200EPA Acoustics: Live Room Design

To design an acoustically sensitive room, early reflections, modal resonance, and reverberation time must be carefully controlled. Early reflections can be absorbed, diffused or delayed. Modal resonances can be smoothed with 'golden' proportions, tuned bass absorbers, or complex room geometries. Reverberation time can be tweaked by adjusting the room volume and surface treatments (Everest 2009). The live room design proposed by this document seeks to provide variable reverberation time and enhanced sound scattering for the suppression of early reflections, improved modal response, and better recordings of instruments with variable directivity.

The live-end-dead-end room design was developed by Don and Carolyn Davis to alleviate comb filtering in small listening rooms where the delay between early reflections and direct sound from speakers is short, and therefore, comb filtering is pronounced (Cox 2009: 40). The front half of the room (where the speakers and mix position are located) should be absorbent, whilst the rear half of the room should be reflective or diffuse. The added distance extends the time delay between the early reflections and the direct sound. The spacing between the nulls of the comb filter shortens and becomes less significant when compared against the critical bands of human hearing (Everest 2006:142-144). Phase grating diffusers stagger the arrival of the early reflections, causing the layered filtrs to blur together (Cox 2009: 43). Diffusers also redistribute a sound's energy across space resulting in greater losses to the inverse square law (Cox 2009: 42).

The live end of a live-end-dead-end mixing room provides far more than a means for extending reverberation time. According Schroeder, lateral reflections are key to one's sense of envelopment (Cox 2009: 54-55). In accordance with Schroeder's predictions, Peter D'Antonio developed the reflection free zone design as a means of preserving the intensity of lateral reflections, whilst suppressing the comb filter effects of early reflections. To create a reflection free zone, the ceiling walls to either side of the mix position are angled to channel reflected sound towards the rear of the room where phase grating diffusers are often mounted as in live end dead end design (Cox 2009: 54-55).

Although these designs cater to the requirements of listening rooms, they are not inherently suited to the design of a recording room. Live end dead end design commonly results in a coupled environment. According to Howard, sound trapped between the walls of the live end will continue to reverberate after reverberation has ceased in the dead end (Howard 2006: 286-288). Further, if a variable reverberation time is desired by means of movable acoustic treatments, it may be difficult to maximize the difference between reverberant states without compromising the early reflection suppression that the dead end is needed for. Reflection free zone design offers extended reverberation times without compromising early reflection suppression; however, the sounds to be recorded in a live room are not as uniform or predictable as speakers are in a mixing room.

Appendix A features images of the room design. Large complex structures project from the merger between the left and right walls and the floor, from the center of the front wall, and from the center of the ceiling. These structures shall be termed Angular Quadratic Residue Scattering Systems (AQRSS). These structures are the result of several investigations into the design of reflection free zones and the ray acoustics of early reflections in such zones, which are featured in Appendix B. The convex surfaces in these diagrams are efficient mechanisms for transporting sound. Whispering galleries are built upon this principal; however, as easily as sound may be distributed throughout the room or to a desired location, it is easily refocused and all of the desirable qualities of a diffuse sound field are compromised (Everest 2009:100). AQRSS are the application of quadratic residue sequences to convex surfaces in an attempt to harness their sound distributing properties whilst maintaining a diffuse environment.

A quadratic residue sequence is derived by squaring the modulo of a prime number and a set of positive integers (Everest 2009: 259-260). In appendix C, a series of prime number sequences and their inverses are presented. The dimensions of the live room design are 42' by 30' by 20', so the N19, N31, and N43 quadratic residue sequences were selected, such that with slight modification, a uniform well width of 1' could be applied to all of the AQRSS modules, and one or more of each AQRSS type could be mounted on all three axis of the room. To produce the AQRSS shape, right-angled, triangular prisms are drawn with a uniform width (1') and base length (4' or 6'). Then the heights of the triangles are modulated according to the quadratic residue pattern. The two AQRSS N19 patterns have been arranged in this configuration to function as a refection free control room window whilst also randomly scattering sound across the length and width of the room. To produce the complex shape of the AQRSS in C.5, an AQRSS of the N31 standard sequence and the N31 inverted sequence are superimposed.

Everest recommends that one-dimensional diffusers be aligned perpendicular to one another (2009: 250-251). Although AQRSS are not diffusers, a similar staggering technique has been applied so that sound will be scattered equally across every axis. Further, it is hoped that positioning the AQRSS in such a way will result in even sound scattering regardless of a sound source's directivity.

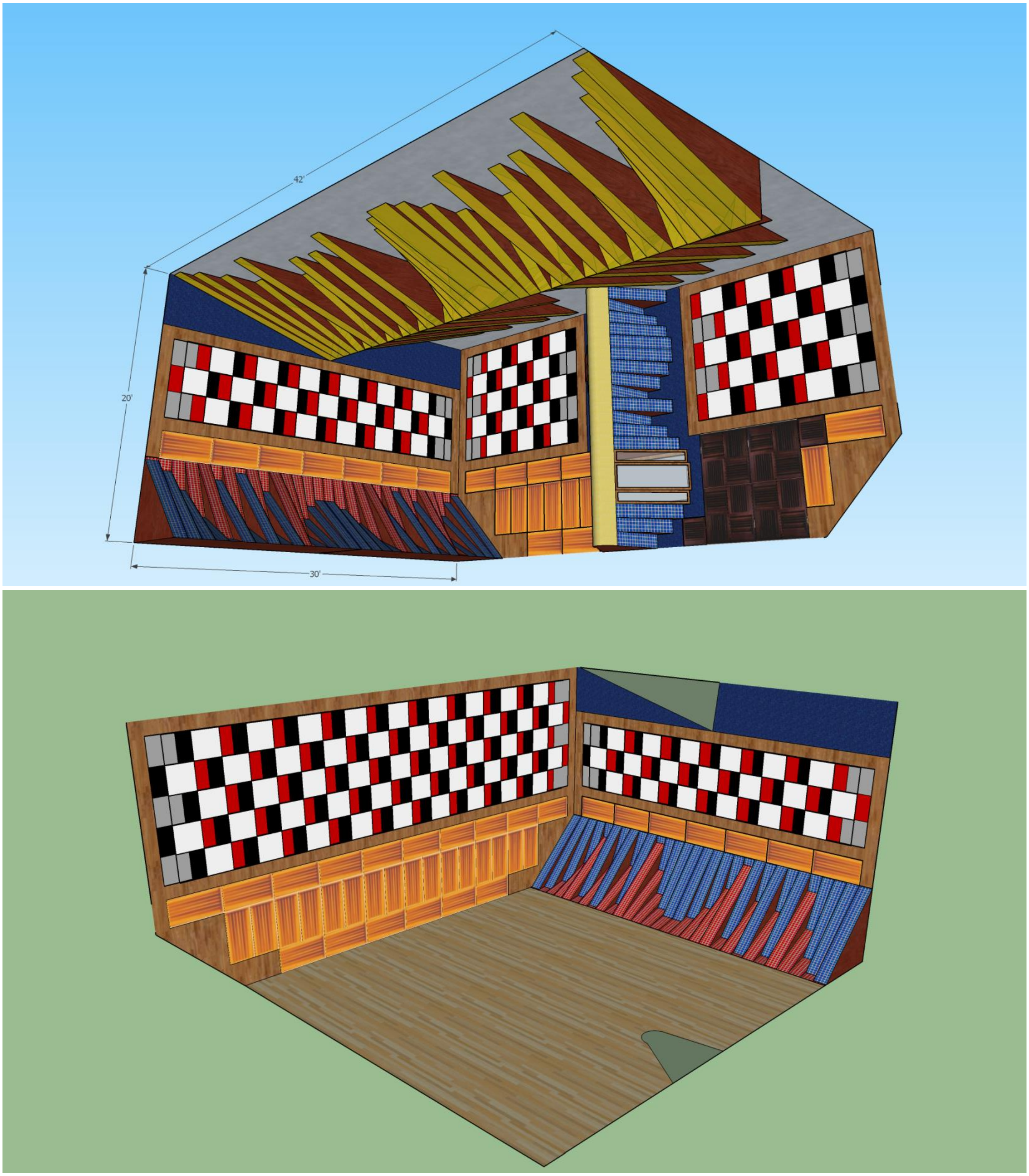
The room is proportioned according to Louden's third best ratio 1:1.5:2.1 (Everest 2009: 247), and the ceiling height of 20' was selected because the dimensions 42' by 30' by 20' accommodate may common building material sizes, and the floor area is appropriate for the recording of a quintet or similarly-sized ensemble for whom the room is primarily intended. The large size also improves the room's modal characteristics. Appendix D features information about the room's modal characteristics. The critical frequency is 89.6 Hz, and the lowest fundamental axial mode is 13.28 Hz. The bonello criterion states that the total number of modes (axial, tangential, and oblique) in a third-octave band should be greater than the number of modes in the previous third-octave band, and axial modes must not overlap, unless the modal density of the octave band is 5 or greater (Everest 2009: 250). Figure D.3 features a bonello graph of the room's modal density. The flat region between 15 Hz and 25 Hz is acceptable, and the ensuing progressive ascent in density is ideal. Two axial modes coincide at 56.5 Hz and again, two others at 94.2 Hz; however, 94.2 Hz exceeds the critical frequency, so it is likely to have little influence. Further. The coincidence at 56.5 occurs in conjunction with 25 other modes, so the bonello criterion permits it. The spacing between axial modes is otherwise excellent: the axial modes are never separated by more than 25 Hz and most are separated by 5 Hz or more. Further, the complex geometry of the AQRSS is likely to result in an increase in tangential and oblique modes. Measurements should be recorded in the room, and in the event that a particular bass frequency is problematic, the sides and faces of the AQRSS are easily transformed into tuned base traps such as perforated Helmholtz resonators or panel traps, which may be used to control the problematic modes on each axis.

Appendix E describes the materials and acoustic treatments used. Variable reverberation time is achieved with the use of sliding panels. Figure E.1 demonstrates the grid of panels in its three states of use: black, midway, and red. Black tiles reflect sound, red tiles absorb sound, and white tiles diffuse or scatter. White tiles collectively form a sliding wall that is mounted on rails and all of these sliding walls may be connected so that reverberation may be adjusted in one fluid movement. Grey tiles represent sections of the pattern that are not modified by the movement of the sliding white tiles.

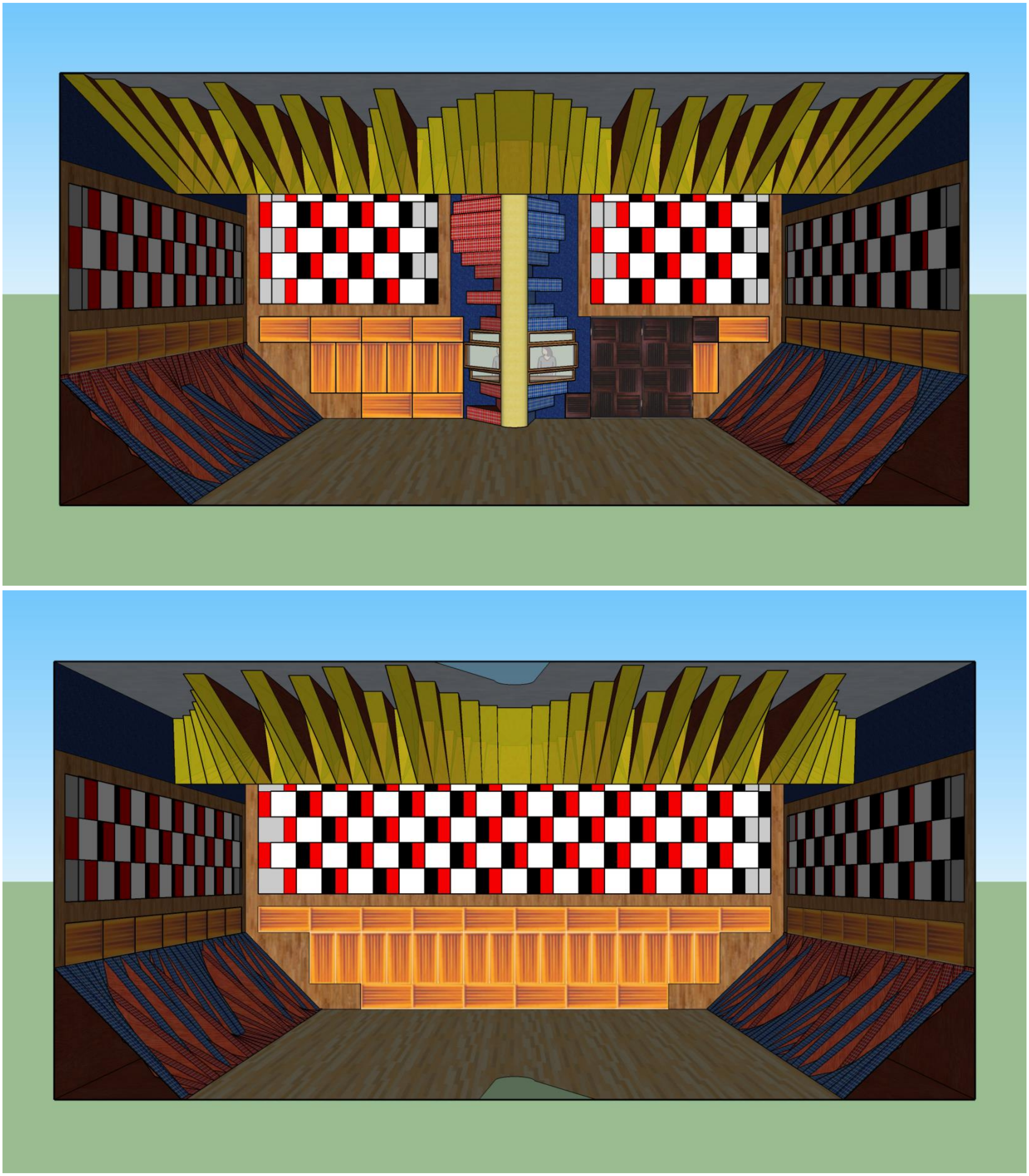
Appendix E describes the wall treatments and materials used and their anticipated influence on reverberation time. A reverberation time of 1 second is appropriate for recording music in a 700 m³ room (Everest 2009: 349), so materials were selected in pursuit of a 1 second, all-black reverb time. The RPG Diffractal (figure E.4) was selected as the primary means for diffusion on ground level because of its excellent diffusion characteristics at both high and medium bandwidths. Its broad bandwidth diffusion is accomplished by building miniature quadratic residue diffusers into the wells of a larger quadratic residue diffuser; the pattern created is a fractal (RPG 2013). When mounted vertically, the Diffractal will diffuse laterally, yet the horizontally mounted Diffractal units will diffuse longitudinally. The RPG Formedffusor (E.5) is also a quadratic residue diffuser but is substantially thinner. Accordingly, to mask reflections from the door, a door will be lined with 2’ by 2’ RPG Formedffusor tiles. Such a door is shown in E.6. The wall area surrounding the AQRSS N19 and AQRSS N43 is a potential source of first order reflections, so it is an appropriate location for absorbent surfaces.

Tiles are aligned such that similar tiles do not face one another. This is visible in the two dimensional profiles A.3 and A.4. Further, to guarantee that flutter echo will not occur between white tiles and black tiles, the RPG 2’ by 2’ golden pyramid (figure E.7) has been selected as the face for all white tiles. The other materials in the design were selected to achieve consistent reverberation times at all frequencies. However, the Sabine reverberation time equation was used to calculate the reverberation time values in figure E.3, so although the average reverberation time of 1.03 seconds for the black state might be accurate because the average absorption coefficient used in the calculation was less than 0.3 Sabines, the 0.75 seconds that was calculated for the red state might not be accurate because the red tiles have an average absorption coefficient near 1. Accordingly, aggressive bass treatment was used to ensure that the base rise of the reverberation time in the red state remains within the tolerances described by the BBC: 60% at 63 Hz and 20% at 125 Hz (Everest 2009: 172-173).

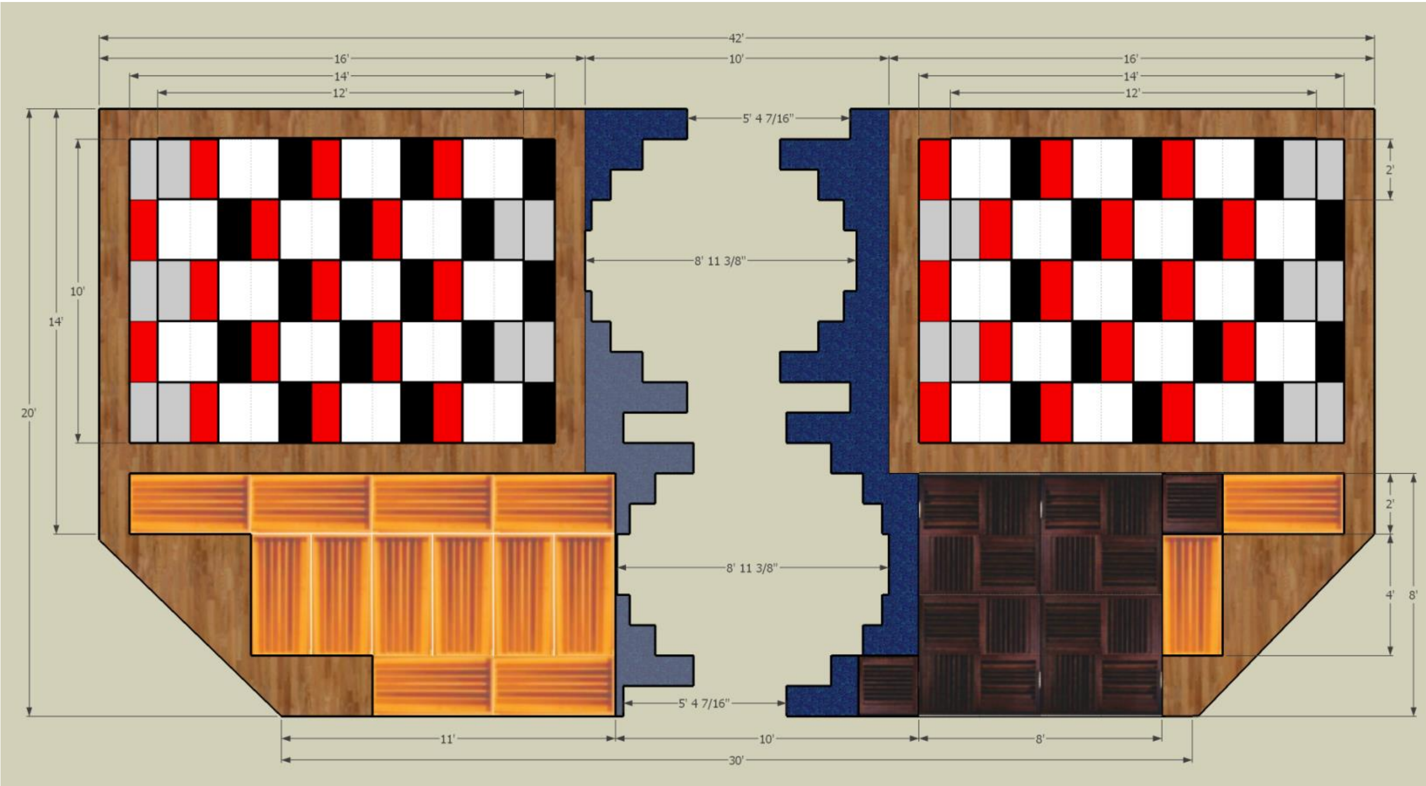
Appendix A: Recording Room Design Renderings

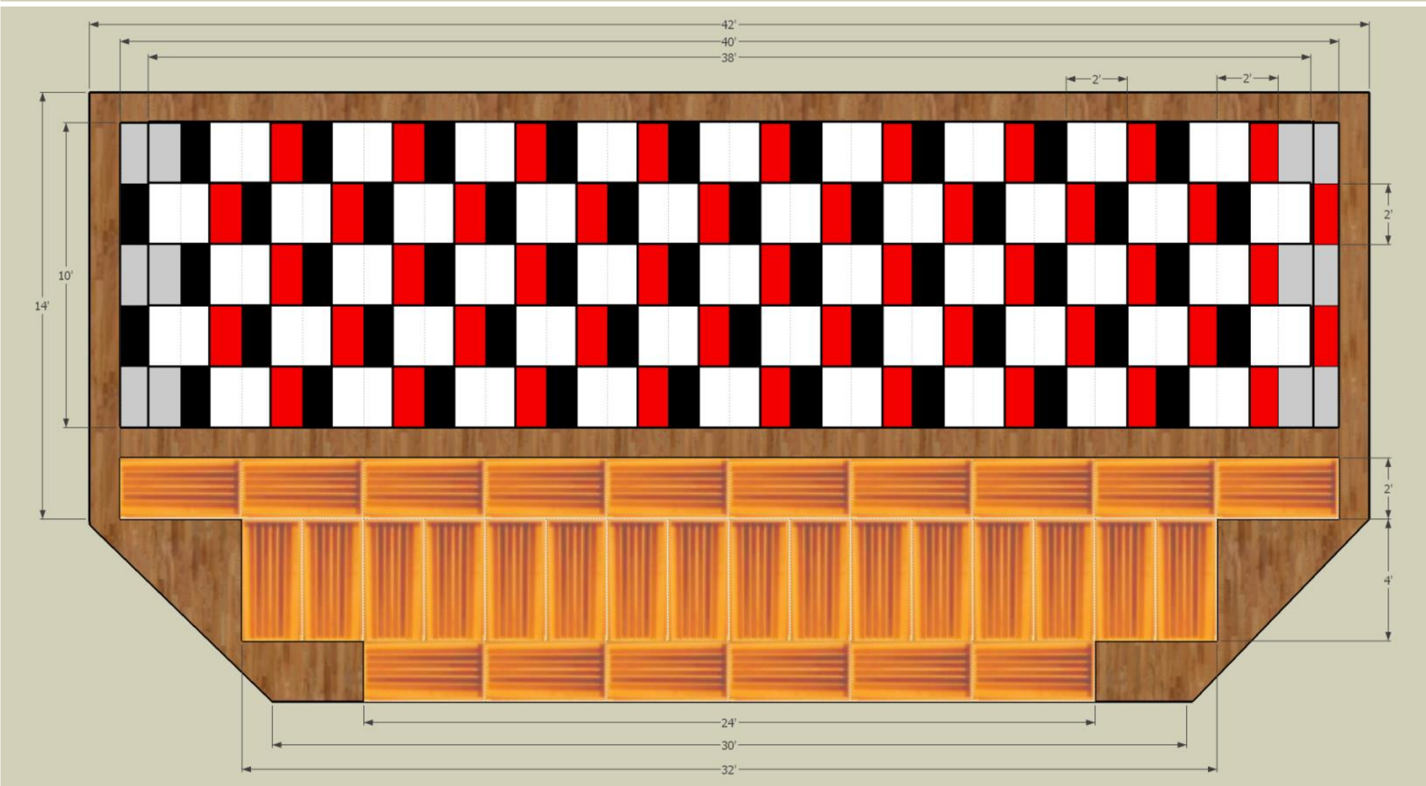


A.1: Isomorphic renderings of the room from the rear lower right corner (upper image) and the front upper left corner (lower image).

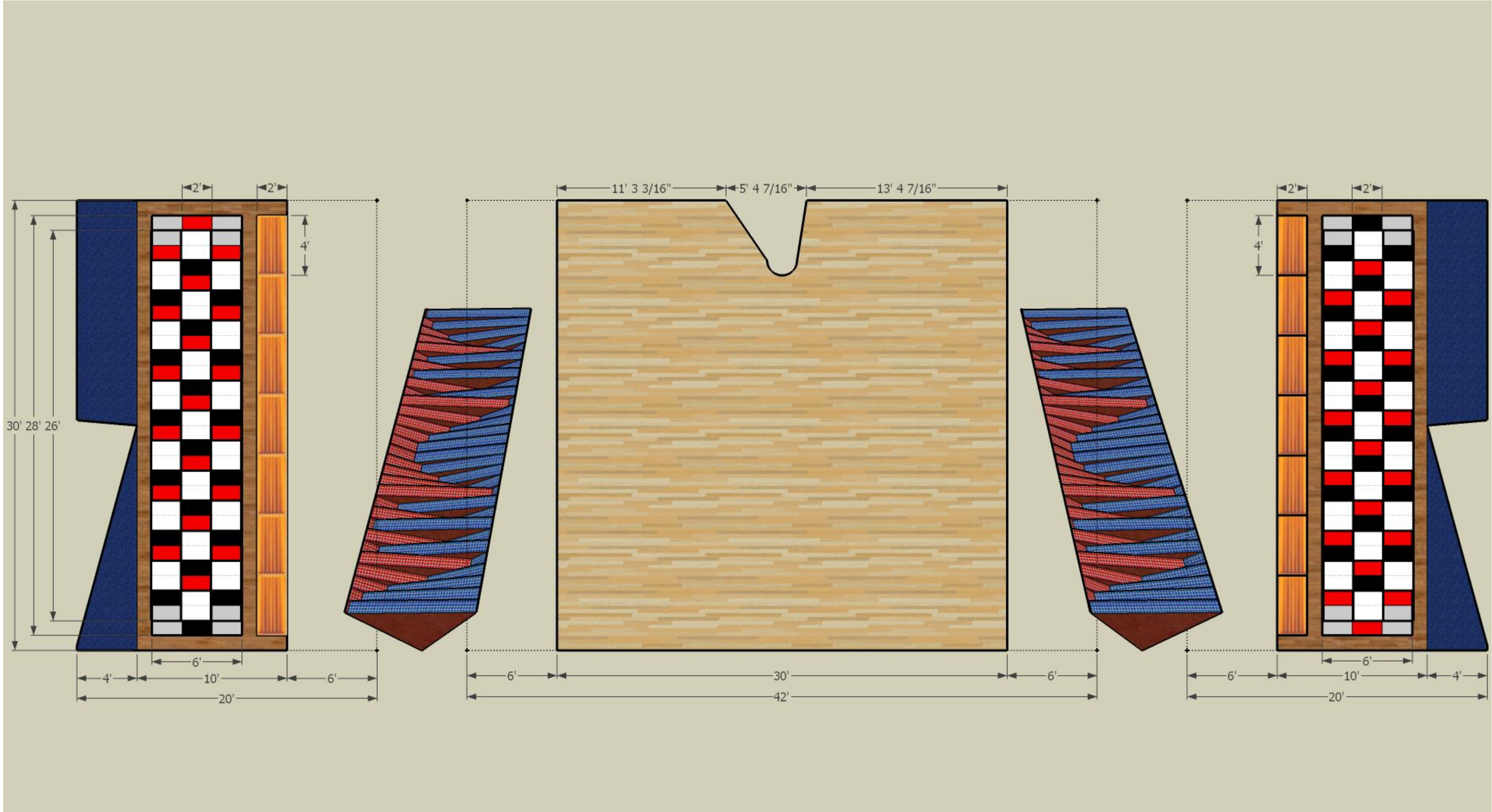


A.2: Two-point perspective renderings of the front (upper image) and rear (lower image) of the room.

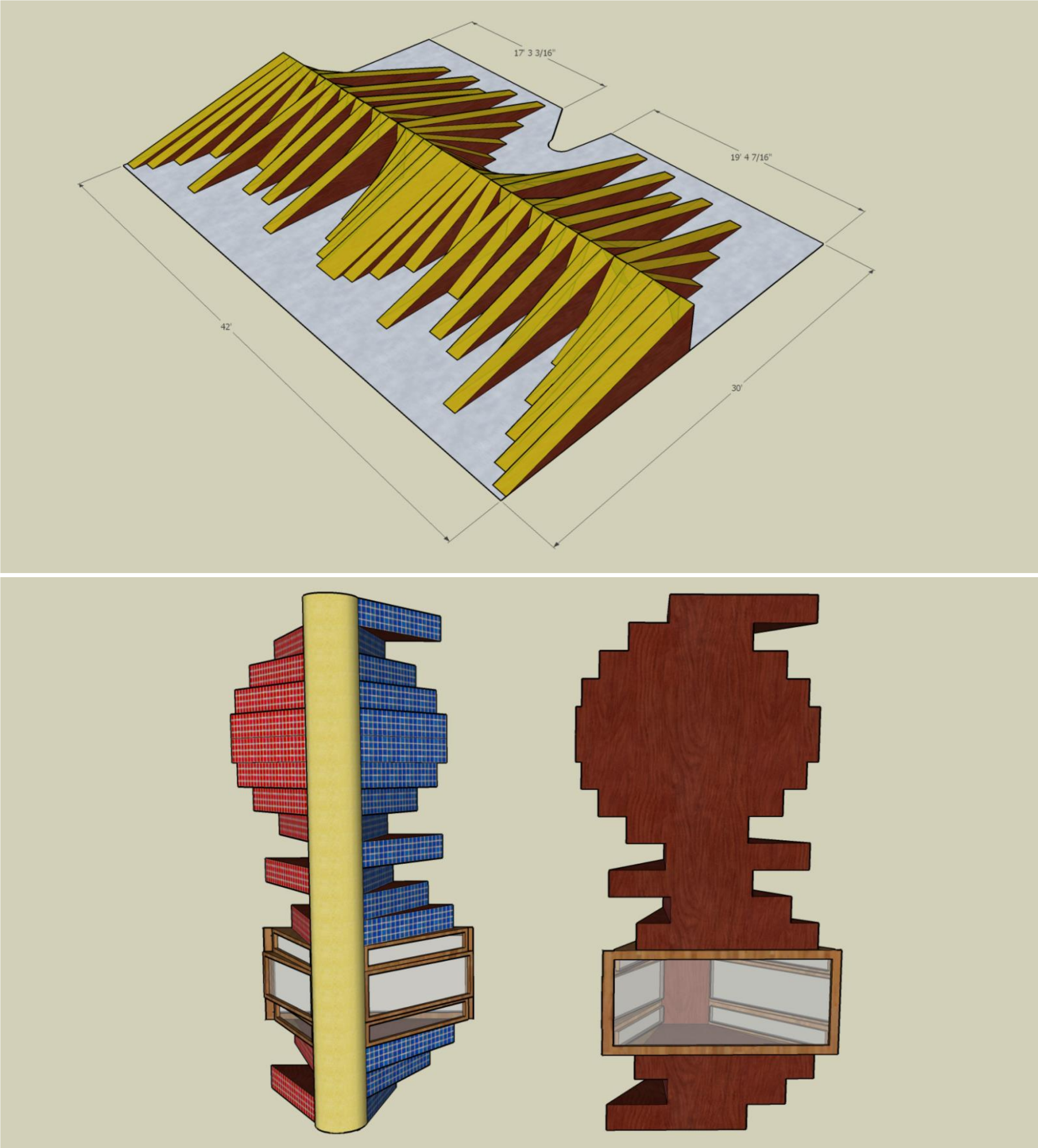




A.3: 2D renderings of the front wall (upper image) and rear wall (lower image). The walls are aligned such that the room left is at the left side of the page (the lower image is the horizontal mirror of what it should be). The proportions within each image are accurate; however, the two images are not equally scaled. Note that red tiles on the front wall face black tiles on the rear wall.



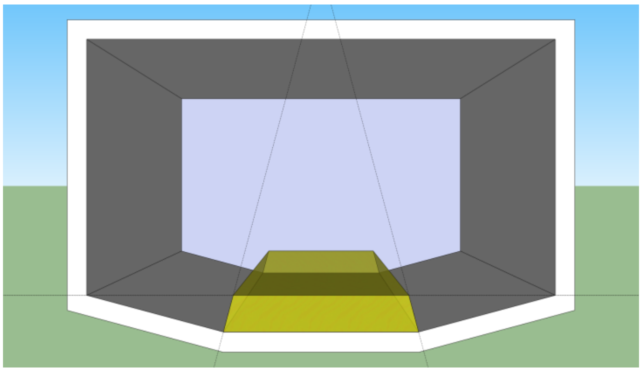
A.4: An exploded view of the (as seen from left to right) left wall, left N31 AQRSS, floor, right N31 AQRSS, and right wall. Dotted lines define the area of the walls and floor where the AQRSS attach. Note that the left and right AQRSS are oriented differently, and that the red tiles on the right wall face black tiles on the left wall.



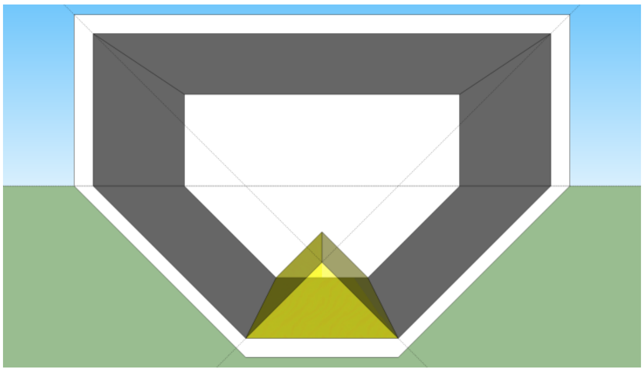
A.5: 3D renderings of the ceiling (above) and the front and rear views of the AQRSS N19 (below). Note that the ceiling features a standard AQRSS N43 and an inverted AQRSS N43. The window at the rear of the AQRSS N19 is intended to face a control room window.

Appendix B: Reflection Free Zone Comparison

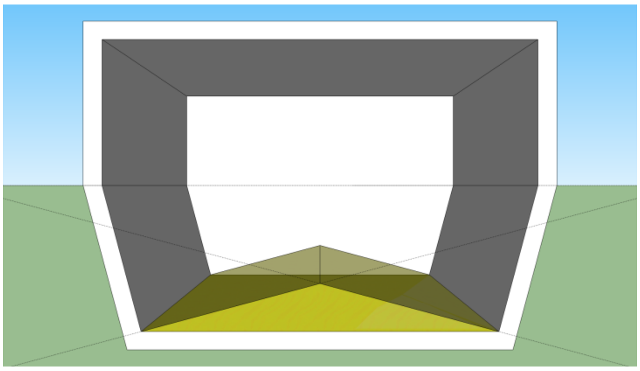
Note: Dotted lines indicate a 90˚ angle to the surface (the angle of the normal) and therefore, the angle at which a sound source and receiver of similar height could exchange a direct reflection from the wall.



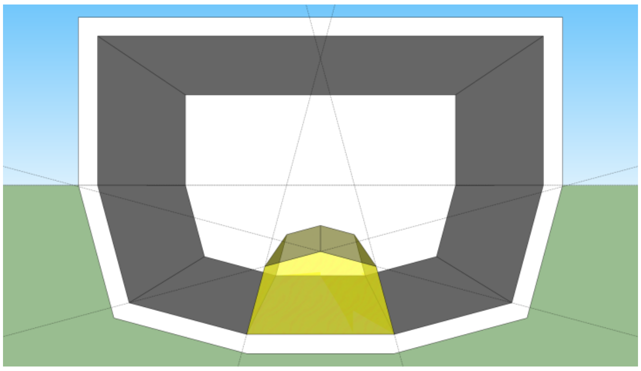
B.1: Google SketchUp rendering of boundary walls with a 30˚ slope



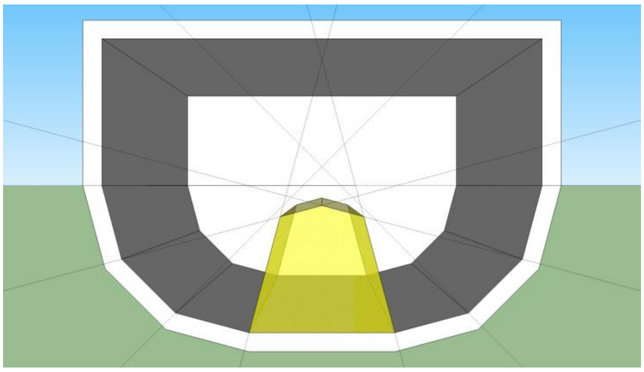
B.2: Google SketchUp rendering of boundary walls with a 45˚ slope



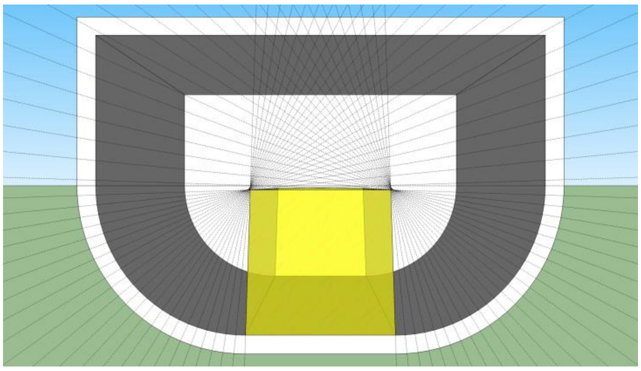
B.3: Google SketchUp rendering of boundary walls with a 60˚ slope



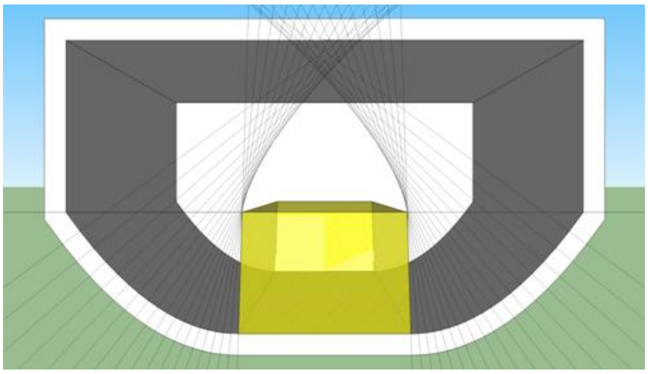
B.4: Google SketchUp rendering of boundary walls with 60˚ and 30˚ slopes



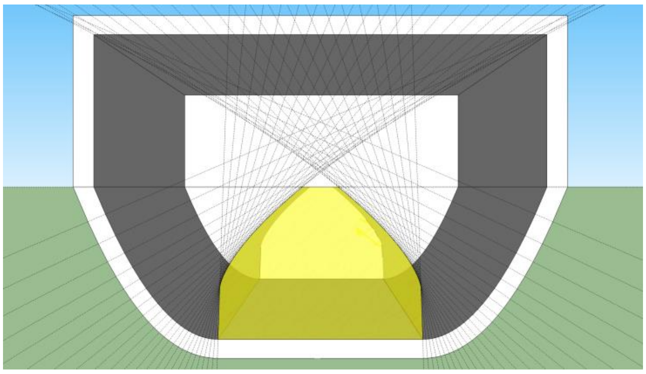
B.5: Google SketchUp rendering of boundary walls with 60˚, 45˚, and 30˚ slopes



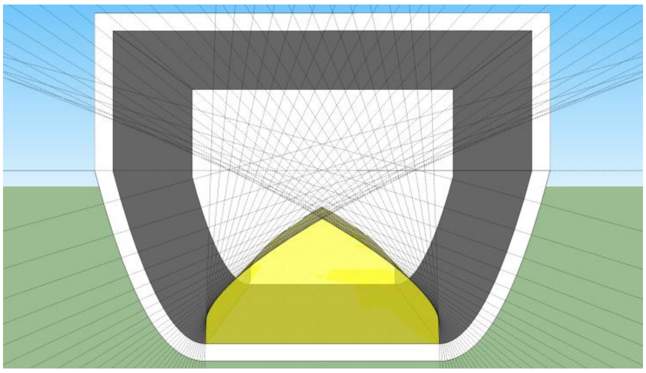
B.6: Google SketchUp rendering of boundary walls circular a slope



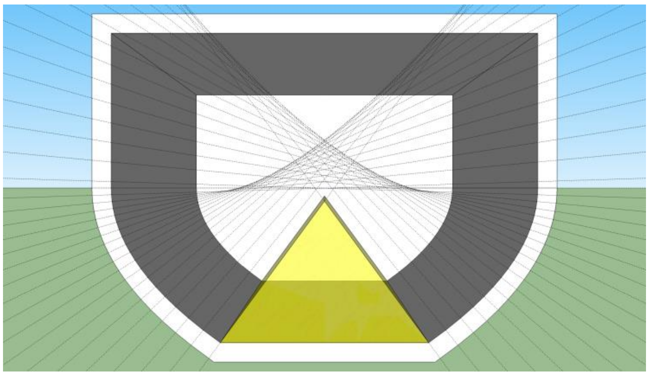
B.7: Google SketchUp rendering of boundary walls with a parabolic slope ($y = \frac{1}{2}x^2$)



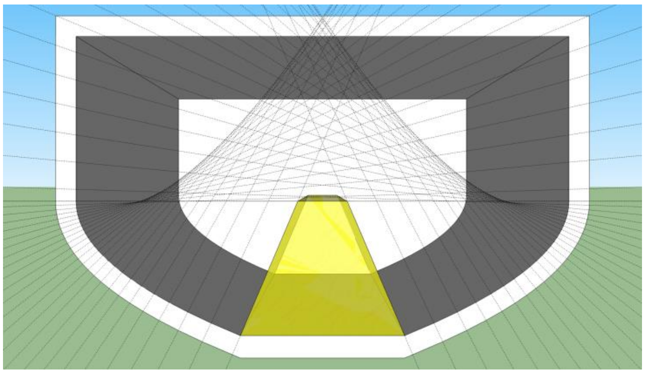
B.8: Google SketchUp rendering of boundary walls with a parabolic slope ($y = x^2$)



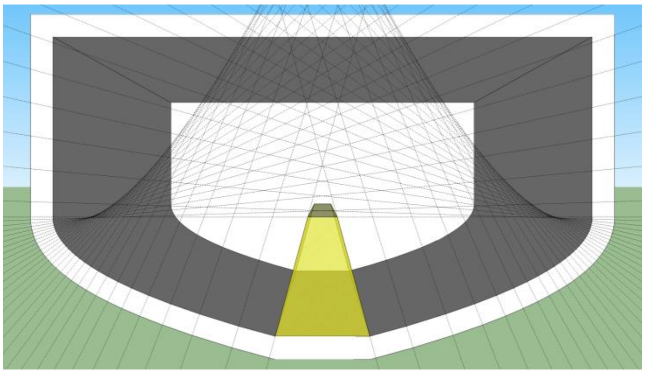
B.9: Google SketchUp rendering of boundary walls with a parabolic slope ($y = 2x^2$)



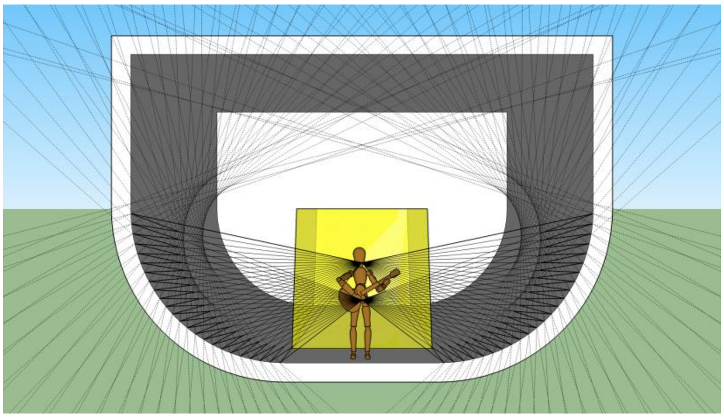
B.10: Google SketchUp rendering of boundary walls with a parabolic slope ($x = \frac{1}{2}y^2$)



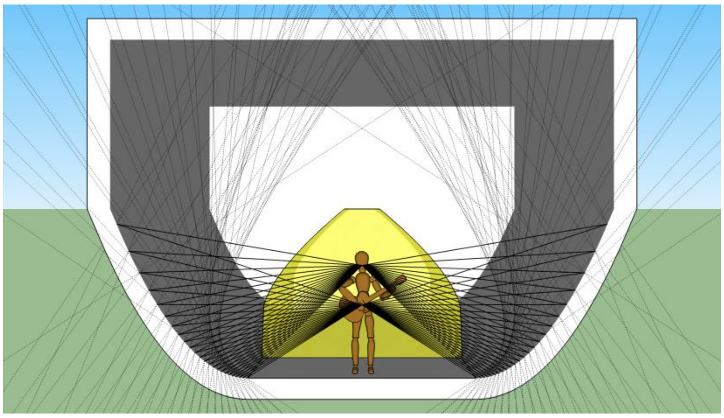
B.11: Google SketchUp rendering of boundary walls with a parabolic slope ($x = y^2$)



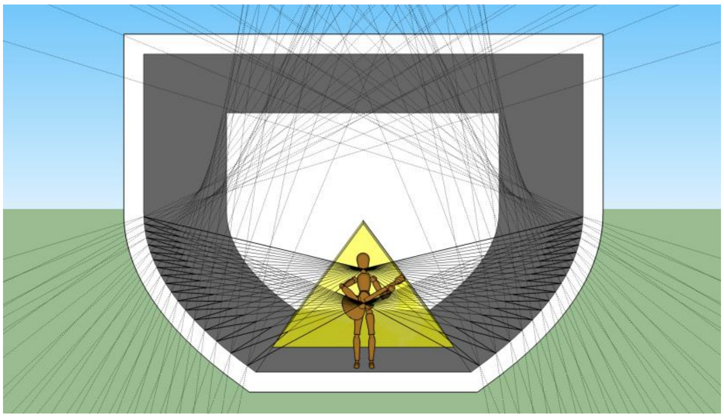
B.12: Google SketchUp rendering of boundary walls with a parabolic slope ($x = 2y^2$)



B.13: Google SketchUp rendering of the absolute first reflections against boundary walls with a circular slope

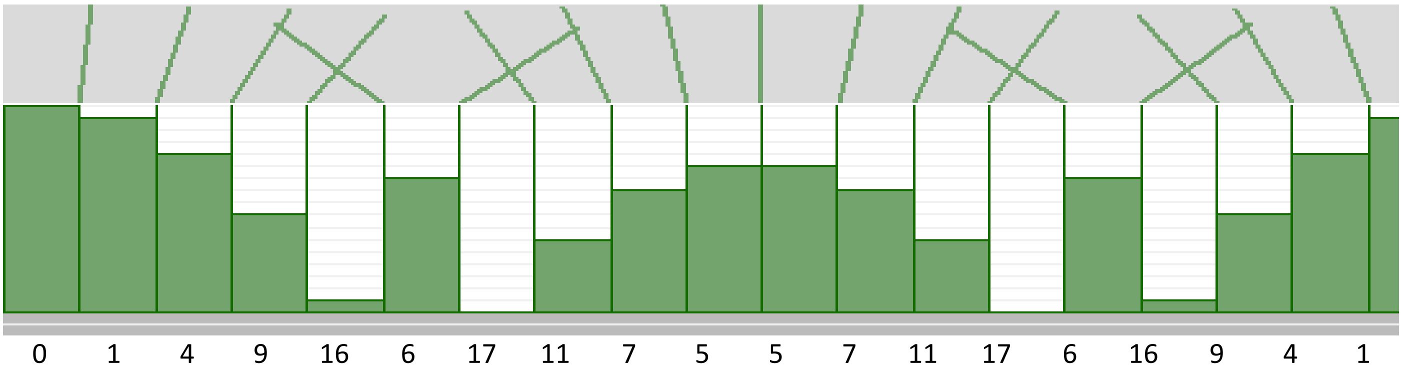


B.14: Google SketchUp rendering of the absolute first reflections against boundary walls with a parabolic slope ($y = x^2$)

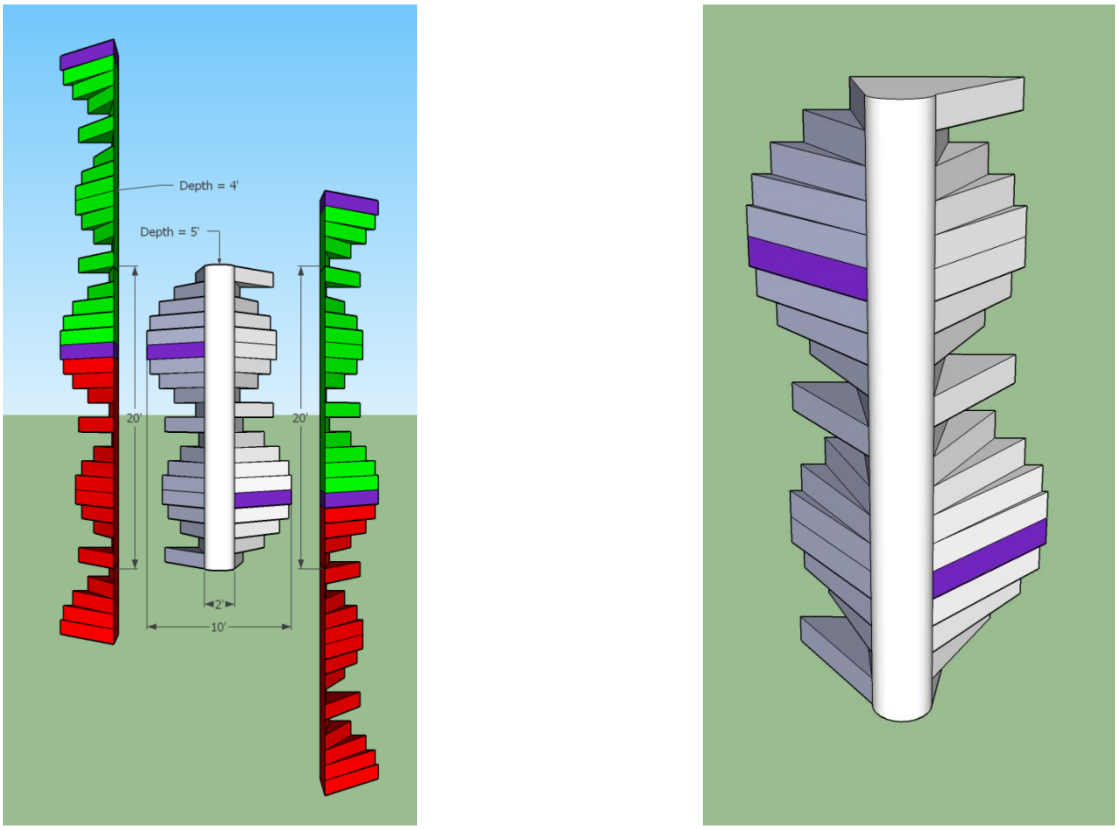


B.15: Google SketchUp rendering of the absolute first reflections against boundary walls with a parabolic slope ($x = \frac{1}{2}y^2$)

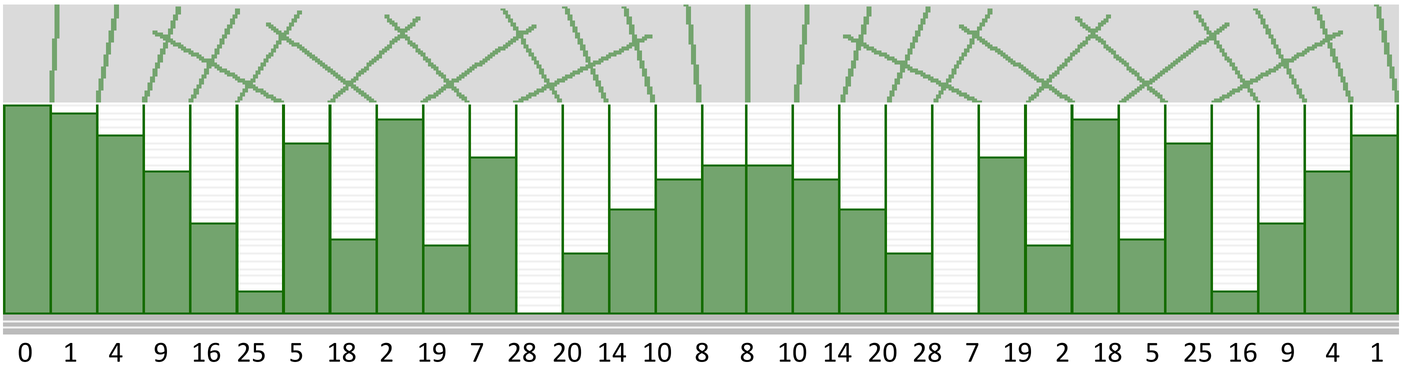
Appendix C: Angular Quadratic Residue Scattering System (AQRSS)



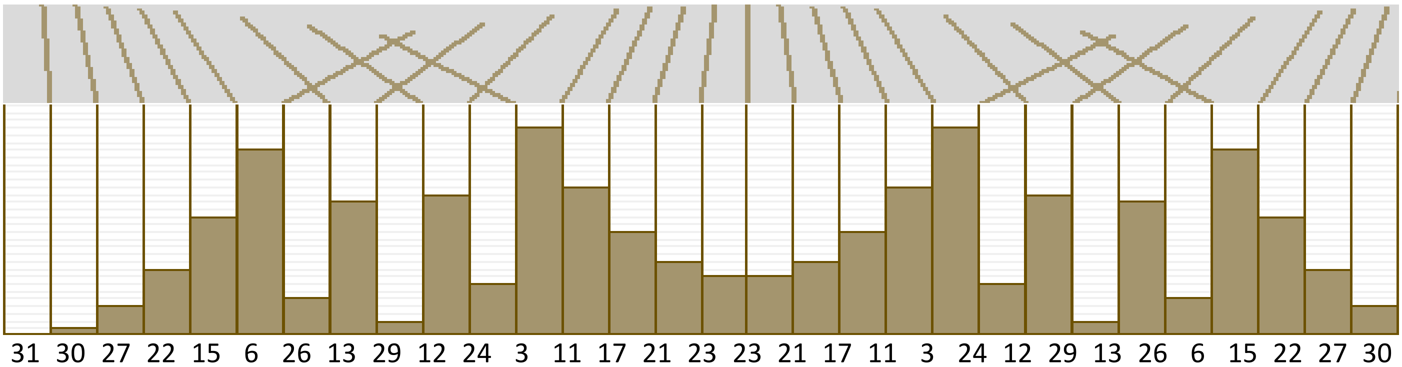
C.1: Standard Prime N19 Quadratic Redisue Sequence (QRDude 2010).



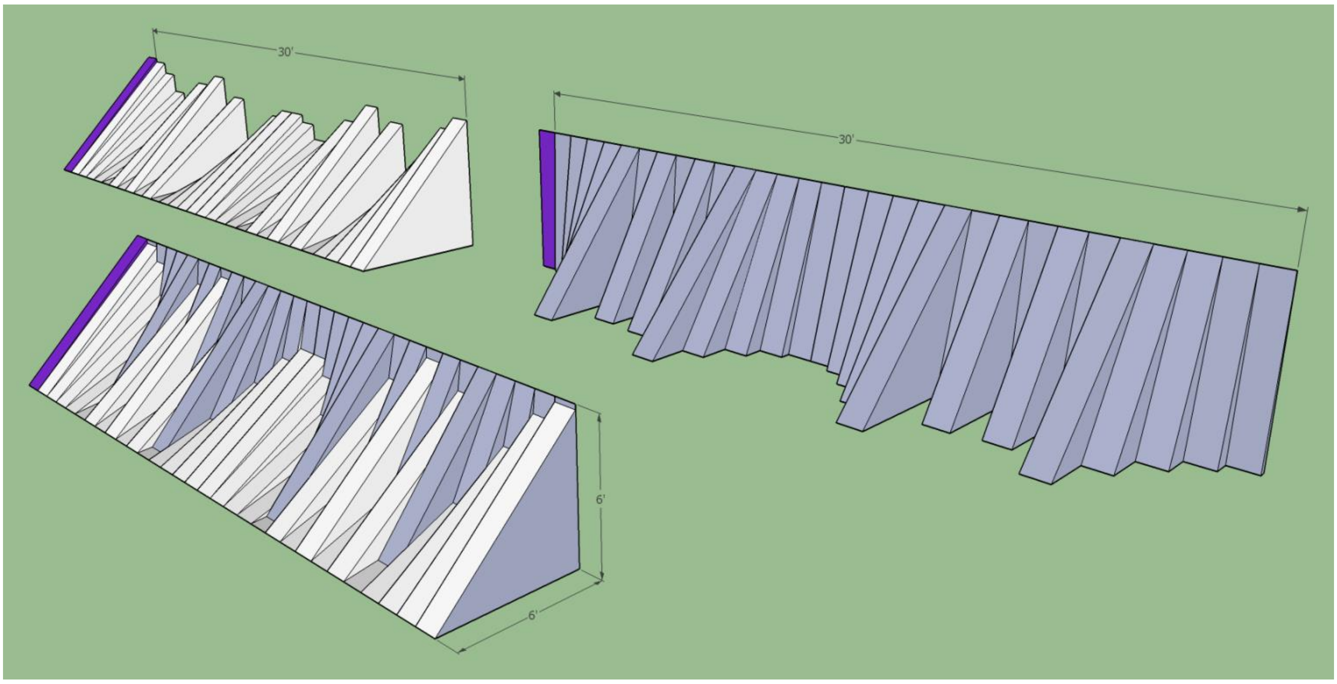
C.2: Google SketchUp rendering of the N19 Angular Quadratic Residue Scatting System (AQRSS) to be mounted vertically on a wall. Red and green signify a complete period of the N19 sequence. Purple indicates the added tile (not part of an N19 numeric sequence). Dimensions as described in the image: AQRSS depth 4’, cylindrical addition depth 1’, total depth 5’, total height : 20’, total width: 10’, cylindrical addition width: 2’.



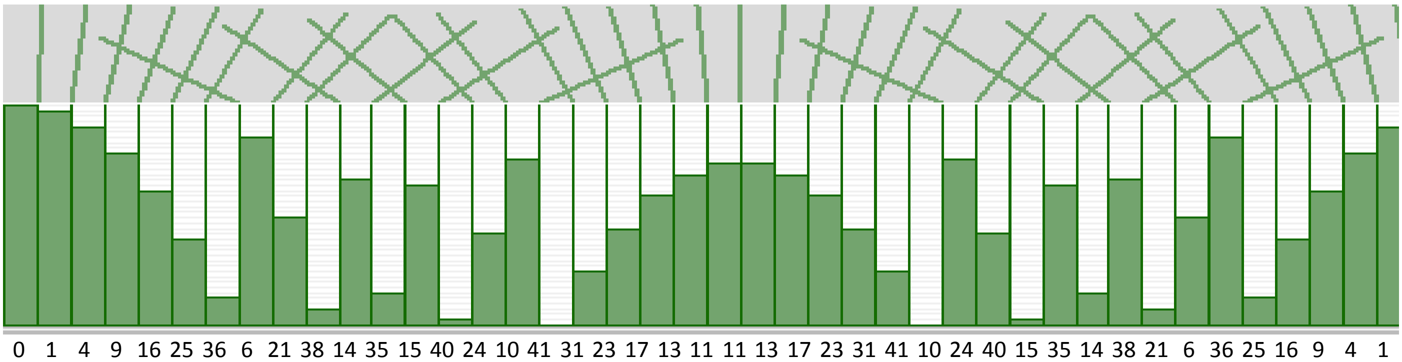
C.3: Standard Prime 31 Quadratic Redisue Sequence (QRDude 2010).



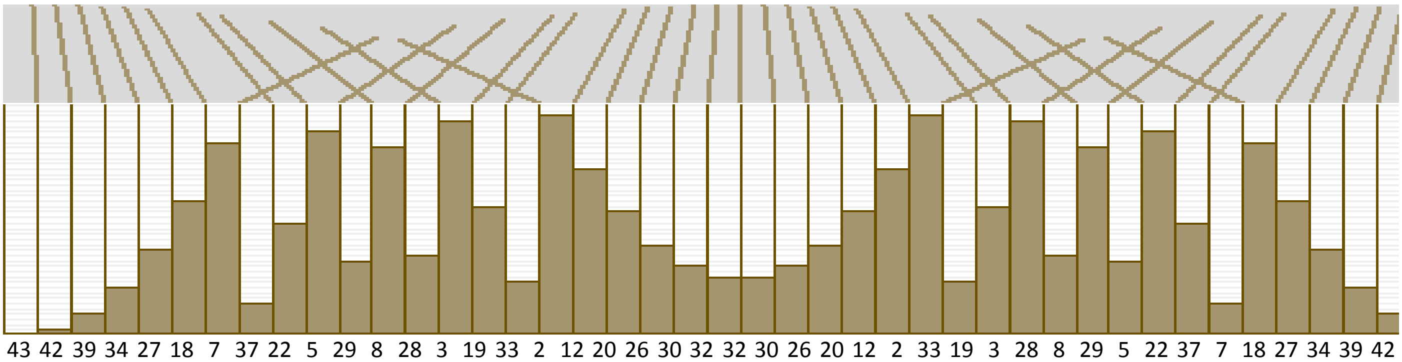
C.4: Inverted Prime 31 Quadratic Residue Sequence (QRDude 2010).



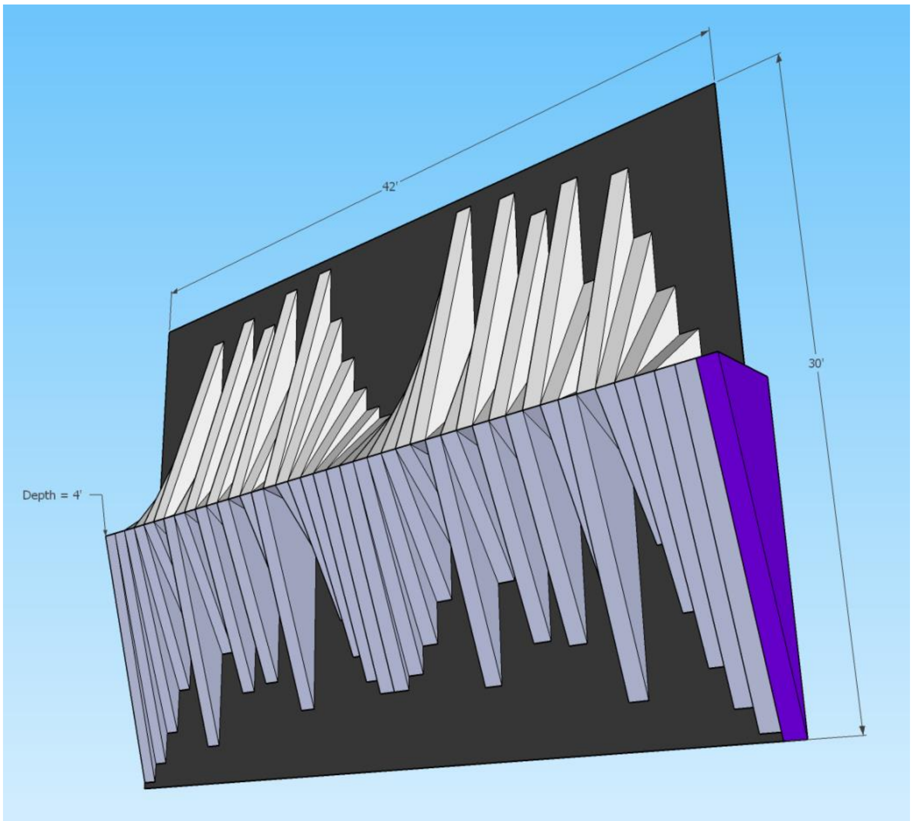
C.5: Google SketchUp rendering of the N31 Angular Quadratic Residue Scatting System (AQRSS) to be mounted horizontally on the floor along two room boundaries. Leftmost is the standard Prime 31 sequence, rightmost is the inverted Prime 31 sequence, and center is the superposition of the two. Purple indicates the omitted tile (part of the N31 numeric sequence but omitted). Dimensions as described in the image: width 30', height 6', depth 6'.



C.6: Standard Prime 43 Quadratic Redisue Sequence (QRDude 2010).



C.7: Inverted Prime 43 Quadratic Redisue Sequence (QRDude 2010).



C.8: Google SketchUp rendering of N43 Angular Quadratic Residue Scatting System (AQRSS) to be mounted horizontally on the ceiling (perpendicular to orientation shown). Above is the inverted Prime 43 sequence and below bottom is the standard Prime 43 sequence. Black indicates the ceiling area. Purple indicates the omitted tile (part of the N43 numeric sequence but omitted). Dimensions as described in the image: depth 4’, length 42’, and width 30’.

Appendix D: Room Mode Calculations

c = 340 m/s
l = 12.8 m
w = 9.14 m
h = 6.1 m

Volume = $l * w * h$
= 12.8 * 9.14 * 6.1
= 713.65 m³

Surface Area = $2(lw) + 2(wh) + 2(lh)$
= 2(116.99) + 2(55.75) + 2(78.08)
= 233.98 + 111.5 + 156.16
= 501.64 m²

$f_{critical}$ $= 1.5\,\frac{c}{\frac{4V}{S}}$

$= 1.5\,\frac{340}{(4*713.65) \div 501.64}$

$= 1.5\,\frac{340}{2854.6 \div 501.64}$

= 1.5 * 340 / 5.69

= 1.5 * 59.7

= 89.6 Hz

$f_{Length\ Axial}$ = $c/2l$
= 340 / 2(12.8)
= 13.28 Hz

$f_{Width\ Axial}$ = $c/2w$
= 340 / 2(9.14)
= 18.6 Hz

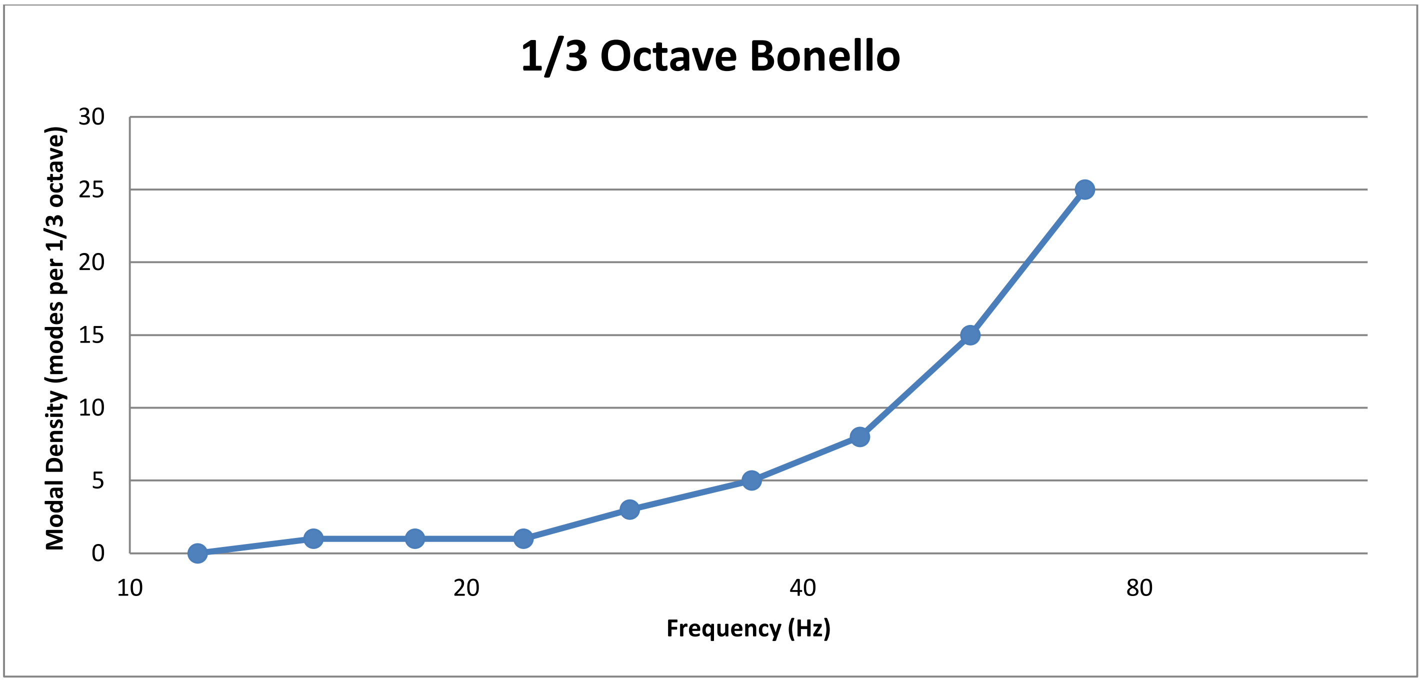
$f_{Height\ Axial}$ = $c/2h$
= 340 / 2(6.1)
= 27.9 Hz

D.1: The calculated volume, surface area, critical frequency, and fundamental axial modes of the room.

$$Frequency = \frac{c}{2}\sqrt{\frac{p^2}{L^2} + \frac{q^2}{W^2} + \frac{r^2}{H^2}}$$

where L, W, H = room length, width, and height in meters
p, q, r = integers {0, 1, 2, 3…}
c = the speed of sound in meters

D.2: This formula, as described by Everest, is used to derive the frequencies of all axial, tangential, and oblique modes represented in figure **D.4** (2009: 230).

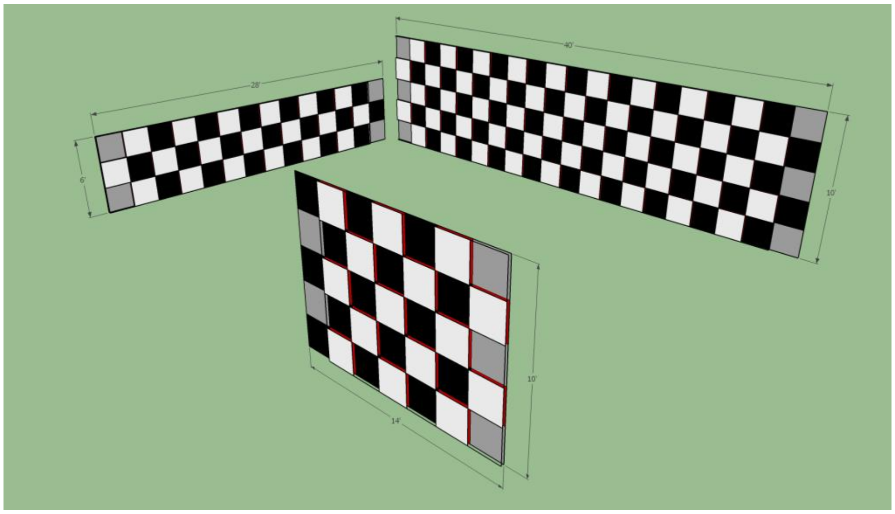


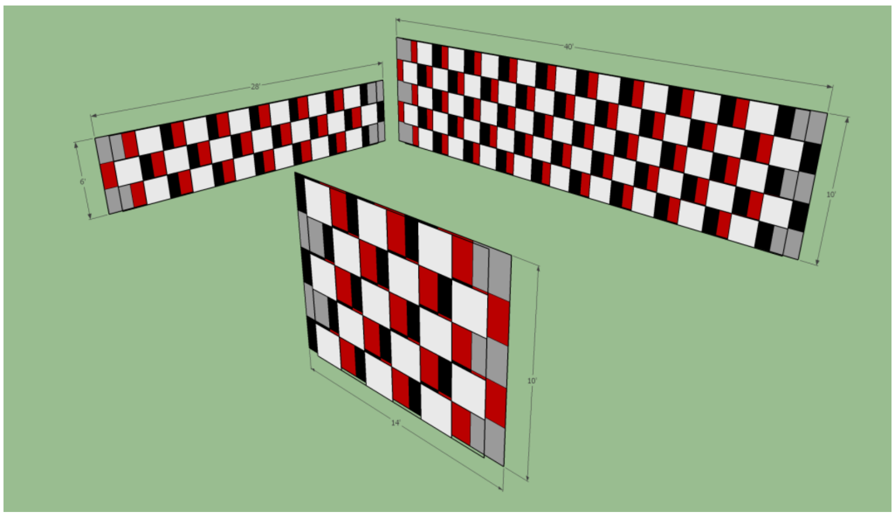
D.3: The modal frequencies represented in figure **D.3** were counted and plotted on this Bonello graph to represent the modal density of the room at each third octave band between 10 Hz and 100Hz (below the room's lowest axial mode of 13.3 Hz and above the room's critical frequency of 89.6 Hz).

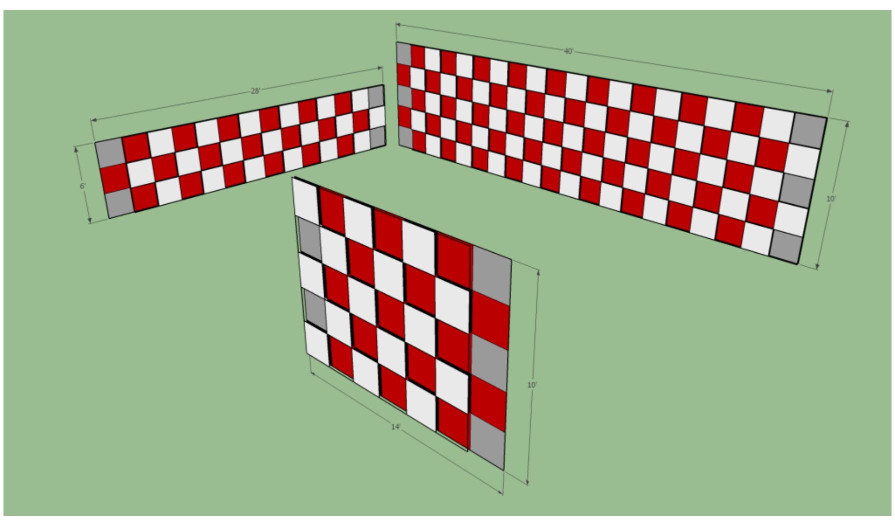
p	q	r	Frequency	Mode Type	p	q	r	Frequency	Mode Type
1	0	0	13.5	Axial	4	0	2	78	Tangential
0	1	0	18.8	Axial	4	3	0	78	Tangential
1	1	0	23.1	Tangential	3	2	2	79	Oblique
2	0	0	26.9	Axial	0	3	2	79.9	Tangential
0	0	1	28.3	Axial	2	4	0	80	Tangential
1	0	1	31.3	Tangential	4	1	2	80.3	Oblique
2	1	0	32.8	Tangential	0	4	1	80.5	Tangential
0	1	1	34	Tangential	6	0	0	80.7	Axial
1	1	1	36.5	Oblique	1	3	2	81	Oblique
0	2	0	37.7	Axial	1	4	1	81.6	Oblique
2	0	1	39	Tangential	5	2	1	82.1	Oblique
1	2	0	40	Tangential	6	1	0	82.9	Tangential
3	0	0	40.4	Axial	4	3	1	83	Oblique
2	1	1	43.3	Oblique	2	3	2	84.3	Oblique
3	1	0	44.5	Tangential	0	0	3	84.8	Axial
2	2	0	46.3	Tangential	2	4	1	84.8	Oblique
0	2	1	47.1	Tangential	3	4	0	85.5	Tangential
1	2	1	49	Oblique	6	0	1	85.5	Tangential
3	0	1	49.3	Tangential	1	0	3	85.8	Tangential
3	1	1	52.7	Oblique	4	2	2	86.6	Oblique
4	0	0	53.8	Axial	0	1	3	86.8	Tangential
2	2	1	54.2	Oblique	6	1	1	87.6	Oblique
3	2	0	55.2	Tangential	5	0	2	87.8	Tangential
0	0	2	56.5	Axial	5	3	0	87.8	Tangential
0	3	0	56.5	Axial	1	1	3	87.9	Oblique
4	1	0	57	Tangential	2	0	3	88.9	Tangential
1	0	2	58.1	Tangential	6	2	0	89.1	Tangential
1	3	0	58.1	Tangential	3	3	2	89.5	Oblique
0	1	2	59.6	Tangential	5	1	2	89.8	Oblique
4	0	1	60.8	Tangential	3	4	1	90	Oblique
1	1	2	61.1	Oblique	2	1	3	90.9	Oblique
3	2	1	62	Oblique	5	3	1	92.3	Oblique
2	0	2	62.6	Tangential	4	4	0	92.6	Tangential
2	3	0	62.6	Tangential	0	2	3	92.7	Tangential
0	3	1	63.2	Tangential	6	2	1	93.4	Oblique
4	1	1	63.6	Oblique	1	2	3	93.7	Oblique
1	3	1	64.6	Oblique	3	0	3	93.9	Tangential
2	1	2	65.4	Oblique	0	5	0	94.2	Axial
4	2	0	65.7	Tangential	7	0	0	94.2	Axial
5	0	0	67.3	Axial	0	4	2	94.2	Tangential
0	2	2	67.9	Tangential	1	4	2	95.1	Oblique
2	3	1	68.7	Oblique	1	5	0	95.1	Tangential
1	2	2	69.2	Oblique	5	2	2	95.6	Oblique
3	0	2	69.4	Tangential	3	1	3	95.7	Oblique
3	3	0	69.4	Tangential	7	1	0	96	Tangential
5	1	0	69.8	Tangential	4	3	2	96.3	Oblique
4	2	1	71.5	Oblique	2	2	3	96.6	Oblique
3	1	2	71.9	Oblique	4	4	1	96.8	Oblique
5	0	1	73	Tangential	2	5	0	97.9	Tangential
2	2	2	73	Oblique	2	4	2	97.9	Oblique
3	3	1	75	Oblique	0	5	1	98.3	Tangential
0	4	0	75.3	Axial	7	0	1	98.3	Tangential
5	1	1	75.3	Oblique	6	0	2	98.5	Tangential
1	4	0	76.5	Tangential	6	3	0	98.5	Tangential
5	2	0	77.1	Tangential	1	5	1	99.2	Oblique

D.4: A table describing the axial, tangential, and oblique modes of designed room. The frequencies of the axial modes are highlighted in yellow. The columns *p, q,* and *r* are described in the formula in figure **D.2**. The chart was generated by a room mode calculator obtained online (Brandt 2010).

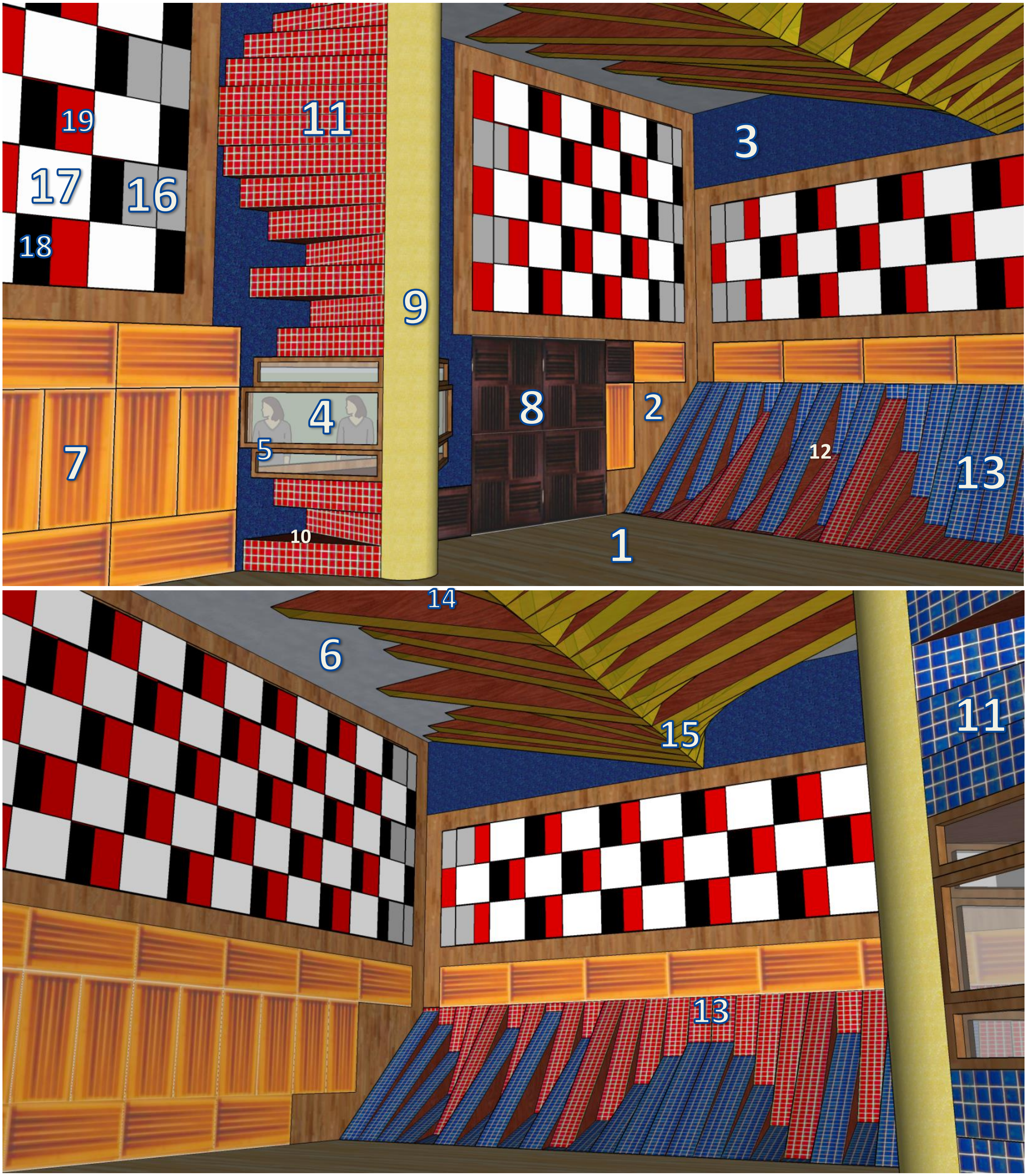
Appendix E: Surface Treatments







E.1: The sliding panels of the variable acoustic system. The black position (top image) maximizes the length of reverberation time, the midway position (middle image) moderates the length of reverberation time, and the red position (bottom image) minimizes reverberation time.

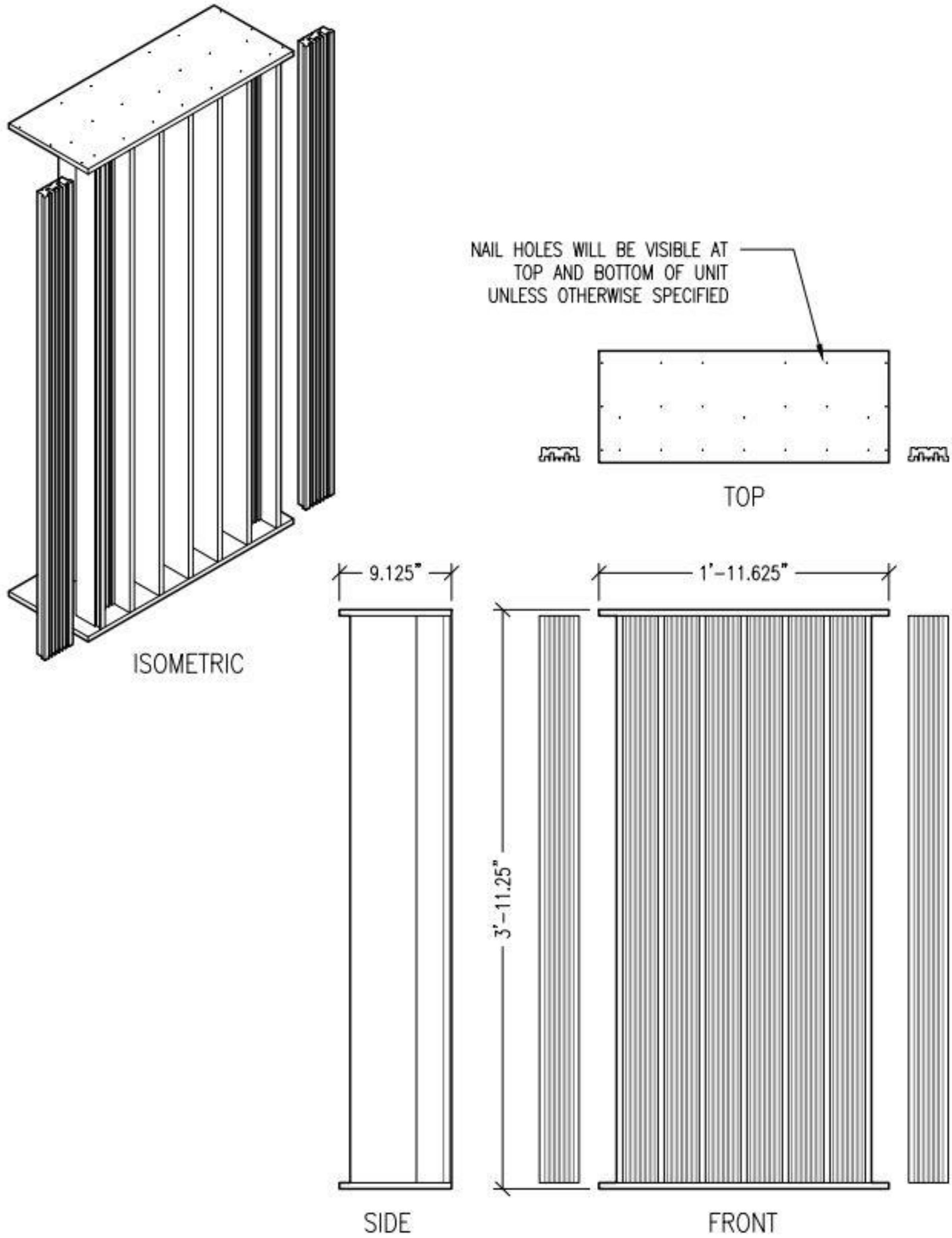


E.2: The textures in these Google SketchUp renderings are numbered for reference with figure **E.2.** Note that 13 and 11 occur on both red and blue textures: these materials are the same. Otherwise, all components are represented by one texture.

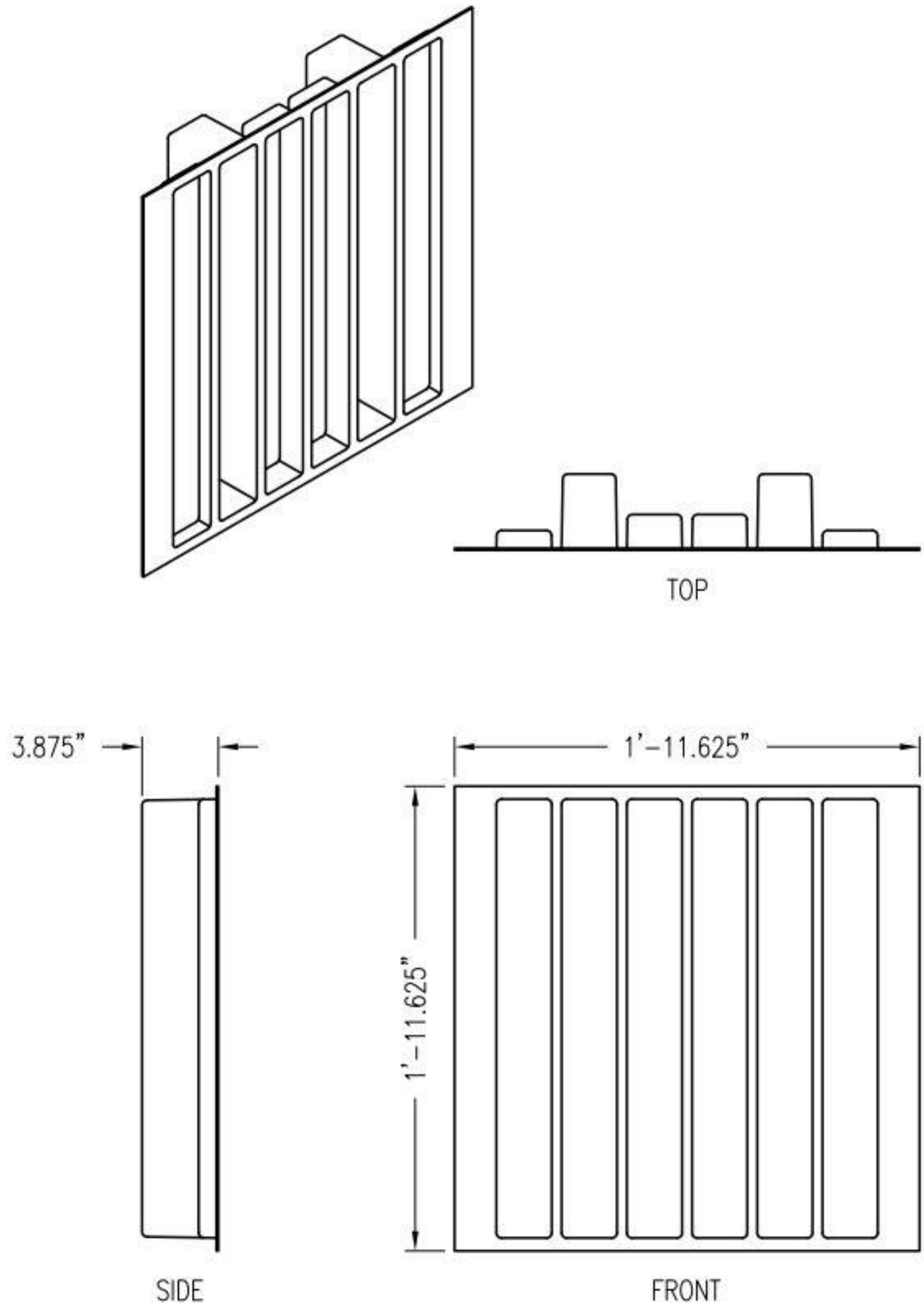
E.3: Live Room Design Reverberation Time Data Sheet

	COMPONENT (SEE E.1)	AREA (M²)	MATERIAL	125	250	500	1000	2000	4000	SRC.
1	Floor	82.1	Wooden floor on joists	0.15	0.11	0.10	0.07	0.06	0.07	4
2	Wall (Reflective)	42.83	Wood boards on joists or battens	0.15	0.20	0.10	0.10	0.10	0.10	1
3	Wall (Absorbent)	22.3	Glass wool 25mm 16 kg/m3	0.12	0.28	0.55	0.71	0.74	0.83	1
4	Window	5.46	Double glazing, 2-3mm glass, 10mm air gap	0.15	0.05	0.03	0.03	0.02	0.02	1
5	Window Trim	3.02	Hardwood, mahogany	0.19	0.23	0.25	0.30	0.37	0.42	1
6	Ceiling (Absorbent)	57.03	0.8mm perforated metal tiles 2mm diameter holes 29440/m2. 13% open area backed with 25mm thick resin-bonded fibreglass slab. No airspace.	0.10	0.30	0.60	0.75	0.80	0.80	1
7	RPG Diffractal (2' x 4' x 60 units)	44.59	RPG Diffractal	0.23	0.24	0.35	0.23	0.2	0.2	3
8	RPG Formedfussor (2' x 2' x 18 units)	6.69	RPG Formedfussor	0.53	0.37	0.38	0.32	0.15	0.18	3
9	Polycylindrical diffuser	5.82	3-4mm plywood, 75mm cavity containing mineral wool	0.5	0.3	0.1	0.05	0.05	0.05	
10	AQRSS N19 Sides	6.1	Wood boards on joists or battens	0.15	0.20	0.10	0.10	0.10	0.10	1
11	AQRSS N19 Faces	13.86	Ceramic tiles with smooth surface	0.01	0.01	0.01	0.02	0.02	0.02	2
12	AQRSS N31 Sides	15.2	Wood boards on joists or battens	0.15	0.20	0.10	0.10	0.10	0.10	1
13	AQRSS N31 Faces	49.27	Ceramic tiles with smooth surface	0.01	0.01	0.01	0.02	0.02	0.02	2
14	AQRSS N43 Sides	72.04	12mm wood panelling on 25mm battens	0.31	0.33	0.14	0.10	0.10	0.12	1
15	AQRSS N43 Faces	68.86	6mm glass	0.10	0.06	0.04	0.03	0.02	0.02	5
16	Grey tiles (2' x 2' x 24 units)	8.92	Wood boards on joists or battens	0.15	0.20	0.10	0.10	0.10	0.10	1
17	White tiles (2' x 2' x 115 units)	42.74	RPG Golden Pyramid	0.39	0.19	0.1	0.1	0.08	0.14	3
18	Black tiles(2' x 2' x 115 units)	42.74	Ceramic tiles with smooth surface	0.01	0.01	0.01	0.02	0.02	0.02	2
19	Red tiles (2' x 2' x 115 units)	42.74	Glass wool 100mm, 33 kg/m3	0.53	0.92	1.00	1.00	1.00	1.00	1
	BASIC VOLUME (M³)	713.58	**(BLACK) TOTAL SABINES**	96.7	99.97	99.82	101.07	99.91	107.1	
	DIFFUSER VOLUME (M³)	70.36	**(RED) TOTAL SABINES**	118.92	138.86	142.13	142.95	141.79	148.98	
	NET VOLUME (M³)	643.22								**AVERAGE↓**
			(BLACK) REVERB TIME (SECONDS)	1.07	1.04	1.04	1.02	1.04	0.97	1.03
	SOURCES		**(RED) REVERB TIME (SECONDS)**	0.87	0.75	0.73	0.72	0.73	0.7	0.75

1 Original figures from Building Bulletin 51 published in 1976
2 Odeon
3 RPG Acoustical Data specifications sheet
4 Ingerslev, Copenhagen 1949 (Odeon)
5 Lord & Templeton



E.4: RPG Diffractal 2’ x 4’ double layer fractal of 1 dimensional Quadratic Residue Diffusers to be mounted in an array both horizontally and vertically along the exposed walls of the ground level (RPG 2013).



E.5: RPG Formedffusor 2’ x 2’ 1 dimensional Quadratic Residue Diffuser to be mounted in a 4x4 grid of alternating orientations over the door (See figure E.3). Two are located next to the door (but not attached to the door) to compliment the Diffractal array (RPG 2013).

E.6: Example image of door-mounted Formedffusor array to be implemented on a double door (Montlick 2010).

E.7: RPG Golden Pyramid to be mounted on white tiles of the sliding acoustic panel array (RPG 2013).

References

Brandt, J. H. (2010) *Room Mode Calculator* [online] available from <http://www.gearslutz.com/board/studio-building-acoustics/473500-new-improved-room-mode-calculators-more.html> [15 April 2013]

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RPG (2013) *RPG Diffuser Systems Inc.* [online] available from <http://www.rpginc.com> [5 April 2013]