffraction: The bending (Change of direction) or scattering of sound waves around obstacles such as, corners, columns, walls, and beams (Doelle, 25). "Long-wavelength (low frequency) sounds will diffract more than high frequency sounds. Sound also diffracts after passing through a small hole or slit. The opening acts as if it were a source of sound but of lower intensity than the original source (Lechner, 165)."

Diffusion: "Dispersion of sound within a space so that there is uniform energy density throughout the space (Yerges, 188)."

Echo: "Any reflected sound which is loud enough and received late enough to be heard as distinct from the source (Yerges, 189)."

Flanking Transmission: "Transmission paths which transmit acoustic energy around a sound barrier (Yerges, 189)." "Leakage of sound through its transmission path ("Acoustics in Buildings")."

Flutter: "A rapid reflection or echo pattern between parallel walls, with sufficient time between each reflection to cause a listener to be aware of separate, discrete sounds (Yerges, 189)."

Hertz (Hz): Measurement of the pitch or frequency, of a sound ("Building Acoustics").

Masking: When background noises are used to drown out sounds that are not being absorbed (Doelle, 19).

Noise: Unwanted sound (Yerges, 192).

Noise Reduction Coefficient (NRC): "The average of sound absorption coefficients as tested at 250, 500, 1000 and 2000 cycles per second (Propst, 58)."

Reflection: "The return from surfaces of sound energy not absorbed upon contact with the surfaces (Yerges, 191)." "The angle of incidence equals the angle of reflection when surfaces are large. However, for small surfaces, the angle of incidence equals the angle of reflection only for short wavelength (high frequency) sounds (Lechner, 164)."

Refraction: The change of direction of a sound wave as it moves from one medium to another. This is mainly an outdoor sound quality issue because changes in temperature will cause sound to refract (Lechner, 166).

Resonance: "The natural, sympathetic vibration of a volume of air or a panel of material at a particular frequency as the result of excitation by a sound of that particular frequency (Yerges, 191)."

Reverberation: "The persistence of sound within a space after the source has ceased (Yerges, 191)."

Reverberation time: "The time in seconds required for a sound to decay... [by 60dB] after the source ceases (Yerges, 191."

Sound: Transmission of energy through solid, liquid or gaseous media in the form of vibrations (Lawrence, 2).

Sound Absorption Coefficient (SAC): "The performance of sound-absorbing materials, ranging from 0-1, where zero equals no sound and one equals complete sound absorption (Lechner, 180)."

Transmission: Sound energy that travels through a material (Lechner, 166).

INTRODUCTION: THE OPEN-PLAN OFFICE TYPOLOGY

The open-plan layout of office design is a trend that is here to stay. The need for large private offices and closed off spaces, is fading out, and the desire for open, multi-functional, and communal workspaces is growing. Employers, as well as employees, have realized that there are plenty of benefits to this open-plan design, especially since technology rapidly became an integral part of office life. Some of these benefits include cost-effectiveness and increased collaboration, flexibility, and communication. However, there are also many drawbacks that accompany this open-plan design, which include lack of privacy and increased noise, distractions, stress, and germs (Howard). The majority of these drawbacks are directly related to the poor level of acoustics that unfortunately goes hand-in-hand with any open-plan space. Therefore, this research will focus on exploring various solutions for improving the acoustical quality in existing buildings being used for open-plan office spaces.

Fig. 1. SC Johnson Administration Building by Frank L. Wright

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PROS

Cost-effectiveness

Increased Collaboration

Increased Communication

Multi-functional Spaces

Flexibility

-

CONS

Lack of Privacy

Increased Noise

Increased Stress

Distractions

Easy Spread of Germs

THE EVOLUTION OF THE OFFICE PLAN

Ancient, Medieval & Renaissance Times
Medieval scriptoriums and Renaissance alcoves were used to enhance focus while writing/ working.

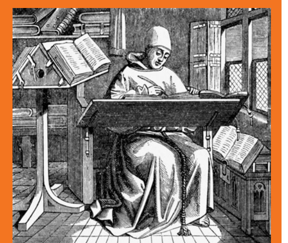


Fig. 2. Monk writing in a scriptorium

1600s-1800s
Office spaces were created in major cities because professionals, such as lawyers and civil servants, stopped working from home.

1726
Old Admiralty buildings-
First buildings built in Britain specifically for office use

Fig. 3. Exterior view of the Old Admiralty buildings

1906
Larkin Administration Building by F. L. Wright-
First modern office

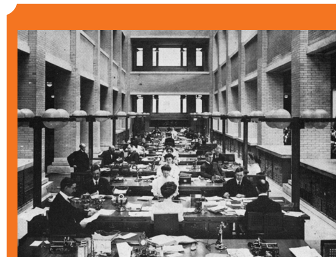


Fig. 4. Interior view of the Larkin Administration Building

1936
SC Johnson Administration Building by F. L. Wright-
First open-plan office building

Fig. 5. Interior view of the SC Johnson Administration Building

1940s
Secretaries placed in centralized open spaces.

1960s
Office Layout evolved into being a way of illustrating the company's culture and the idea that the leaders were just like all the other employees, to match the German design style called 'Bürolandschaft,' which directly translates to "office landscape" (Dishman).

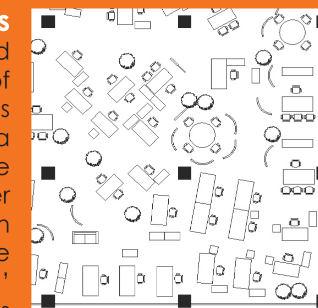


Fig. 6. Portion of a landscape office plan

1970s
Herman Miller Research Corporation/ Robert Propst invented the "Action Office," which is considered "the first flexible cubicle space" (Dishman).

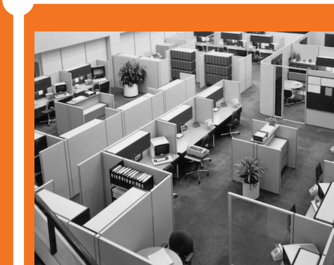


Fig. 7. Interior view of an office using the "Action Office System"

1990s
Tech start-ups adopted the open-plan layout because it was important to have a collaborative and flexible work environment.

2005
Google's renovated open-plan headquarters became the precedent for office design.

Fig. 8. View of enclosed offices in the Google Headquarters

2015
Facebook created the largest known open-plan office, "seating 2,800 employees across a 10 acre campus" ("Open Plan Design: What Have We Learned?").

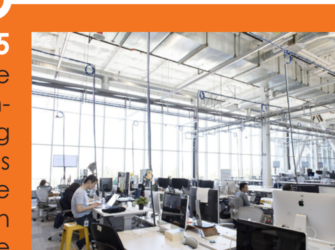


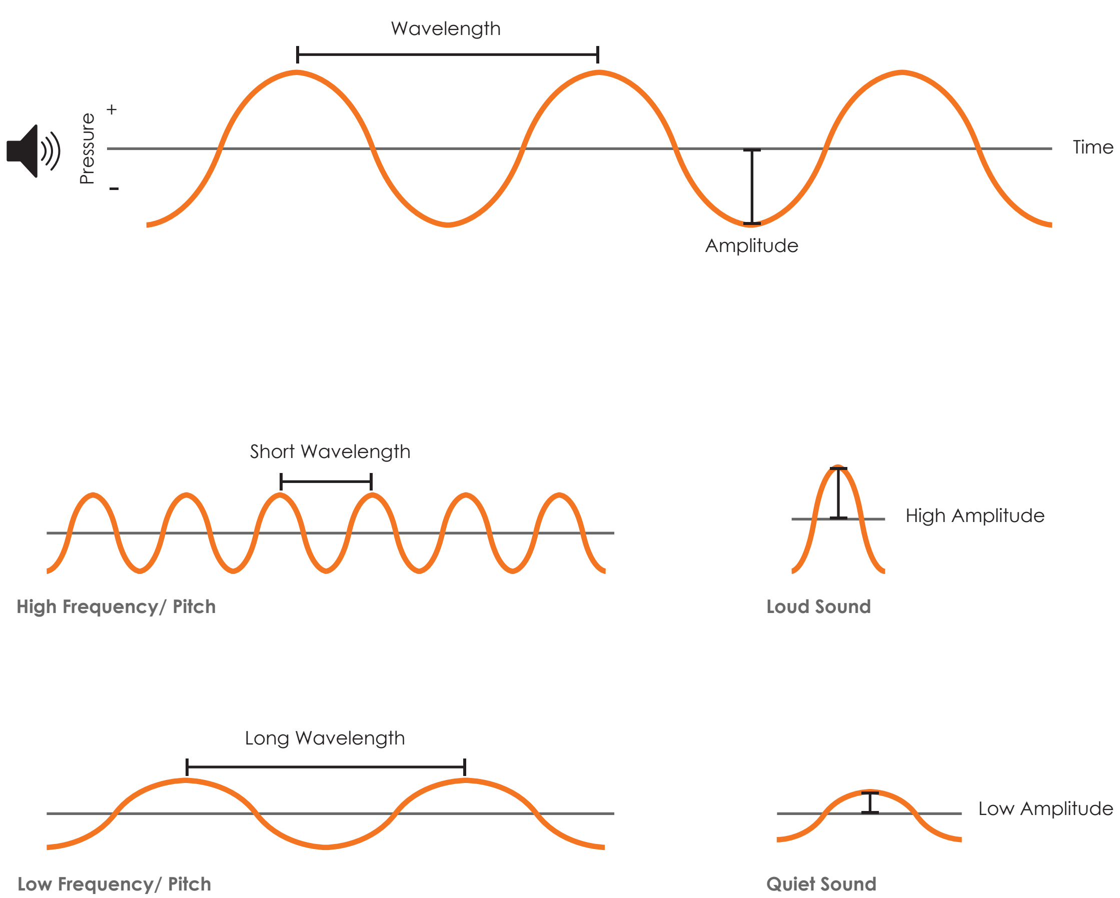
Fig. 9. View of employees working in an open-plan office area

Now
The emergence of working remotely/ from home since technology is an integral part of work life.

WHAT IS SOUND?

Sound can be described as the transmission of energy through solid, liquid, or gaseous media in the form of vibrations. A sound's intensity, or volume, is determined by the height of the sound wave's amplitude and is measured in decibels (dB). The higher the amplitude, the louder the sound, and the lower the amplitude, the quieter the sound. Moreover, a sound's frequency, or pitch, is determined by the length of the sound wave's wavelength and is measured in hertz (Hz). A shorter wavelength means a higher frequency, and a longer wavelength means a lower frequency (Lechner, 161).

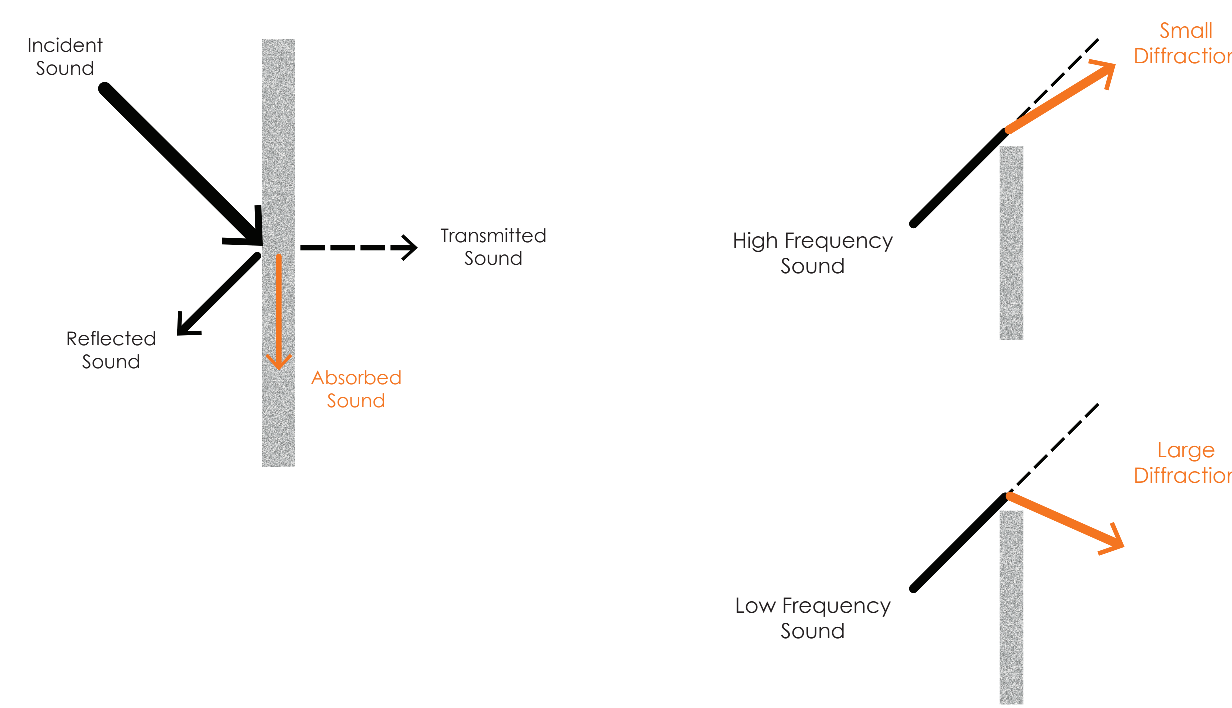
SOUND WAVES



1. BEHAVIOR OF SOUND WAVES

Sound waves behave differently when they interact with various objects, surfaces, and spaces. When a sound is created and comes in contact with an object or surface, it can either be reflected, diffused, diffracted, absorbed, transmitted, or a combination of them all. This research will focus on sound reflection, diffusion, absorption, and transmission. Also, as a result of the shape and size of a space, sound waves can cause echoes, flutter, and increased reverberation times, all of which negatively affect the sound quality of a space.

SOUND WAVE PATHS



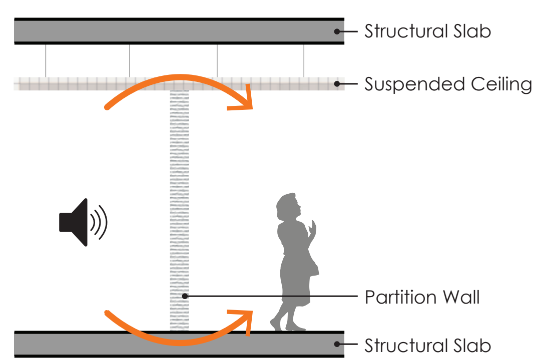
METHODS FOR REDUCING NOISE AND IMPROVING ACOUSTICAL QUALITY

When referring to "acoustics" in architecture, the goal is always to improve the sound quality within a given space. To do so, there must first be a basic understanding of soundproofing and acoustical treatment, which are the two categories used in acoustics. Soundproofing is described as "less noise" and acoustical treatment is described as "better sound" (Souza).

1. SOUNDPROOFING

To soundproof a space, "one must increase the structural mass of the walls, floor and ceiling, and seal the air gaps surrounding doors and windows, as well as the openings for refrigeration and electrical outlets," all according to the level of noise outside of the space and the desired sound reduction level within the space (Souza). Soundproofing can be used, for example, to block the noise transmission from a busy street or railway that is adjacent to an office space. Flanking transmission is a result of sound leaking around a wall or through its weak points. This is most common with the use of partial walls or room walls that do not extend all the way to the structural slab ("Acoustics in Buildings").

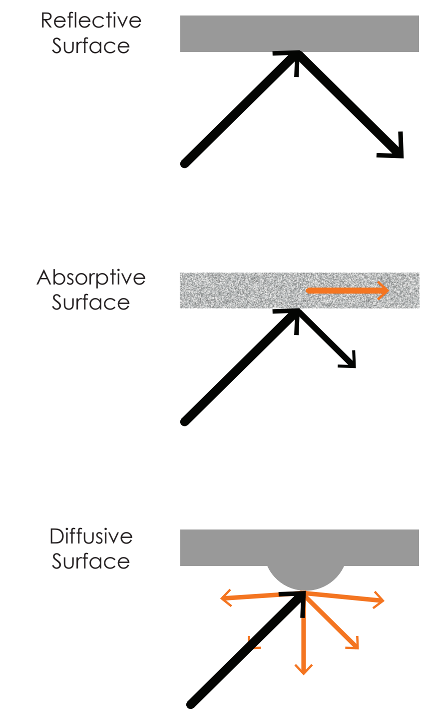
FLANKING TRANSMISSION



2. ACOUSTICAL TREATMENTS

Since acoustical treatments are great for improving sound quality, they can be used to improve the quality of speech within the more conversationally active spaces of an office, such as the conference room. Every building material can either reflect, absorb, and/or diffuse sound; however, to be able to treat a room or space to allow for the best acoustic performance, sound absorption and diffusion are the two methods that must be implemented. The reflection of sound off different materials is what causes echoes and increased reverberation times, which negatively affects the acoustics of a space (Souza).

TYPES OF SURFACES



EXAMPLES OF ACOUSTICAL TREATMENTS

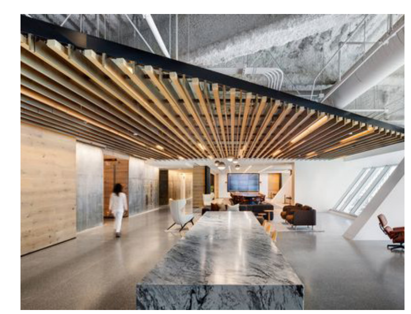


Fig. 10. Suspended Ceilings

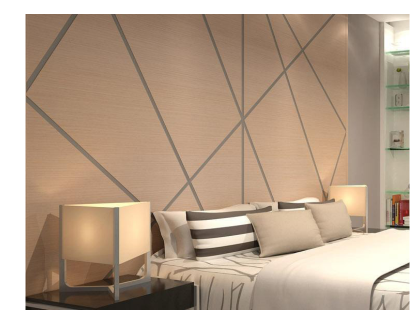


Fig. 11. Wall Panels


Fig. 12. Acoustic Floor Coverings


Fig. 13. Space Absorbers

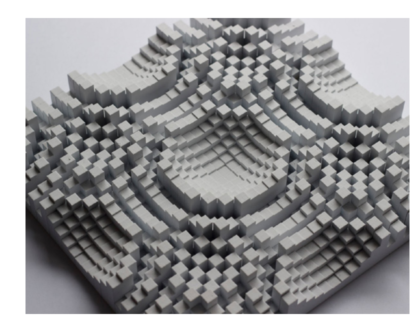


Fig. 14. Diffuser Panels

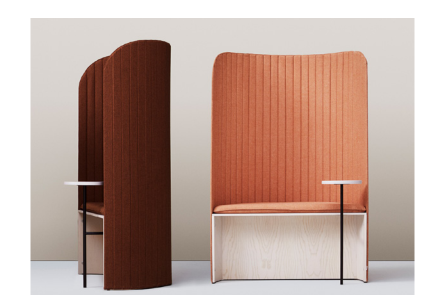
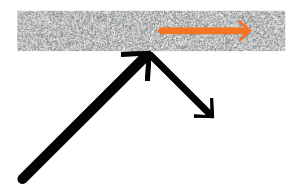


Fig. 15. Acoustic Furniture

2.1 Sound Absorption

Sound absorption occurs when some or none of the sound that hits a surface is reflected into a space. The best materials for absorption are those that are more porous, as opposed to those that are impermeable. The level of absorption for different materials can vary depending on if the sound's frequency is high or low. High frequency sounds are more impactful to the human ear and are easier to absorb than low frequency sounds because they have shorter wavelengths. Therefore, acoustical treatments are extremely beneficial for spaces with high frequency sounds (Souza).



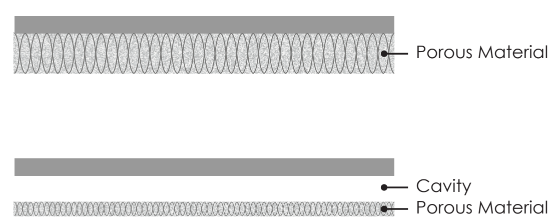
Sound Absorption

2.1.1 Types of Sound Absorption Mechanisms

There are three main types of sound absorption mechanisms: porous, membrane (panel), and resonator absorbers.

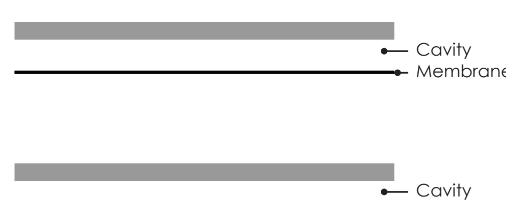
Porous absorption is described as, when sound energy gets trapped in the pores of the absorptive material and is subsequently absorbed by the material due to friction. With porous materials, such as wool and foam, sound absorption is most effective at high frequencies (Rindel, 4).

POROUS ABSORBERS



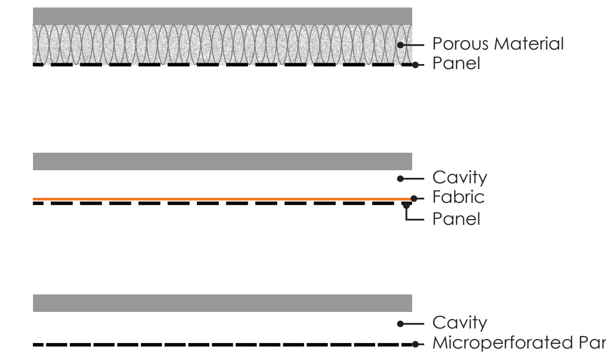
Membrane (panel) absorption is described as, when sound energy hits an impervious material, such as thin plywood or painted canvas, causing it to vibrate and absorb some of the energy, but also transferring some of the energy back into the room. Similar to porous materials, high sound absorption is achieved at high frequencies; however, to achieve such levels of absorption at low frequencies, a porous material must be placed in the cavity behind the panel (Rindel, 4).

MEMBRANE (PANEL) ABSORBERS



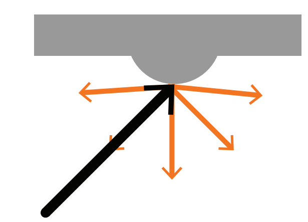
Furthermore, resonator absorption is described as, when sound energy hits a resonator, which consists of a cavity with an opening, and produces large air vibrations at the opening of the resonator, causing maximum energy absorption at a resonant frequency. Resonators come in three different forms: individual cavity resonators, perforated panel resonators, and slit resonators (Rindel, 5).

RESONATOR ABSORBERS



2.2 Sound Diffusion

Sound diffusion occurs when sound hits a diffuser and is dispersed back into the space uniformly, which enhances the sound quality. This method is recommended in spaces such as training halls or conference rooms because they require high speech intelligibility (Souza).



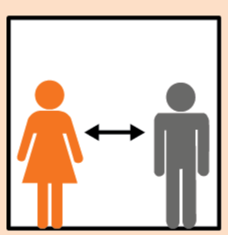
Sound Diffusion

ACOUSTICAL SOLUTIONS BASED ON ROOM SHAPE, SIZE, AND LAYOUT

1. ROOM SHAPE AND SIZE

SMALL ROOMS/ SPACES

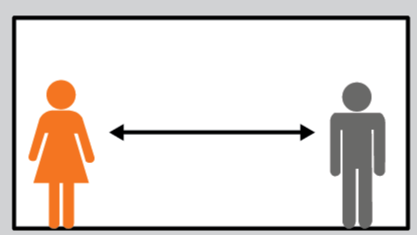
- Short reverberation time and travel distance for sounds



Short Travel Distance

LARGE ROOMS/ SPACES

- Long reverberation time and travel distance for sounds
- Echoes are more prominant
- Uneven distribution of sound



Long Travel Distance

IDEAL ROOM RATIOS

- Performs best to varying types of sounds frequencies

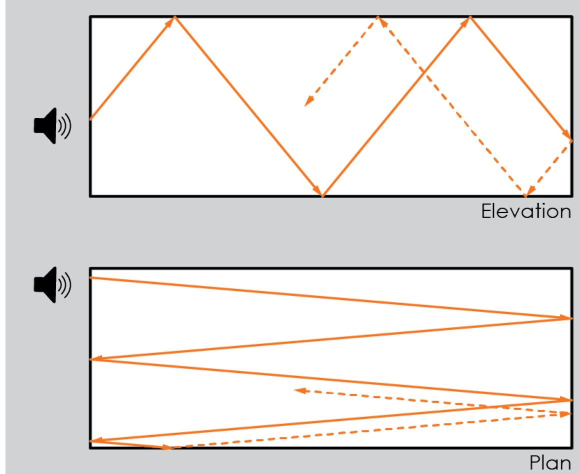
H	x	W	x	L
1.00		1.14		1.39
1.00		1.26		1.59
1.00		1.28		1.54
1.00		1.30		1.90
1.00		1.40		1.90
1.00		1.50		2.50
1.00		1.60		2.33

Fig. 16. Acoustic Ratios

LONG, NARROW ROOMS WITH LOW CEILINGS

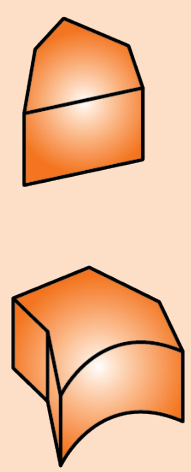
- Excessive flutter because walls are closely spaced, parallel, and are most often reflective.

  Example: Corridors



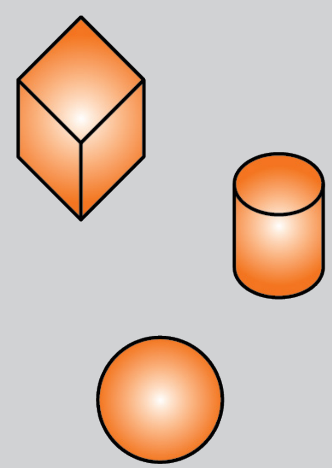
IRREGULAR ROOM SHAPES

- Allows better control of how sound behaves within the space



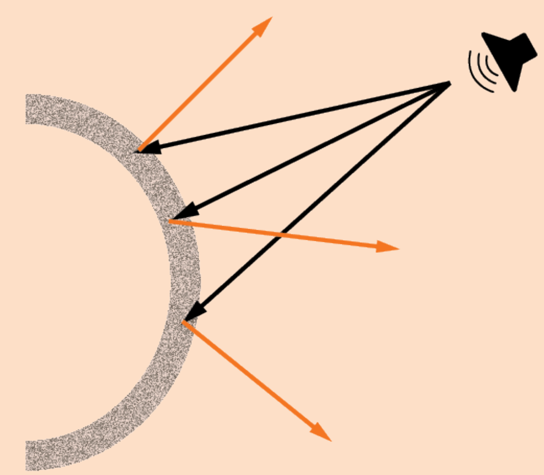
PURE GEOMETRIES

- Excessive flutter
- Sound focusing in round/ curved spaces



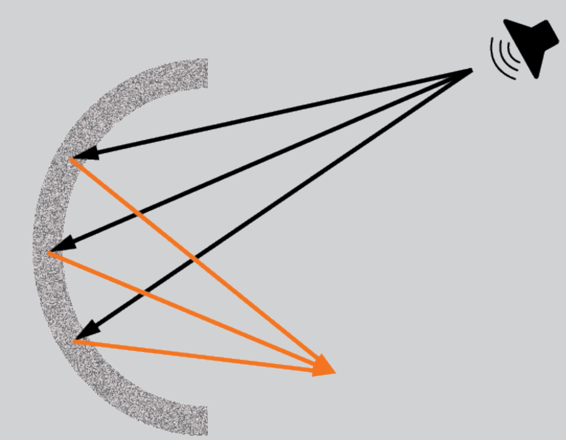
CONVEX SHAPES

- Permits sound diffusion



CONCAVE SHAPES

- Causes sound focusing

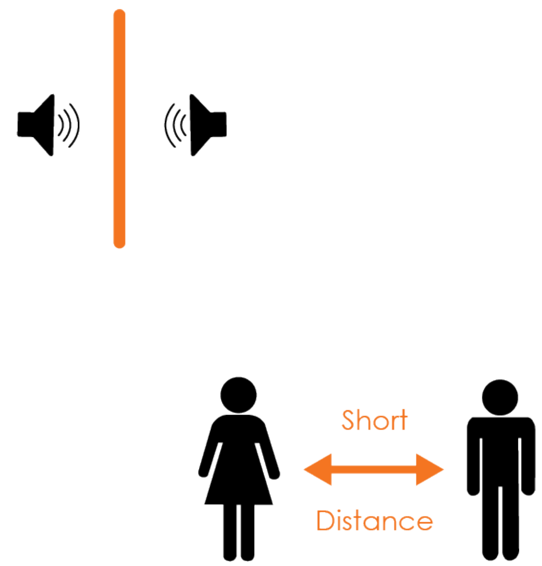


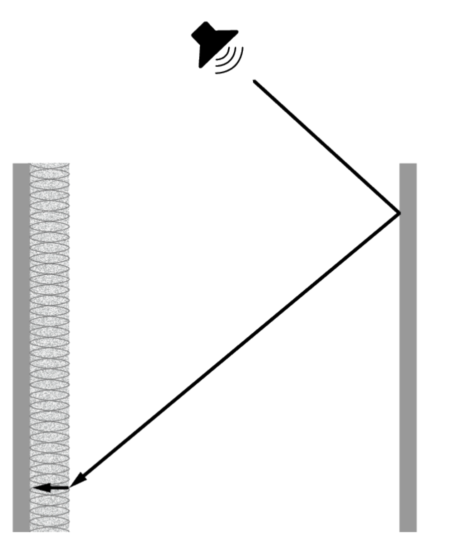
2. ROOM LAYOUT

TIP 1

SEPARATE SOUND SOURCES & KEEP SPEAKING DISTANCES SHORT

- Use sound absorbing screens or partitions to separate sound sources, and where possible, use walls.
- Use traffic aisles to help define spaces within the open-plan office.





TIP 2

PLACE ABSORPTIVE SURFACES ACROSS FROM REFLECTIVE SURFACES

- Use an abundance of high-quality acoustic treatments on the ceilings, walls, and floors.
- Distribute acoustic treatments throughout the space. DO NOT concentrate them in one area.

TIP 3

CREATE SOUND DIVISIONS BETWEEN INDIVIDUAL WORKSTATIONS

- Place sound absorbing partitions in between desks.

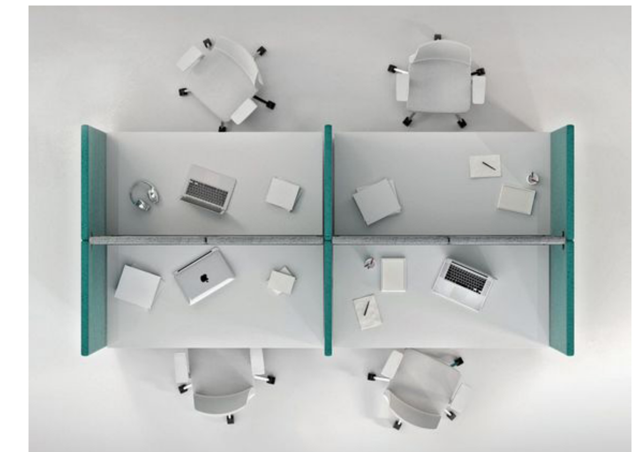


Fig. 17. Acoustic Partitions

Fig. 18. Focus Pod

TIP 4

USE SOUND ABSORBING FURNITURE THROUGHOUT THE SPACE

- This is particularly helpful in collaborative and social areas.

INNOVATIVE METHODS FOR SOLVING BUILDING ACOUSTICS

1. NEO - CONCRETE BUBBLES

Location: Stockholm, Sweden
Client: Karolinska Institutet
Completion Date: 2018
Architect: Tengbom
Manufacturer: Butong
Lighting Designer: Philips Lighting

The project consists of two bubble-like forms, comprised of 250 translucent concrete panels made using bubble wrap, which serve as lecture halls. The overall form allows for a rich acoustic quality within the bubbles, as well as, for separate speeches to take place outside of the bubbles with incredible acoustic performance. The overall shape of the bubbles permits low frequency sound diffusion, while the cavities within the panels permits high frequency sound diffusion. Also, the many perforations within the panels allow for the absorption of sound ("NEO – Concrete Bubbles of Love").

Fig. 19. Detailed View of the Panels

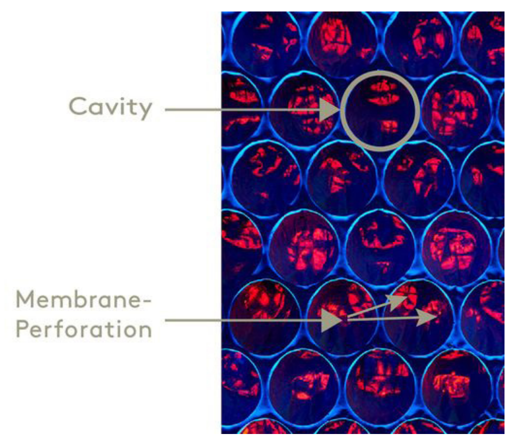


Fig. 20. Cavities vs Perforations in the Panels

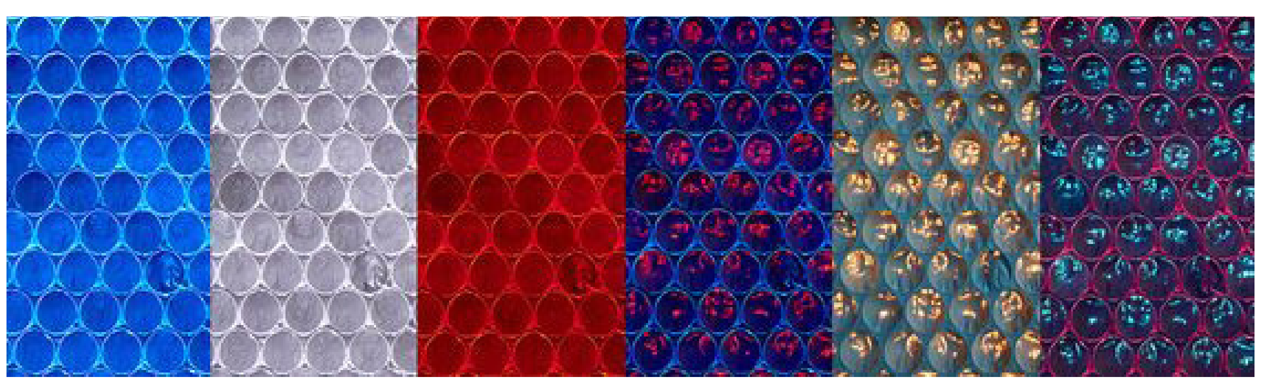


Fig. 21. Front and Rear Panel Illumination Study

Fig. 22. Exterior View of the Bubbles

Fig. 23. Structure of the Bubbles

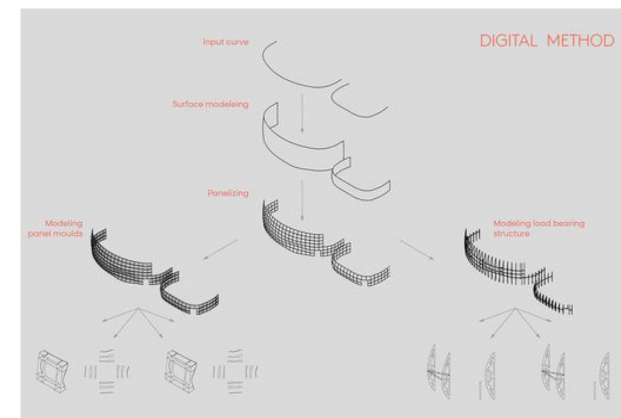


Fig. 24. Form and Structure Diagram

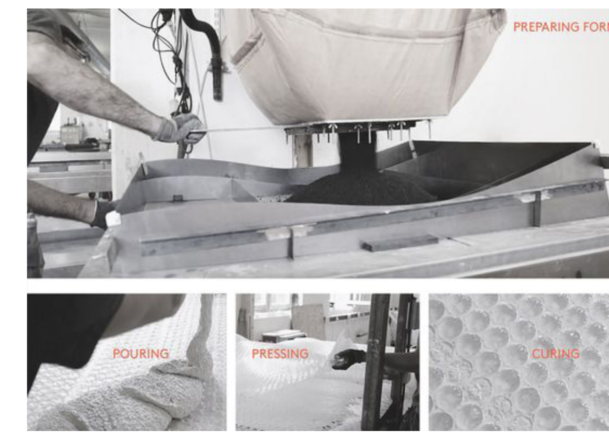


Fig. 25. Construction of the Panels

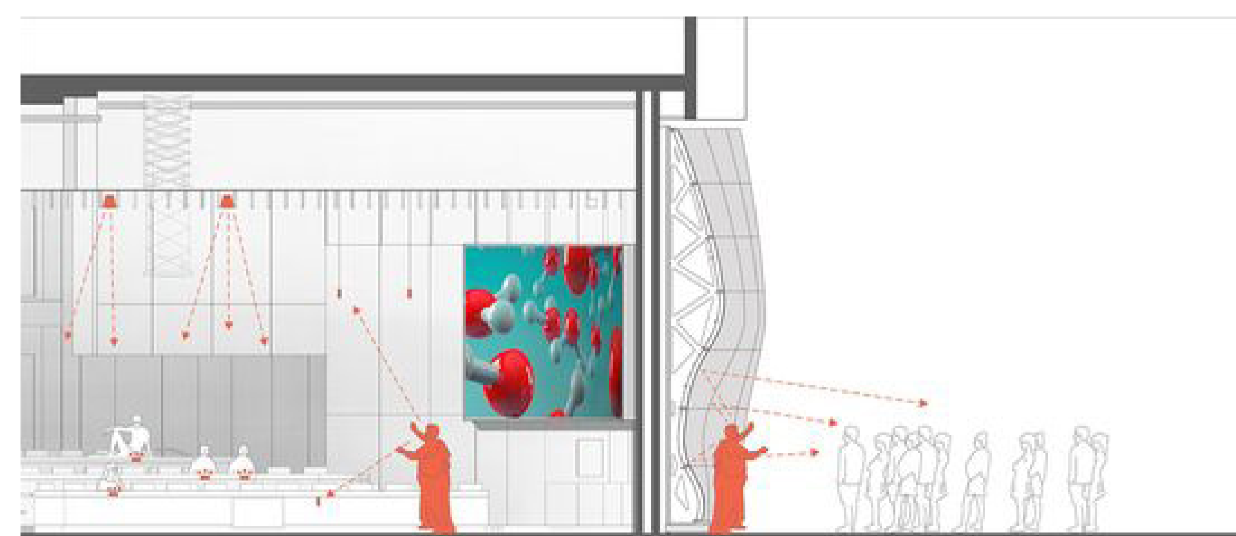


Fig. 26. Section of the Large Bubble

2. FABPOD MEETING ROOM PROTOTYPE

Location: Melbourne, Australia
Client: RMIT University
Researcher: Brady Peters

The project consists of a partially enclosed meeting room that sits in the center of an open-plan office space. The overall form of the meeting room was designed by intersecting various spheres to create concave geometries, while the surface of the meeting room was created using hyperboloid geometries. The overall form and smaller hyperboloid geometries allow for high and low frequency sounds to be diffused, while the holes in each cell and the fabric material that adorns the meeting room allow for sound absorption. Also, acoustic simulation was an integral part of the design process. Not only is the interior of the meeting room sound-isolating, but also the exterior of the meeting room acts as an acoustical treatment for the larger open-plan space in which it sits (Peters).

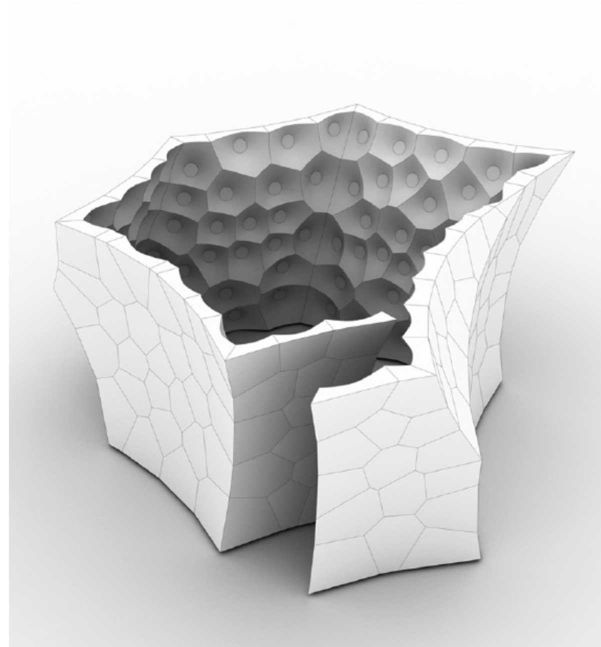


Fig. 27. 3D Model

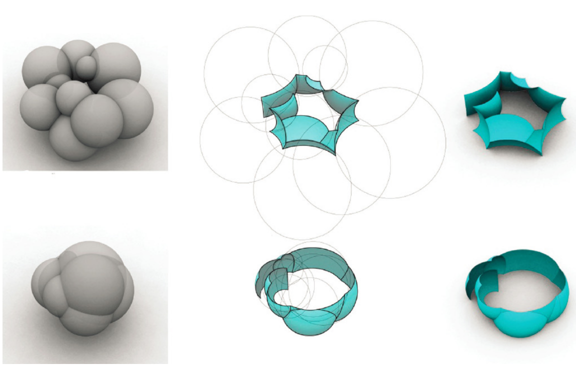


Fig. 28. Concave vs Convex Form Diagram

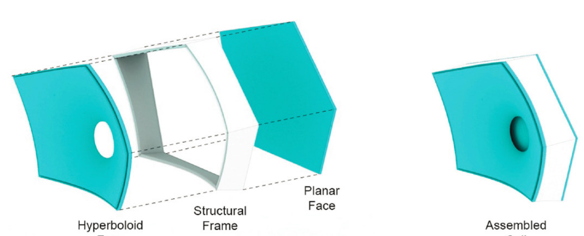


Fig. 29. Cell Assembly Diagram

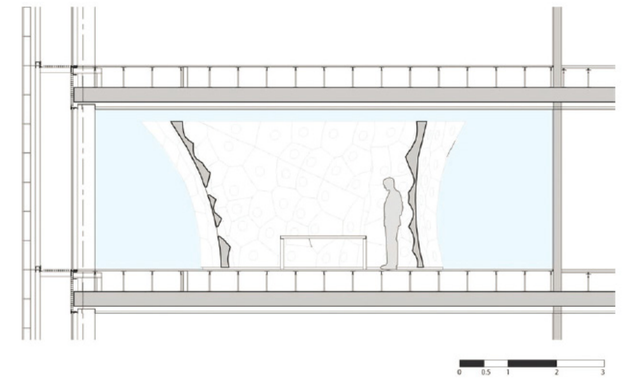


Fig. 30. Section

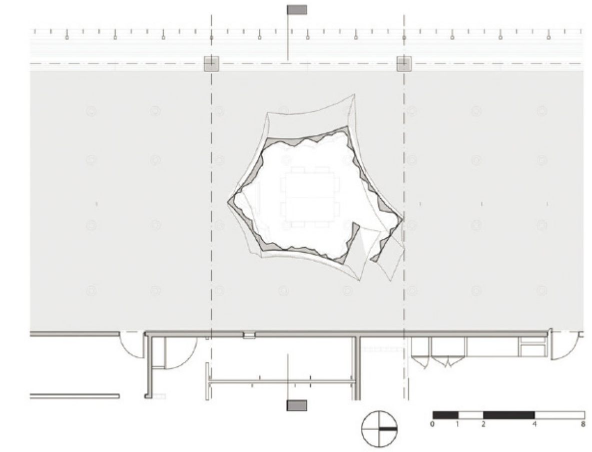


Fig. 31. Plan

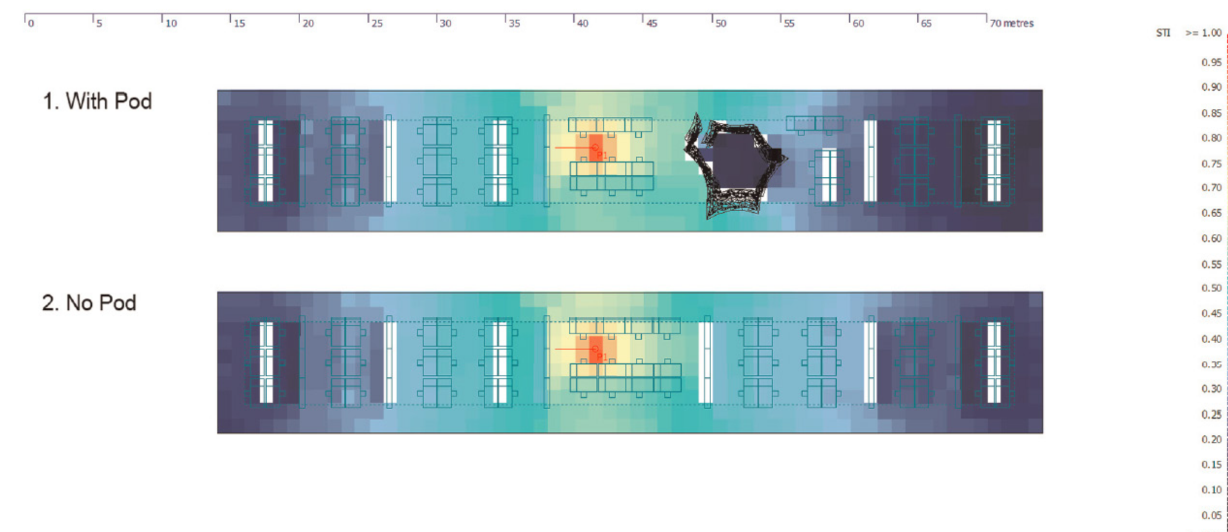


Fig. 32. Speech Transmission Index (STI)

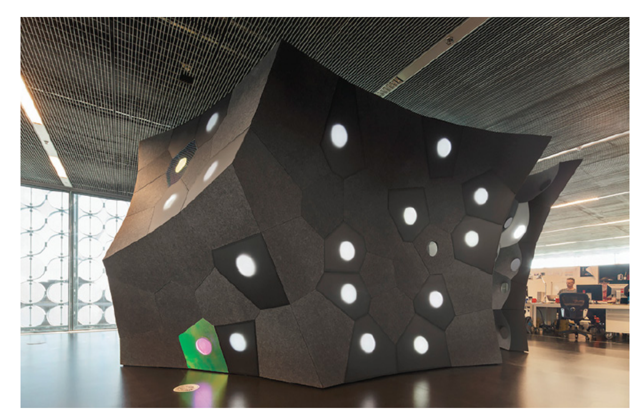


Fig. 33. Exterior View

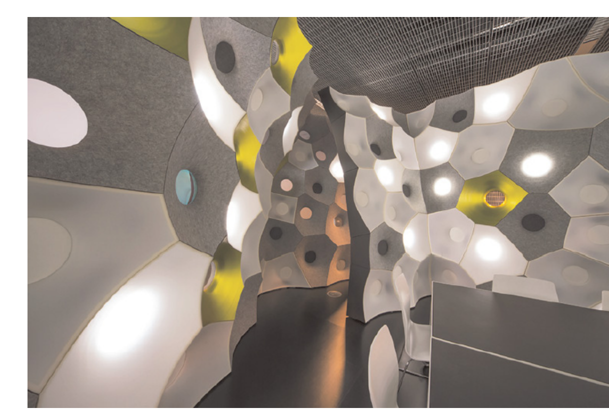


Fig. 34. Interior View

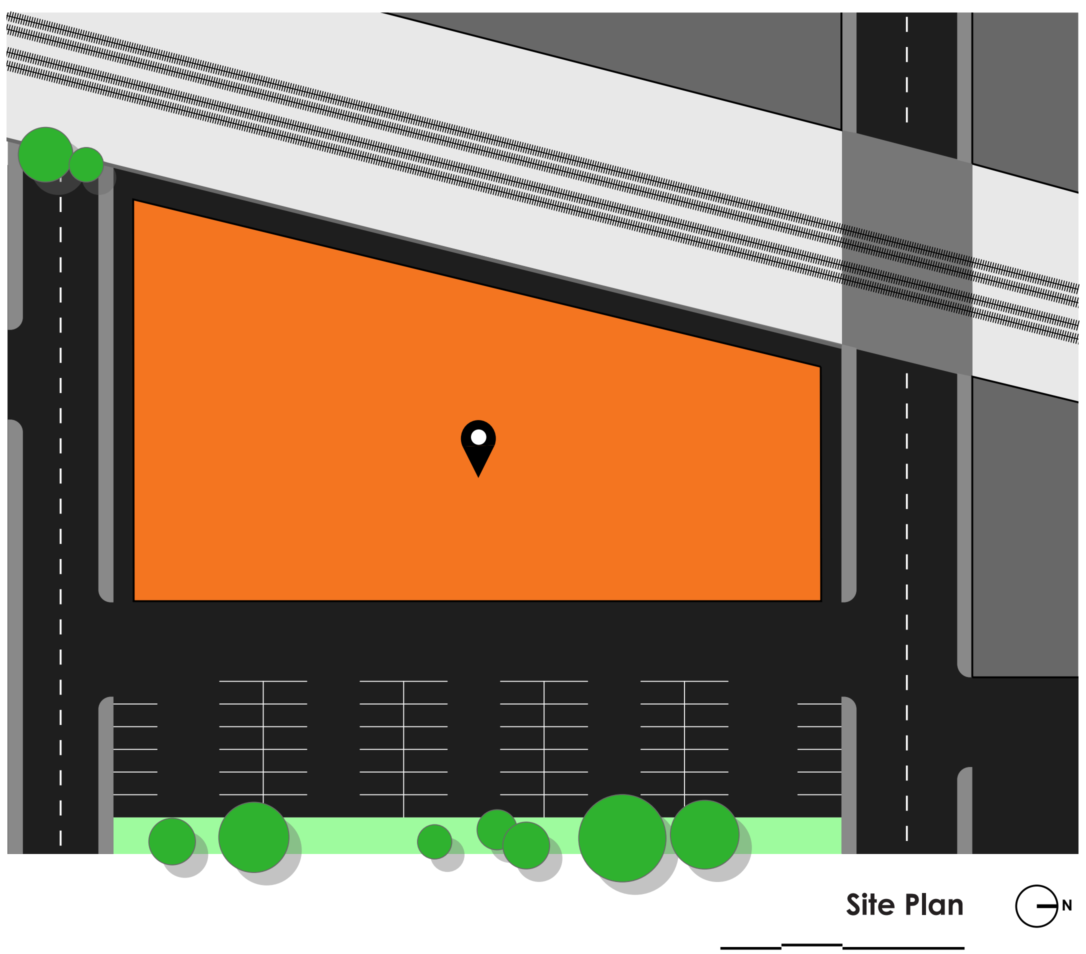
CASE STUDY:

Improving the Acoustic Quality of an Existing Open-Plan Office Space

CASE STUDY

1. THE SITE AND ITS ACOUSTIC CHALLENGES

This case study will delve into the various potential acoustic solutions for an open-plan office space in an old warehouse. This warehouse has streets on the north and south side of the building, a large parking lot on the east side and an active railway on the west side. Not only does this building present acoustical problems because of its location and open-plan, it also poses acoustical challenges because it has exposed concrete floors and columns, exposed brick walls and a large window on the north facade, as well as, exposed metal beams, trusses, and ceiling pipes.

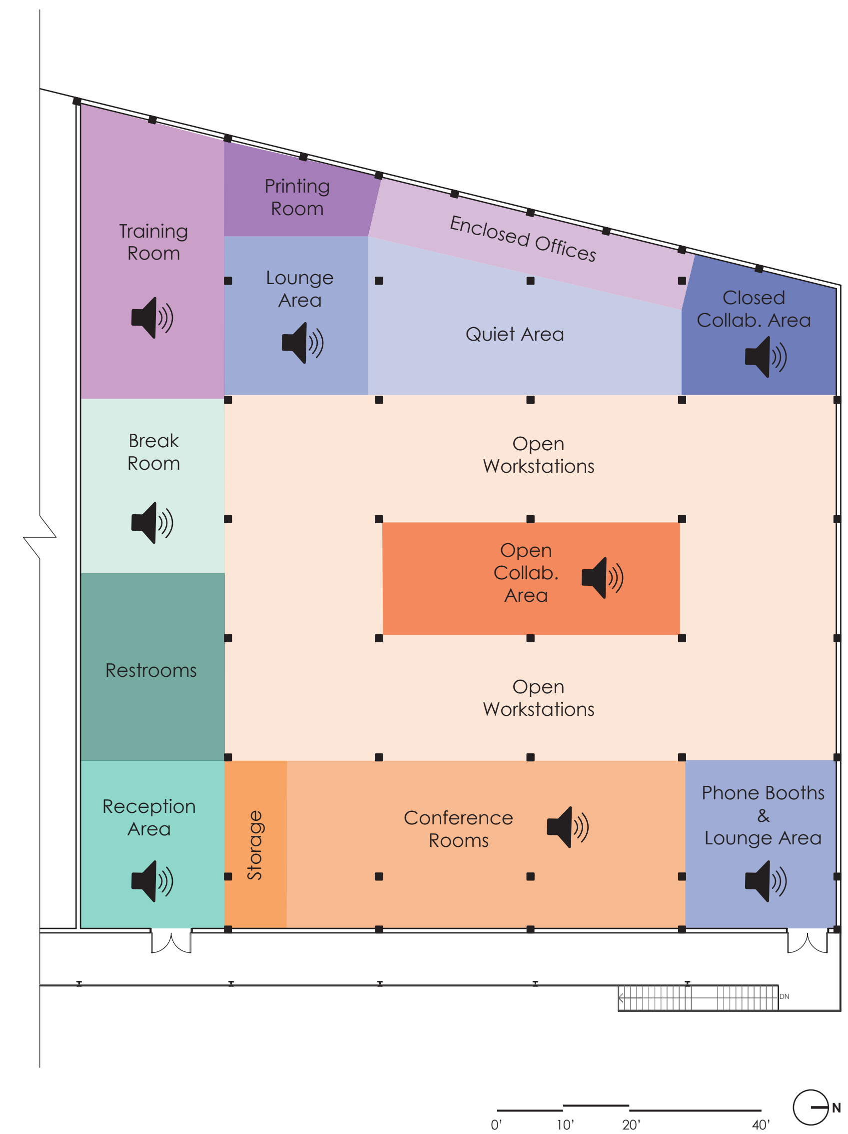


2. STEPS FOR SOLVING THE ACOUSTICS IN THE BUILDING

STEP I: OFFICE LAYOUT REQUIREMENTS (GIVEN)

- Reception Area
- Storage
- Restrooms
- Break Room
- Training Room
- Conference Rooms
- Open Workstations
- Enclosed Offices
- Open Collaboration Area
- Closed Collaboration Area
- Quiet Area
- Phone Booth
- Printing Room
- Lounge Area

STEP 2: SEPARATE SOUND SOURCES

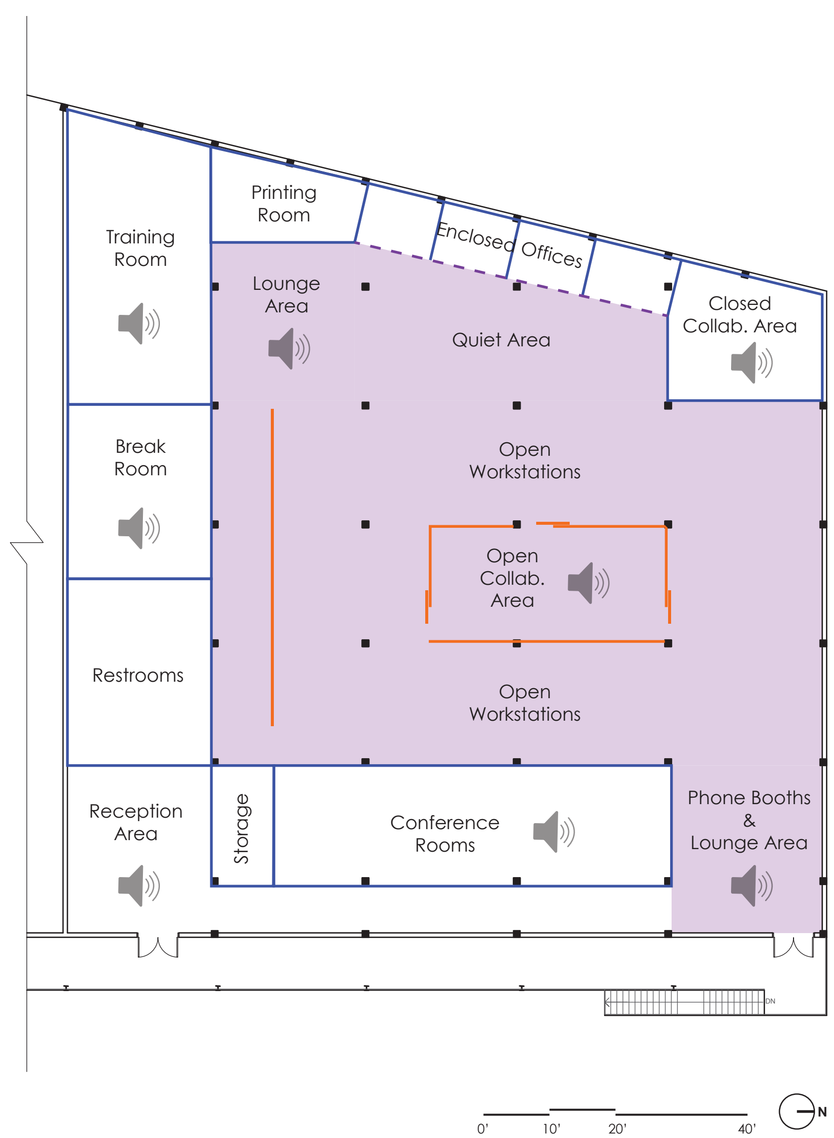


STEP 3: DEFINE ENCLOSED & OPEN SPACES

- Solid Walls
- Walls with Partial Glazing
- Partitions/ Sound Absorbing Screens

STEP 4: DETERMINE WHERE SOUND ABSORBING FURNITURE IS NEEDED

- Sound Absorbing Furniture Needed



STEP 5: DESIGN THE CONFERENCE ROOMS

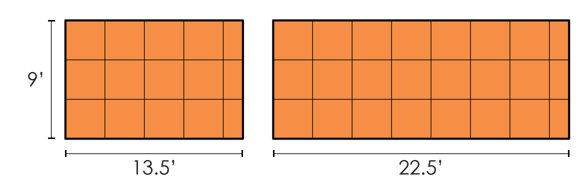
GOAL: To design the conference room as a soundproof room that also improves the overall acoustics of the entire open-plan office space.

ROOM PROPORTIONS

Large Conference Room (Seats 12-14)

H = 9'
W = 13.5'
L = 22.5'

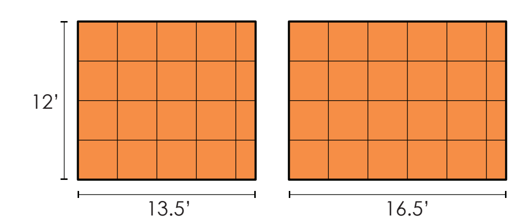
H	x	W	x	L
1.00		1.14		1.39
1.00		1.26		1.59
1.00		1.28		1.54
1.00		1.30		1.90
1.00		1.40		1.90
1.00		1.50		2.50
1.00		1.60		2.33



Small Conference Room (Seats 6-8)

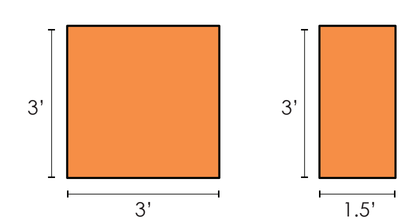
H = 12'
W = 13.68' (simplified 13.5')
L = 16.68' (Simplified 16.5')

H	x	W	x	L
1.00		1.14		1.39
1.00		1.26		1.59
1.00		1.28		1.54
1.00		1.30		1.90
1.00		1.40		1.90
1.00		1.50		2.50
1.00		1.60		2.33



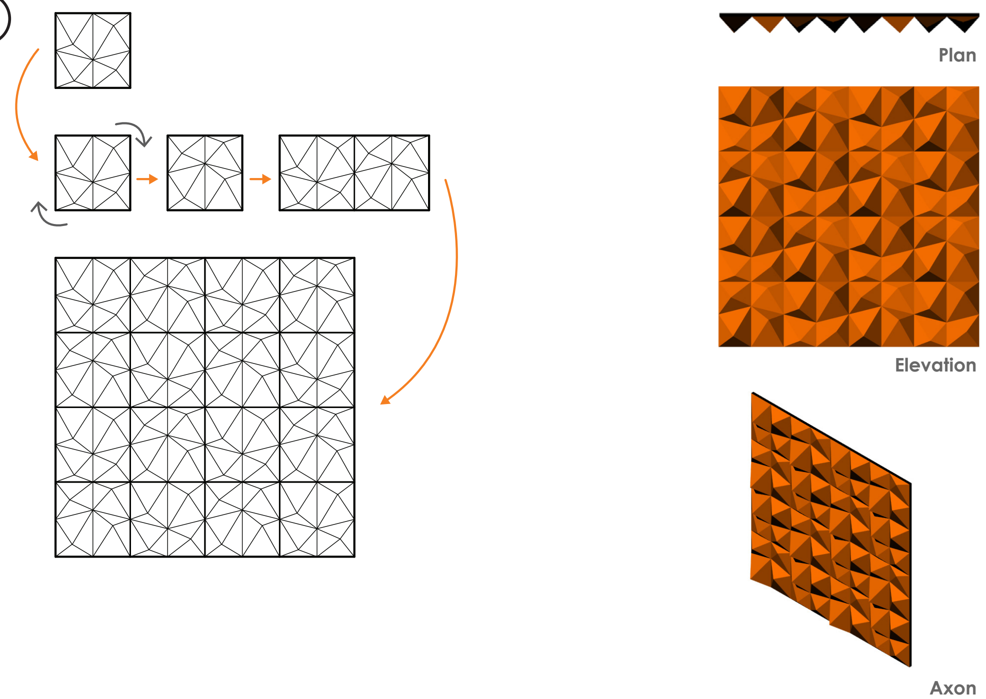
SOUND ABSORBING PANELS

Panel Sizes



Potential Panel Design & Configuration

1



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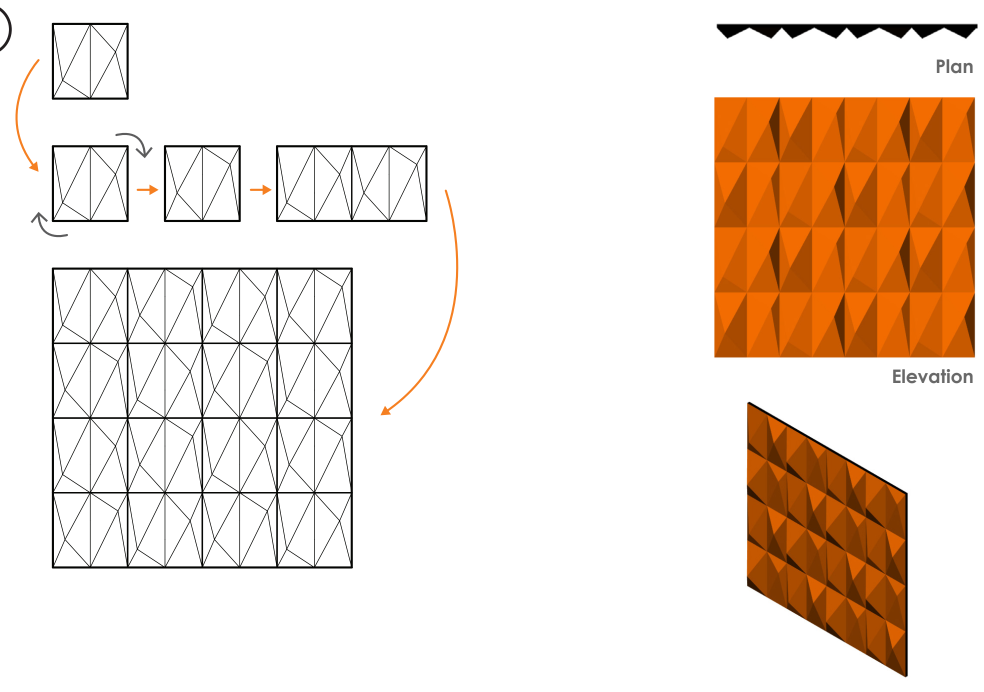
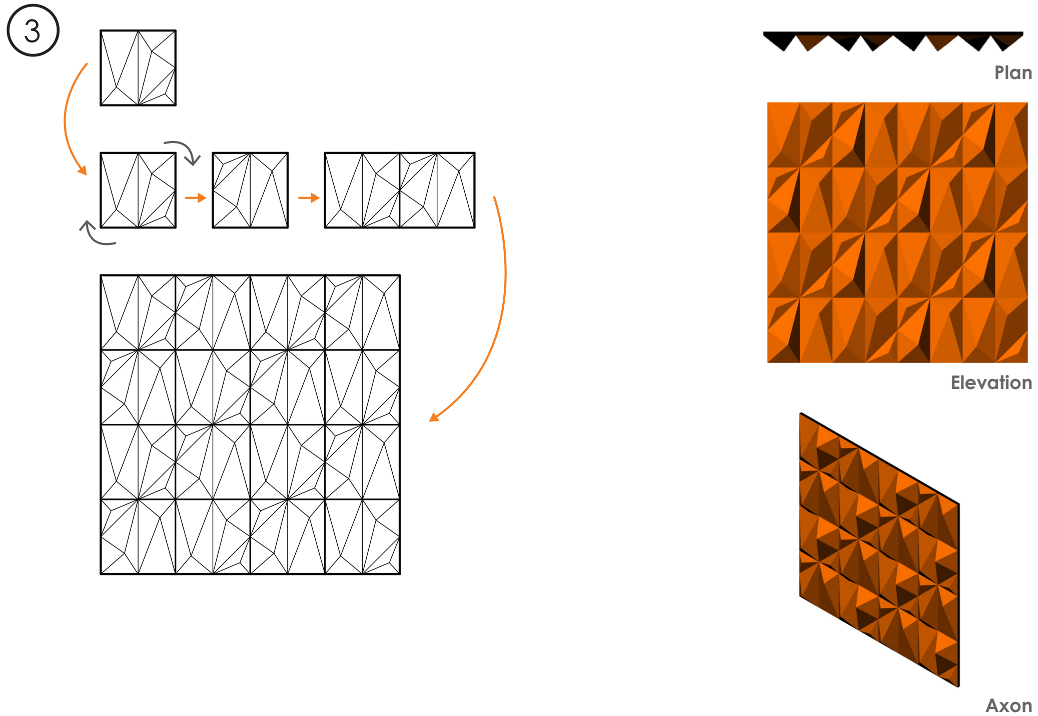
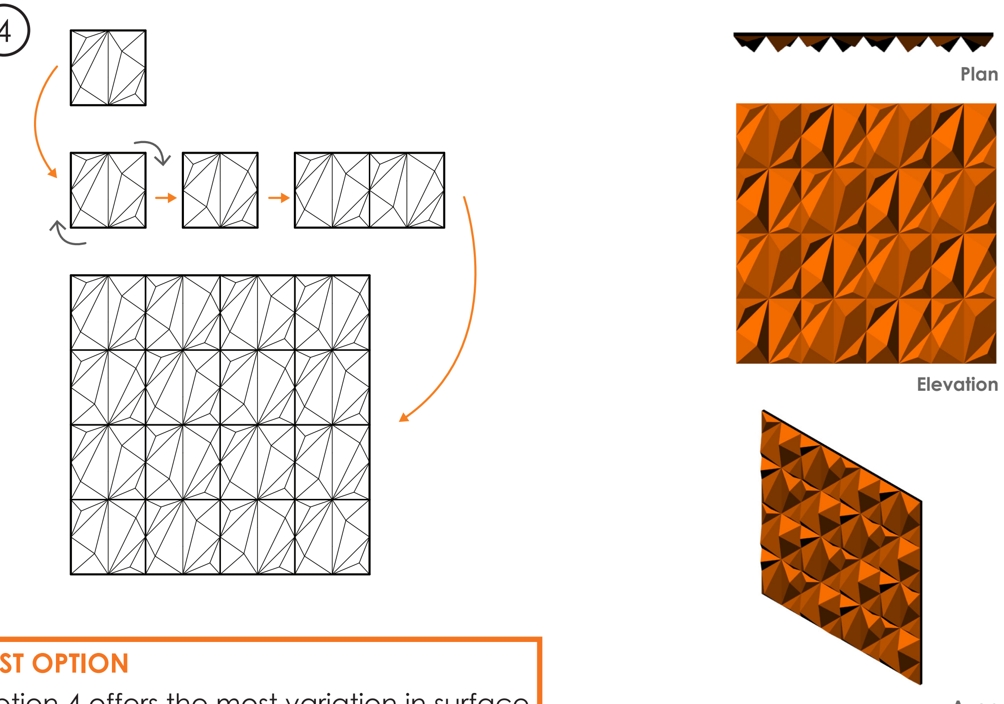


3

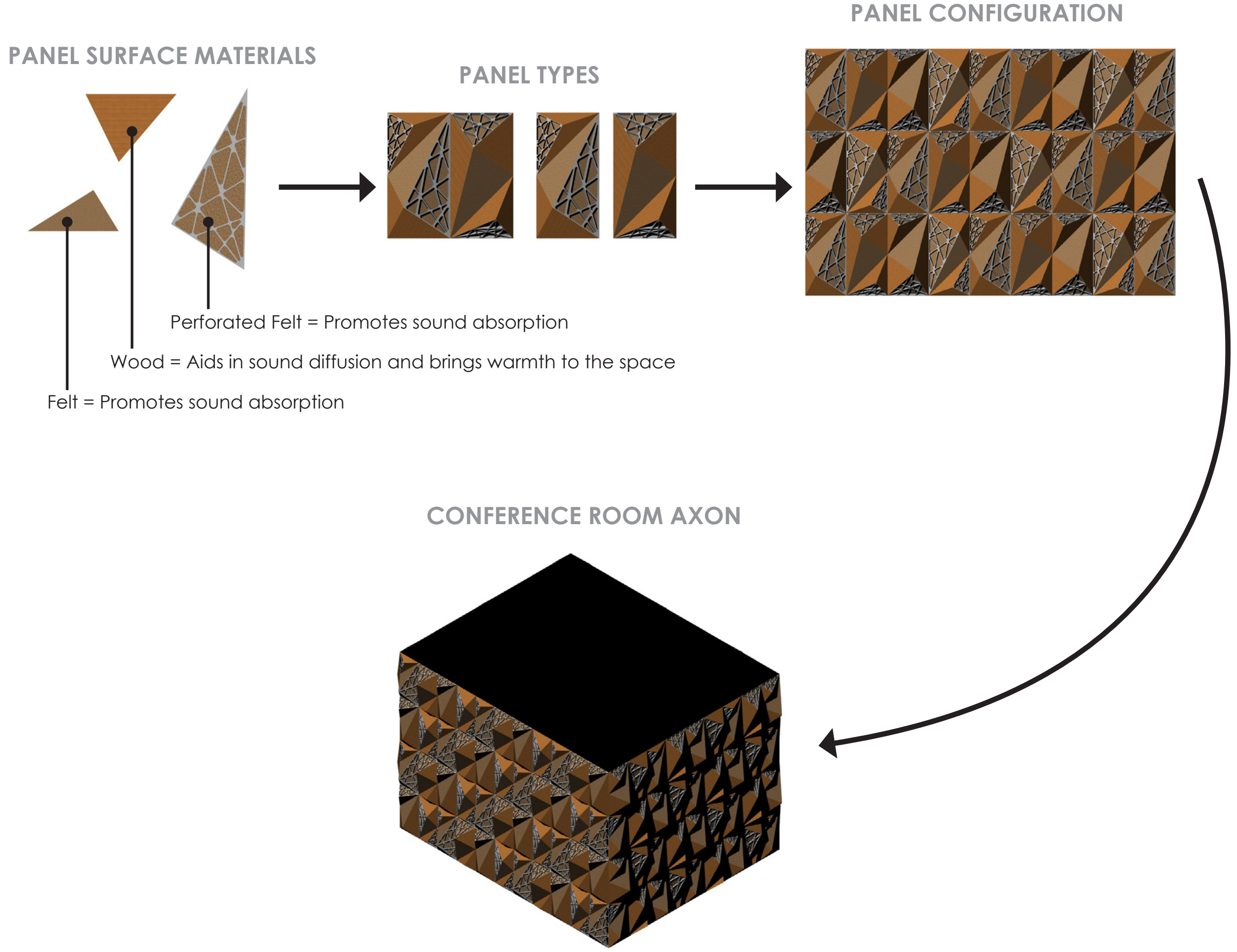


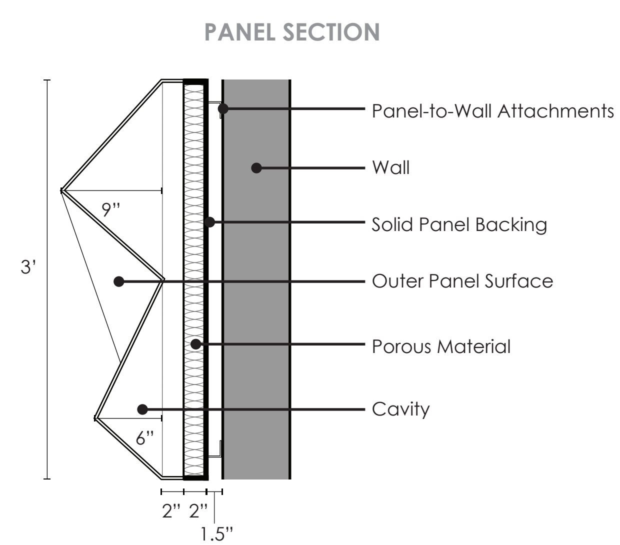
4



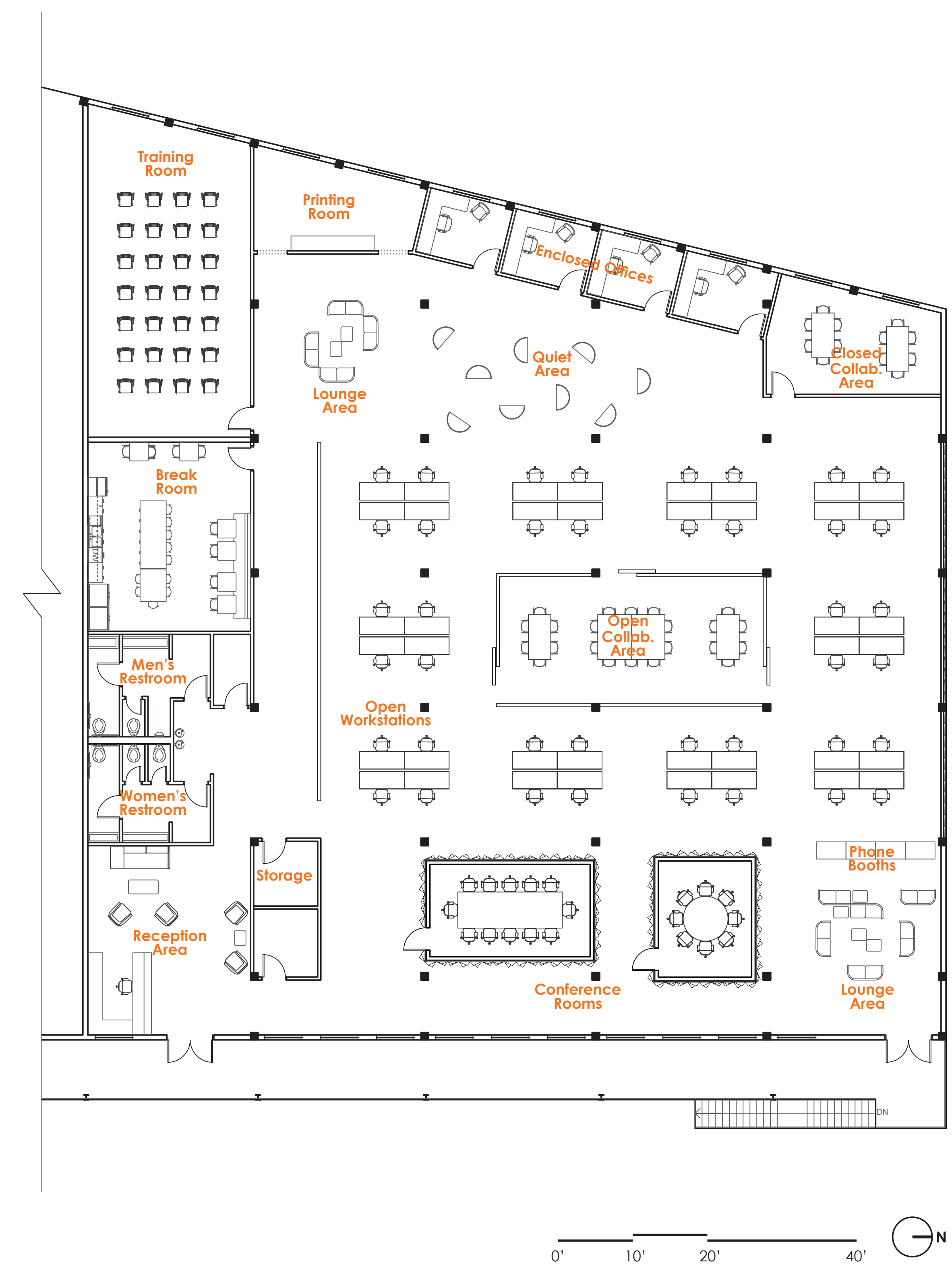
BEST OPTION
Option 4 offers the most variation in surface angles for adequate sound diffusion.

Development of Option 4

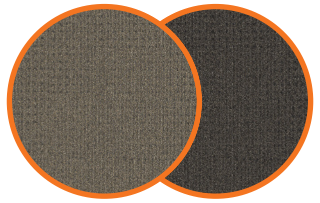




STEP 6: CREATE A FINAL LAYOUT



STEP 7: ACOUSTICAL TREATMENTS & FURNISHINGS



Interface Carpet Tile
Collection: NY+LON Streets Collection
Style: Dover Street
Color: Concrete Dot or Iron Dot
(to imitate concrete flooring everywhere except the restrooms and break room)

Zilenzio Sound Absorbing Sofa
Collection: Tune
Designer: Norm Architects

Zilenzio Ceiling Absorber
Collection: Delta

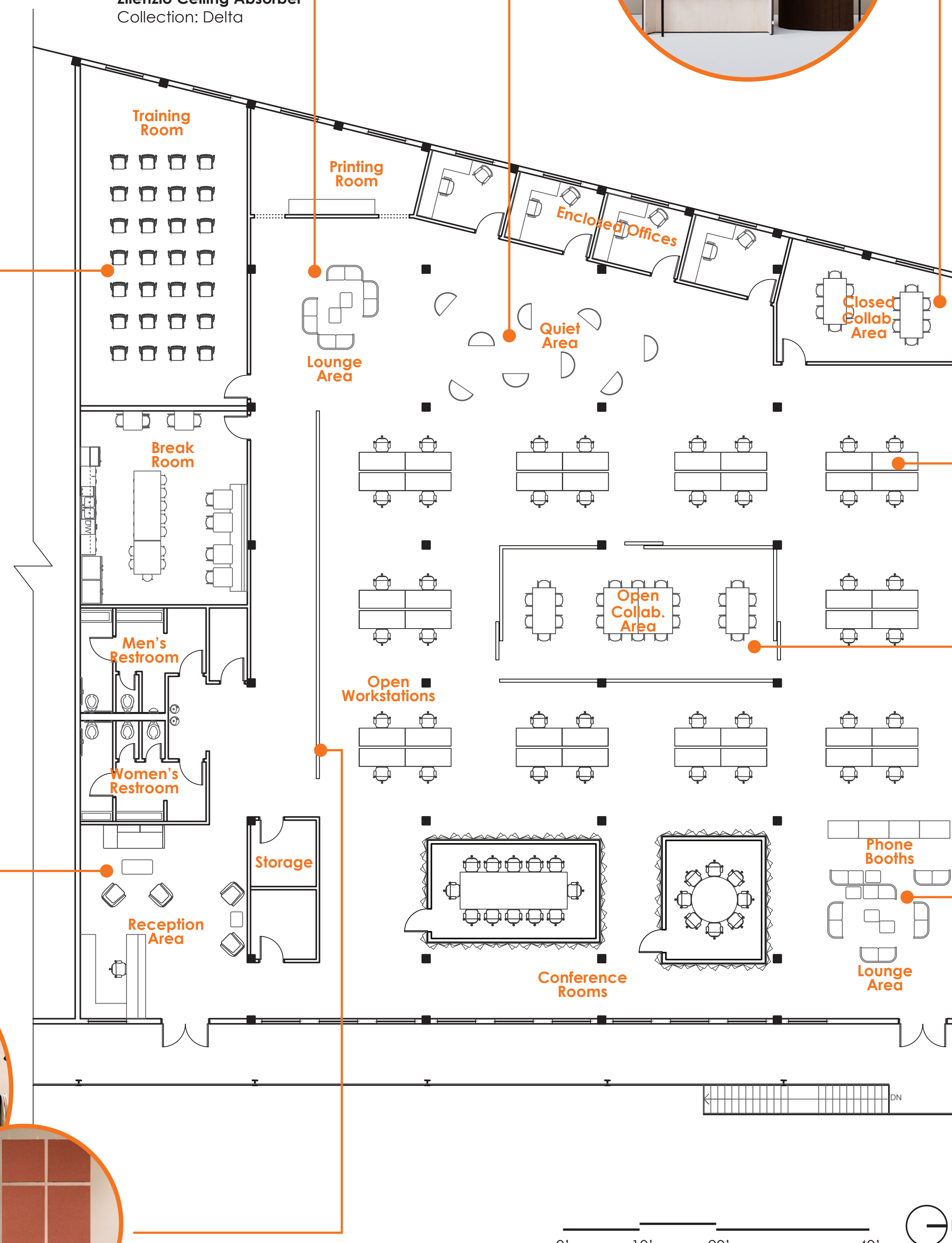
Zilenzio Easy Chair
Collection: Focus Pod
Designer: Note Design Studio

Zilenzio Ceiling Absorber
Collection: Dezign

Zilenzio Wall Absorber
Collection: Timber

Zilenzio Ceiling Absorber
Collection: Dezign

Zilenzio Wall Absorber
Collection: Timber



Zilenzio Desk Screen
Collection: Light

Zilenzio Ceiling Absorber
Collection: Delta

Zilenzio Floor Screen
Collection: Offizz

Spacestor Phonebooth

Zilenzio Ceiling Absorber
Collection: Delta

Zilenzio Sound Absorbing Sofa
Collection: Tune
Designer: Norm Architects

Zilenzio Ceiling Absorber/ Space Separartor
Collection: Mute

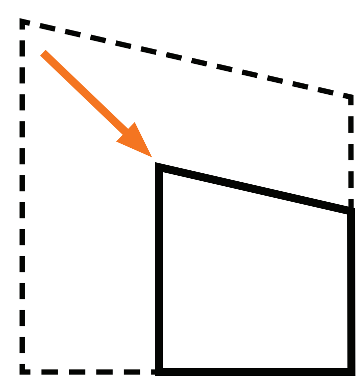
3. WHAT'S NEXT FOR OFFICE DESIGN?

Given the current health crisis, there has been an unprecedented amount of people working remotely. This leads me to believe that future office design will need to reduce the number of people that are working in close proximity to one another, as well as, adapt to remote working being as important as working within an office space. Office square footage will have to become more flexible to allow the office space to grow and shrink as they need. Also, offices will have to introduce more laptops and other forms of portable technology, in addition to accommodating an increased use of virtual collaboration and worksharing. It's safe to say that we are entering a new phase of office design.

As with any new design, there will be challenges, but potentially more benefits. Regarding acoustics, this new phase of office design could potentially eliminate many of the acoustic challenges that accompanied the open-plan office layout. For example, if people aren't working in such close proximity, then there will be less noise caused by the people within the space. Only necessary collaboration will happen face-to-face, while all others will be conducted virtually. The following images will highlight the potential ways in which the open-plan office layout could change after the health crisis and the acceptance of remote working as the new "normal".

Reduced Office Square Footage

- Since less people are working in the office at the same time, there is no need for a large office space.
- The smaller the room, the less acoustical challenges.



Re-introduction of Cubicle-like Working

- The more sparation there is between people, the lower the chance of distractions and sound transmission.

Fig. 35. Acoustic Cubicles

Increased Utilization of "Hot Desks"

- Encourages remote work, but also provides a workspace for employees when they have to work from the office.

Fig. 36. Hot Desks

CONCLUSION

The open-plan office layout developed after the need for better collaboration and communication. But as time progressed, workers started to realize that this layout decreased privacy and increased noise, distractions, and stress. These drawbacks are a result of the lack of walls and poor acoustical quality of large open spaces. This research delved into the basic qualities of sound, how the shape and layout of rooms affect the acoustics, as well as, methods for reducing noise and improving acoustical quality. Essentially, when sound waves interact with a surface, they can either be reflected, absorbed, or diffused. Sound reflection is what can cause echoes and increased reverberation times; therefore, it should be avoided as much as possible. Sound absorption is critical to reducing the noise within a space and the noise being transmitted from outside of a space. Lastly, sound diffusion, when done correctly, can dramatically improve the sound quality within a space.

Acoustics is such an integral part of how a building functions, that Architects, designers, and researchers are constantly finding innovative ways to solve poor acoustical quality, while also making these solutions aesthetically pleasing. For example, the "NEO - Concrete Bubbles" by Tengbom Architects used bubble wrap to create a form that promoted sound absorption and diffusion, while the "FabPod" research by Brady Peters focused on using hyperboloid geometries and acoustic simulation to create a meeting room that was not only soundproof, but also improved the sound quality of the entire open-plan office in which it sits. In contrast, the case study highlighted potential acoustic solutions for existing open-plan office spaces by utilizing various acoustical treatments and a similar design strategy as the "FabPod" research, which was applied to the conference rooms. Even though the open-pan office typology posed many challenges, there were many solutions created as a result. It is only a matter of time before a new phase of office design emerges, especially given the current health crisis.

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