Architectural, Acoustic, and Audio System Design for the Modern Music Production Studio

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Final Project

JStudio

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Contents

1 Project Objective

JStudio is conceived a conceptual recording studio, loosely based on the idea of a ”dream” studio for Jon South, an aspiring acoustician, and his partner, a contemporary classical composer, located in Melbourne, Australia. Design constraints, particularly budget, are not heavily considered, though design choices are generally rooted in reality and an opportunity to develop skills in acoustic design.

2 Program

2.1 Musical

JStudio will cater to the rehearsal, performance, recording and mixing of

- Piano, preferably a grand piano.
- Acoustic instrument, violin, guitar, saxophone.
- Digital piano, MIDI, VST's
- Small classical chamber music ensembles
- More typical 4-5 piece bands.

The above core musical needs should integrate smoothly with the workflow of a composer - using physical and virtual instruments to compose a piece, notate in software, mix and master accompaniments and performances.

2.2 Technical

It is suitable to work primarily in-the-box, with little need for large channel count mixers or rack gear - 32/8 I/O would be suitable, with an optional 8-16 channel control surface for physical DAW control.

Stereo near field monitors is the preffered setup, though the option for surround sound in the future would be idea. A large visual monitor or projection screen might be incorporated into the control room and/or live rooms to facilitate composition for film.

2.3 Social

JStudio would be a standalone construction located on owner-occupied residential premises. The studio is not expected to be a hugely commercial venture, and any third-party use of the space would be from personally known, or closely vetted musicians. As such, the facilities of the residential premises would be available for the studio, such as bathrooms, kitchens, lounges, outdoor areas and gardens. This means the studio floor area can be entirely dedicated to musical requirements.

Hours of use for the studio would be nominally day and evening times, but the possibility for late night sessions exists and should be appropriately designed for.

2.4 Auxiliary

In addition to musical uses, Jon would benefit from from a small lab/workshop space that could be integrated into the broader construction of the studio. The space would be similar to a ”maker space”, housing electrical test equipment, and a variety of small hand tools. Noise transmission between the workshop and studio would be a consideration, but could easily managed with social solutions and scheduling.

2.5 Programming Summary

- Primary spaces would be seperate Live Room and Control Room
- Live room large enough for up to 5-6 musicians + Grand piano
- Control Room large enough for mix engineer + 1-2 extras.
- Control Room workspaces prioritise functionality for a composer.

3 Siting

No specific site is considered for this project, but generally would be located in the outer suburbs of Melbourne (Figure 1). These suburbs are typified by the feeling of "getting out of the city", with lush, mountainous landscapes and green spaces (Figure 2.

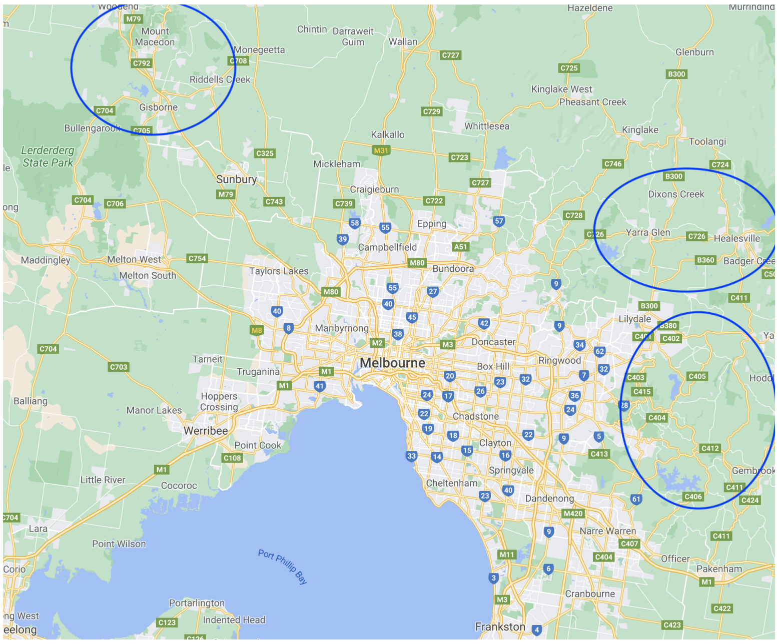


Figure 1: General site location, Greater Melbourne Area.

Figure 2: Typical view aspect from the site.

Nominal lot size (residential + studio) would be 800-1000m^2, with the studio able to be for purpose, slab-on-grade construction. The neighbourhood would be quiet residential, with nearest neighbours anywhere from 20-100m away.

The site would potentially be nearby a railway. Aircraft noise is not likely to be a concern, and nearby road traffic would be light. There may be some light commercial or agricultural activities to take into account, but isolation control would likely be concerned with noise nuisance from the studio itself.

Given the primarily personal use of JStudio, proximity to more central areas of Melbourne is not a huge concern, though large distances from arts and culture hubs are a potential negative for the Studio.

3.1 Siting Summary

- Single storey, slab-on-grade
- Leverage a view aspect
- Noise isolation must be considered to meet internal noise goals and maintain residential noise amenity.

4 Layout

Initial layouts were conceptualised using bubble diagrams, with JStudio consisting of 4 primary rooms/areas.

1. Control Room (CR)
2. Live Room (LR)
3. Isolation Booth and Sound Lock (Iso/SL)
4. Workshop

Four schemes were considered (other schemes shown in Appendix A), with the final choice of scheme, SK-4, summarised and shown in Figure 3 below. SK-4 was further sketched in plan, and to a rough scale to visualise layout and potential issues, shown in Figures 5 and 6.

- Pro's
  - LR Views
  - Symmetric/efficient use of glass in CR
  - CR/Workshop Adjacency
  - Inclusion of Store room
- Con's
  - No views from CR

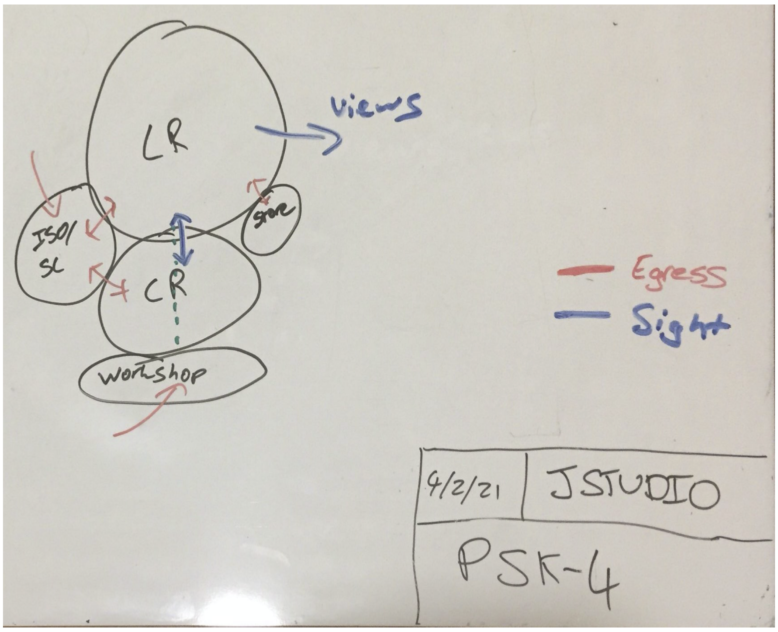


Figure 3: PSK-4.

After some review, it was noted the control room geometry was very square, and would lead to a poor low frequency room response. It was opted that the width be increased to achieve a better room ratio, and improve early reflection response. The increased width necessitated moving the workshop to the "southern" end of the CR.

4.1 Layout Summary

- Three acoustic spaces (LR, CR, ISO)
- Two auxilliary spaces (Workshop, Store)
- Revised CR geometry to avoid poor LF response.

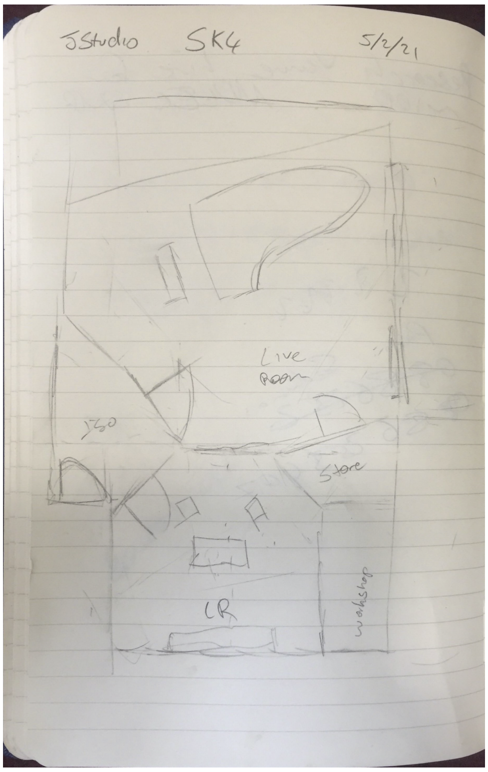


Figure 5: SK-4 concept sketch.

Figure 6: SK-4 scale sketch.

5 Isolation Acoustics

5.1 Noise Criterion Design Goals

- Control Room **NC 20** ideal, **NC≤ 25** acceptable.
- Live Room **NC 15** ideal, **NC≤ 20** acceptable.
- External to Studio **NC≤ 30** for general noise amenity.

5.2 Isolation Requirements

Isolation requirements for each partition element were found by source level analysis, with results shown in Figure 6.

Element	NIC/STC	Minimum Transmission Loss (dB), Frequency (Hz)																						
		50	62.5	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
Control Room Shell	41/51	13	15	26	21	24	26	28	31	33	35	40	39	43	45	45	43	43	43	44	44	44	45	45
Live Room Shell	47/57	19	29	30	32	39	43	45	45	44	44	48	47	48	50	50	48	46	46	45	44	45	44	43
Control to Live Partition	52/62	22	32	32	35	43	47	49	49	48	48	52	51	51	51	51	52	53	54	54	55	55	56	56

Figure 6: Required 1/3 octave TL, and approximate NIC/STC (STC=NIC+10).

Construction elements should be checked against 1/3 octave TL requirements, rather than quoted STC values to ensure performance exceeds requirements, particularly at extended low frequencies. In general, we strive for a conservative requirement of **STC≥60** for the CR and LR outer shell, and **STC≥65** for the CR to LR partition.

5.3 Slab/Floors

The slab shall be poured in three discontinuous forms, separated by neoprene stripping, with the split line shown in Figure 7

Any partitions and/or wall protrusions over the split lines shall be ensured discontinuous.

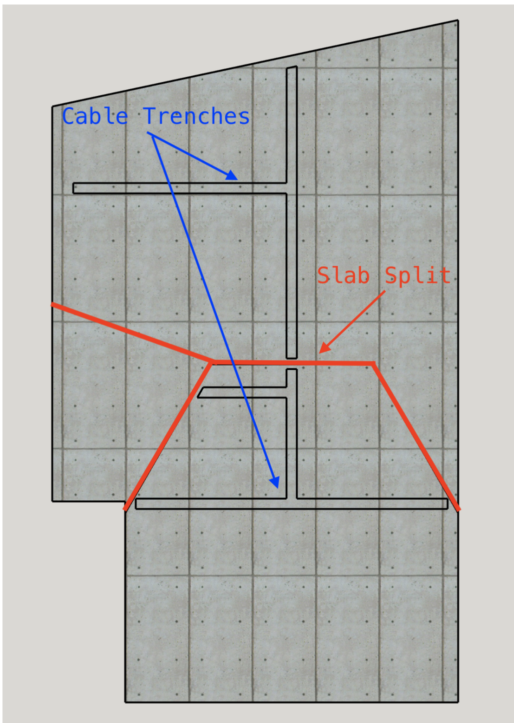


Figure 7: Slab contruction, split lines and trench location.

5.4 External Walls

The main external shell of the structure is opted as masonry construction, providing good LF isolation characteristics, and a solid structural shell for the studio.

Wall Type	Description
A	190mm (8") CMU, filled cavity, sealed and finished exterior, or masonry equivalent.

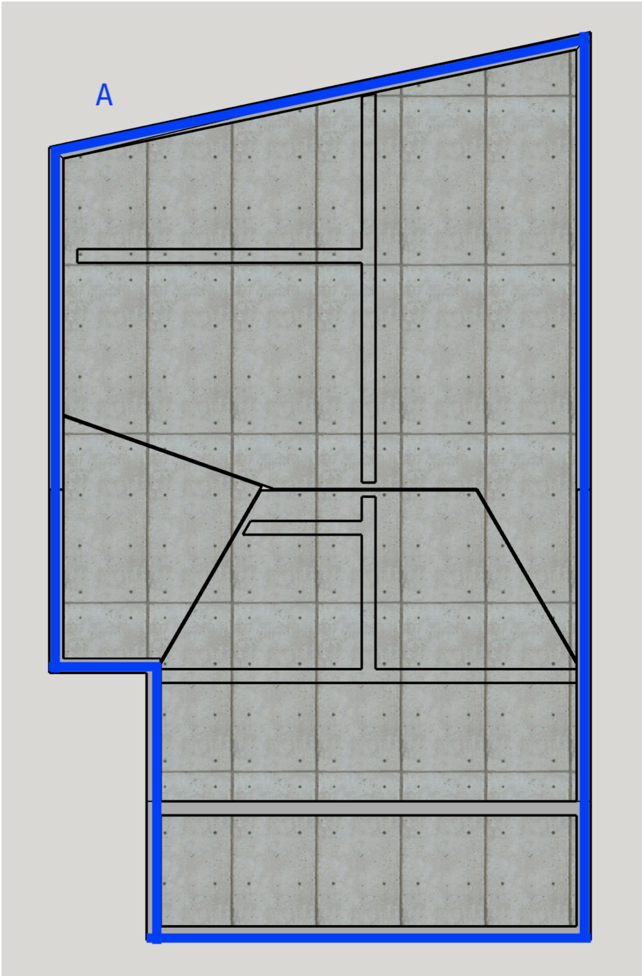


Figure 8: External wall markup.

5.5 Inner Shell Walls

Each of the three acoustically isolated spaces should consist of an internal shell, decoupled from the structural masonry walls.

Wall Type	Description
B	Metal stud, 120mm depth, fibreglass insulation in cavity Resilient channel mount 13mm GWB, 10mm plywood, 16mm GWB, non-hardnening mastic between layers.

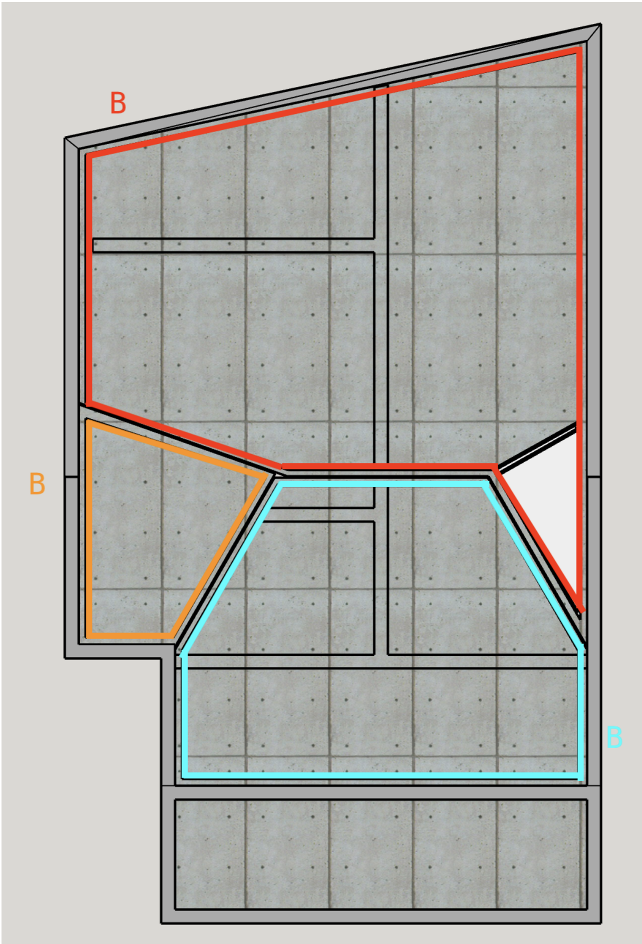


Figure 9: Inner shell markup.

5.6 Ceilings

The primary external ceiling will be supported on structural members between the masonry walls. If possible, inner ceiling construction should be lidded style construction, ensuring the inner shell walls meet loading requirements.

Ceiling Type	Description
C	Lidded construction Joists between inner shell walls Fibreglass insulation in cavity Furring channel 13mm plywood, 16mm GWB, non-hardnening mastic between layers.

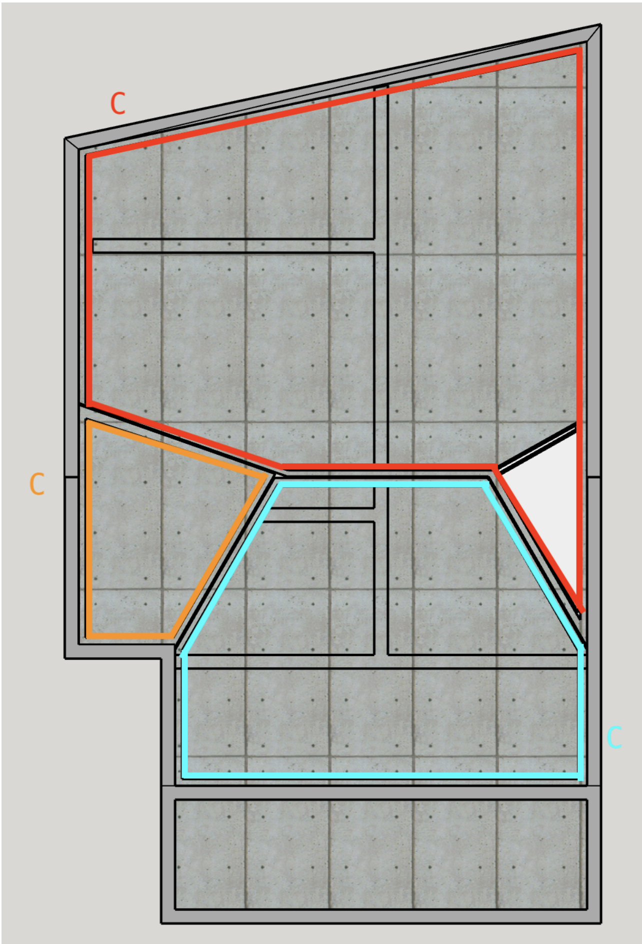


Figure 10: Ceiling markup.

5.7 Doors and Windows

Door Type	**Description**
D	Single massive door Glass window on cammed hinges withfull perimeter acoustic seals STC≥45
E	Single massive steel door on cammed hinges with full perimeter acoustic seals STC≥55
F	Non-acoustic door, in non-acoustic wall
G	Fixed pane, 6.38mm laminated glass angled on control room side, minimum 100mm air gap, 10.38mm laminated glass
H	Fixed pane 10.38mm laminated glass minimum 120mm air gap fixed pane 14.38mm laminated glass

5.8 Isolation Summary

- Room within room construction generally used
- Specified construction should reach STC requirements, though ideally should be checked with Insul, or against 1/3 octave TL data.

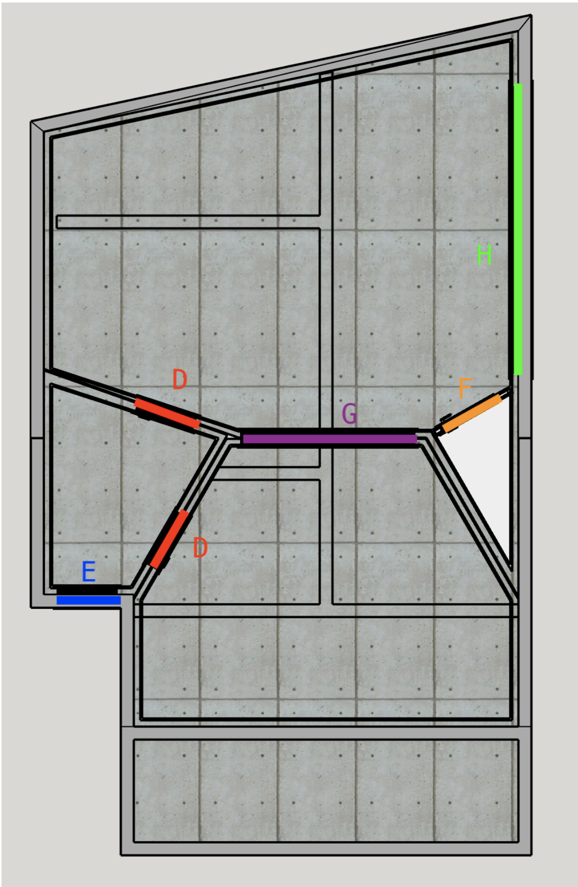


Figure 11: Door and window markup.

6 Low Frequency Analysis

6.1 Control Room

The basic geometry of the control room is shown in Figure 13 and 14 below. To set the geometry, front and rear wall heights were chosen as 2.9m and 3.5m, for an equivalent height of 3.2m. Plan dimensions were found by setting the front wall width (3m), the full width (6m), and the splay angle (120°). This left the front to back length dimension as a free parameter to achieve a reasonable room ratio and overall geometry. A reasonably wide room was chosen to help decrease the effect of first reflections.

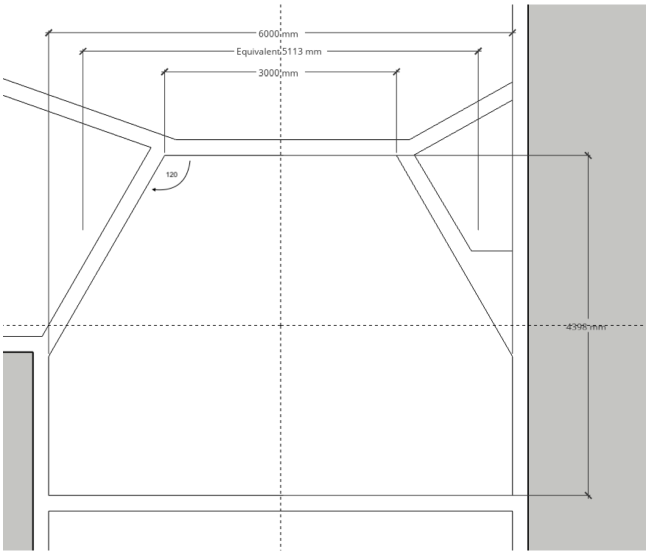


Figure 13: Plan geometry of CR.

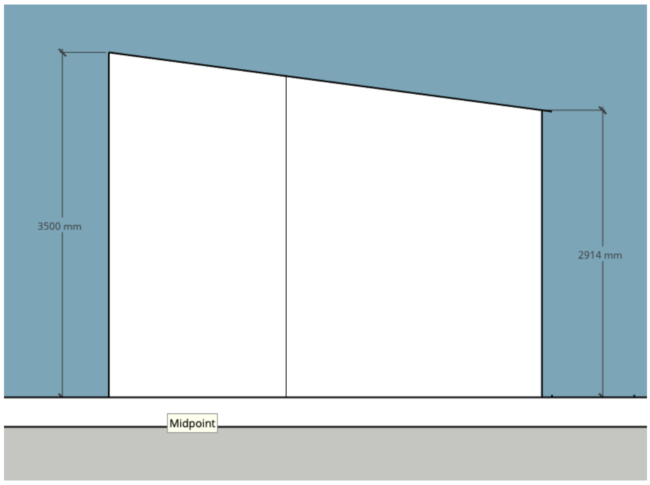


Figure 14: Height geometry of CR.

Cuboid equivalent analysis finds a reasonable ratio in the Bolt area. The analysis is extended with a MATLAB FEM eigenmode analysis of the more complicated geometry, with modal distribution plotted in Figure 14.

The mode distribution from the simulation seems reasonable, though there are a number of potential issues. There are coincident modes at 61Hz, 90Hz, and an unsupported region between 108 and 116Hz, and high mode density between 116-120Hz.

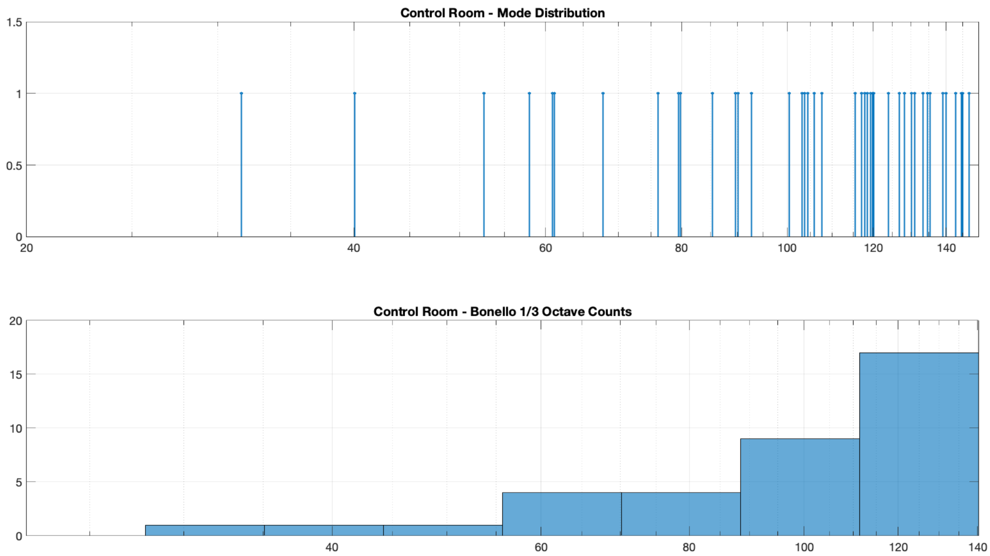


Figure 14: Simulated modal distribution of the control room. No distinction is made between axial, tangential or oblique modes.

6.1.1 Suggested LF Treatment Plan

The following basic treatment is recommended based on theoretical analysis. Comprehensive measurement should be taken at the construction phase to confirm theoretical responses and finalise treatment specifications.

- Tuned (60Hz) membrane absorber within ceiling cloud (RPG modex)
- Tuned (90Hz) membrane absorber within ceiling cloud (RPG modex)
- Broadband LF abosorption, rear corners.

6.2 Live Room

The geometry of the live room was generally set by layout and overall building width (Figures 16 and 17. Splayed walls and ceiling were included for acoustic and architectural character. Some attempt was made to make the equivalent cuboid a reasonable ratio, but comparisons will be limited as geometry does vary significantly from the simple shape.

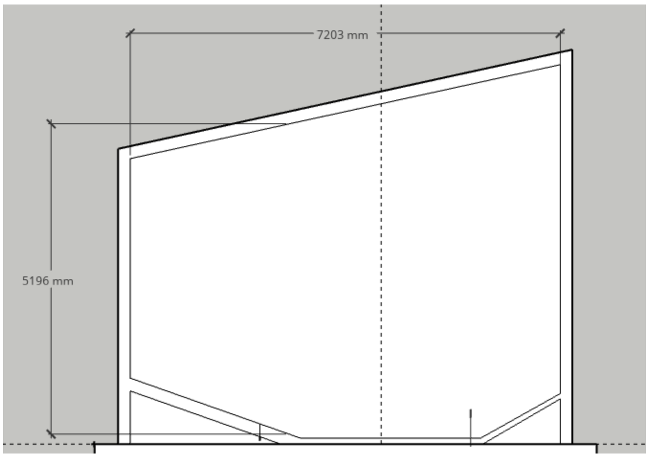


Figure 16: Plan geometry of LR.

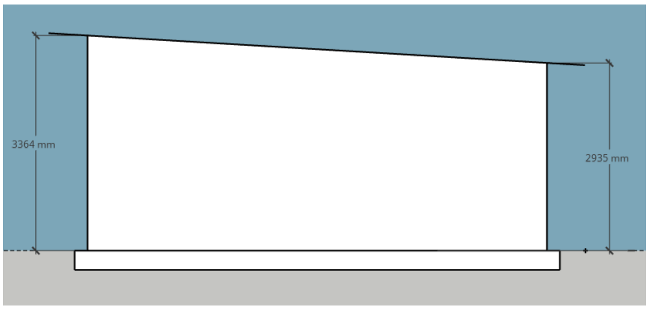
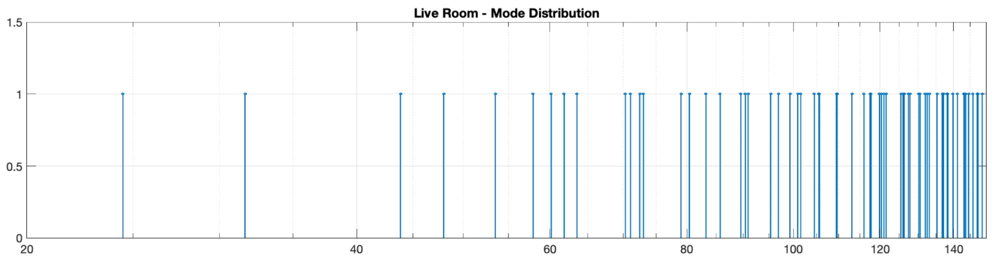


Figure 17: Height geometry of LR.

The Live Room was analysed in a similar method to the Control room, with the modal distribution in Figure 17.



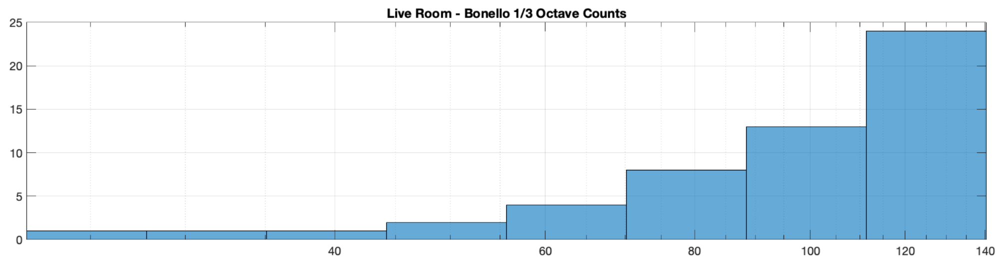


Figure 17: Simulated modal distribution of the live room. No distinction is made between axial, tangential or oblique modes.

6.2.1 Suggested LF Treatment Plan

Some general recommendations are made at this stage, which would be further confirmed with measurements taken during the construction phase.

- Tuned and broadband mebranic absorbers on ceiling
- Broadband absorption, focusing on corners.

6.3 Low Frequency Summary

- Equivalient cuboid and FEM eigenmode analysis proved useful for confirming reasonaable room ratios.
- Targeted LF treatment was able to be considered based on these results
- LF response should be checked at the construction phase to confirm response and applicable treatment plan
- A large portion of LF analysis has been left untouched, namely BEM analysis, allowing for source positioning, object geometry, and boundary impedance to be considered. This analysis would be very illuminating and allow for more specific treatment to be detailed.

7 Equipment and Signal Flow

Core equipment schedule is shown in Figure 18. Basic overview

- Macbook Pro (laptop preffered for portability)
- 24 (expandable) Thunderbolt Audio interface
- Mostly ITB mix style, some use of outboard gear.
  - 16 Channel Control surface
  - Outboard channel strips and mic pres.
- Stereo nearfield monitoring (expandable to 5.1 surround)
- Versatile video switching, including projector.
- ”Synth wall” in control room.

Location	System	Component	Connection Type	Connects to	Realestate	Notes
Control Room	Audio	UAD Apollo x8p	Thunderbolt Audio, XLR/DSUB	USBC Hub, other interface, patchbay	1u	8 mic pres / 8line in (DSUB)
Control Room	Audio	UAD Apollo x8p (or x16)	Thuderbolt Audio, DSUB	other interface, patchbay	1u	Additional pres (or just ADC)
Control Room	Audio	SSL Fusion All-Analogue Stereo channel Strip	XLR mic/line level audio	patchbay	2u	Stero channel strip
Control Room	Audio	Universal 2-610 Dual Channel Valve Mic Pre	XLR mic/line level audio	patchbay	2u	
Control Room	Audio	48 pair patch bay	TRS mic/line level audio	multiple	2u	
Control Room	Audio	Avid S3 16 Channel Control Surface	Thunderbolt/Ethernet	USBC Hub	Desk	
Control Room	Audio	Wall plate E, 8/4 audio, ethernet	XLR, 1/4" TRS, RJ45	multiple	Wall	
Control Room	Audio	Roland RD300NX 88 key Digital Piano	USB MIDI, line level audio	Patchbay, USBC Hub	Under Desk	
Control Room	Audio	Roland Juno DS76 digital synthesizer	line level audio	patchbay	Synth wall	
Control Room	Audio	Moog Matriaarch analog synthesizer	line level audio	patchbay	Synth wall	
Control Room	Audio	Wurlitzer Electric Piano	line level audio	patchbay	synth wall	
Control Room	Audio	Fender Rhodes Electric Piano	line level audio	patchbay	synth wall	
Control Room	Audio	Prohpet6 Analogue synthesizer	line level audio	patchbay	synth wall	
Control Room	Audio	Genelec 7040APM Sub	XLR, line level audio	patchbay	Floor	
Control Room	Audio	2x Genelec 8040BPM Active Nearfield Monitors	XLR, line level audio	patchbay	Speaker stands	Expand to Surround as necessary
Control Room	Core	Macbook/Mac Pro	USBC/Thunderbolt	USBC Hub	Desk	
Control Room	Core	Thunderbolt/USBC Hub/Dock/Expander	USBC/Thunderbolt	Macbook Pro, AV Monitor, Audio Interface	Desk	
Control Room	IT	Ethernet	RJ45	Ethernet Switch	Wall	
Control Room	Power	UPS	Mains Power	Power Outlet	2u	
Control Room	Power	Mains power outlet	Mains Power	Circuit Breaker	Wall, multiple	
Control Room	Video	2x 22" HD monitors	HDMI	HDMI Switch	Desk	
Control Room	Video	2x4 HDMI switch	HDMI	USBC Hub, HD Monitors, projector	2u	Ability to switch computer/HDMI input between monitors, projector and Live room.
Control Room	Video	HD projector	HDMI	HDMI Switch	Ceiling	
Iso Booth/Sound Lock	Audio	Wall plate D, 4/2 audio, ethernet	XLR, 1/4" TRS, RJ45	multiple	Wall	
Iso Booth/Sound Lock	IT	Ethernet Switch	RJ45/TCPIP LAN	USBC hub, wall plates,	1ru	
Iso Booth/Sound Lock	IT	Router	RJ45	Ethernet Switch	rack shelf	
Iso Booth/Sound Lock	Power	Mains power outlet	Mains Power	Circuit Breaker	Wall	
Live Room	Audio/IT	Wall plate A, 16/8 audio, 4xethernet, HDMI	Mutltiple	multiple	Wall	
Live Room	Audio/IT	Wall plate B, 8/4 audio, ethernet	Mutltiple	multiple	Wall	
Live Room	Audio/IT	Floor plate C, 8/4 audio	Mutltiple	multiple	Floor	
Live Room	Power	Mains power outlet	Mains Power	Circuit Breaker	Wall	
Live Room	Power	Floor	Mains Power	Circuit Breaker	Floor	
Workshop	IT	Ethernet	RJ45	Ethernet Switch	Wall	
Workshop	Power	Mains power outlet	Mains Power	Circuit Breaker	Wall	

Figure 18: Schedule of equipment.

7.1 Equipment Block Connections

Basic block diagrams are shown for each studio room. Troughs shall be built into the slabs to facilitate cable runs. Power to wall sockets shall primarily be run through conduit in wall/ceiling cavities, using dedicated troughs when needing to route power mid room.

A rough overview of trough runs, and wall plate layout are shown in Figure 19 below.

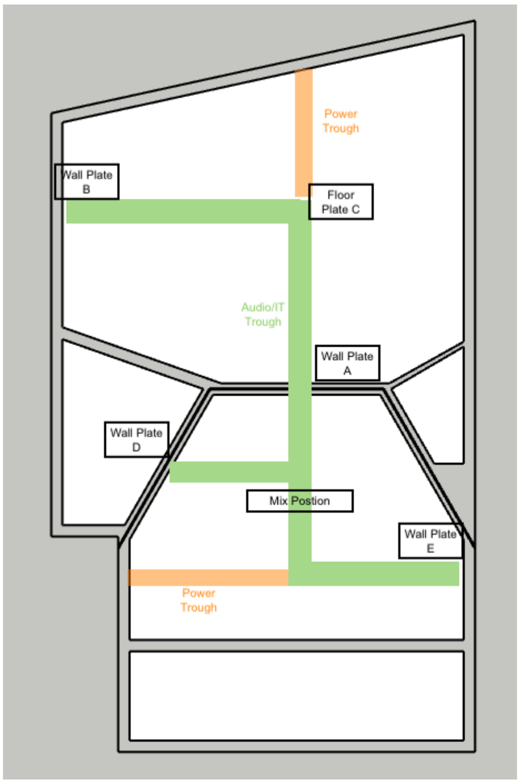


Figure 19: Trough Layout.

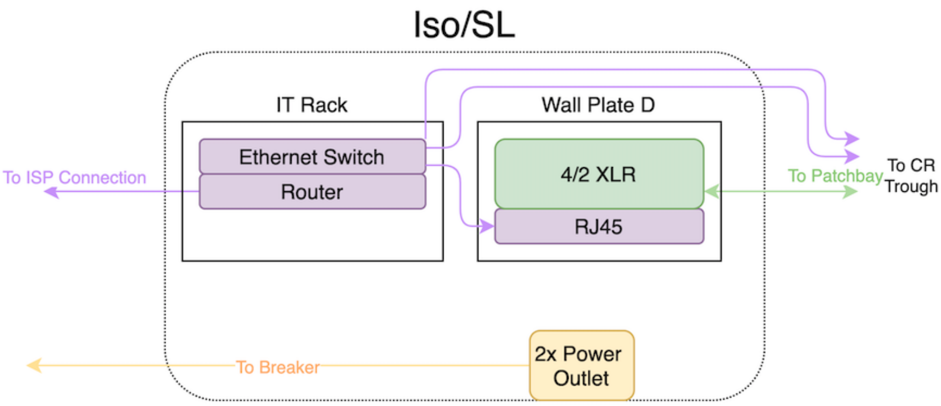


Figure 20: Iso Booth - Block Connections.

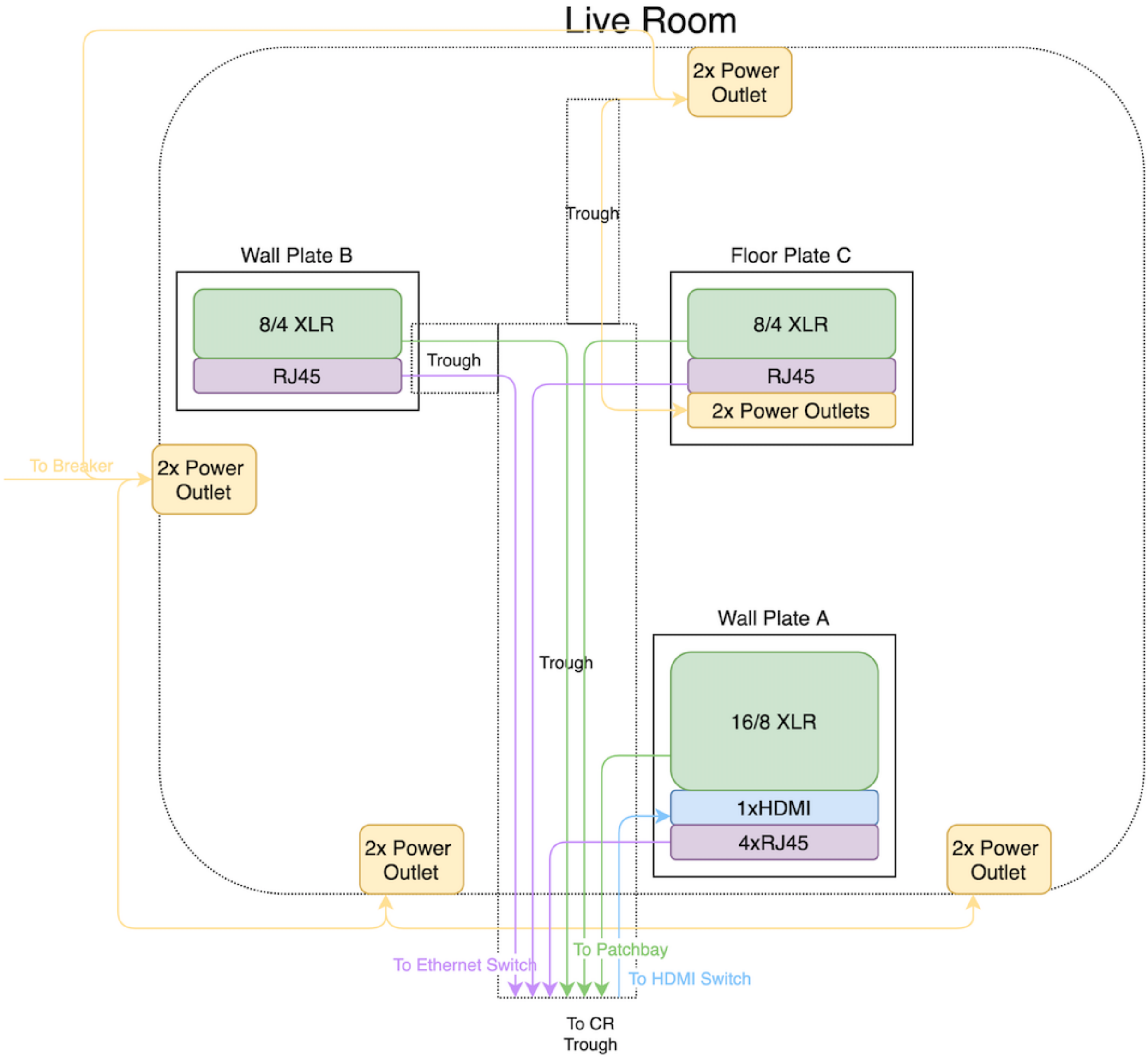


Figure 21: Live Room - Block Connections.

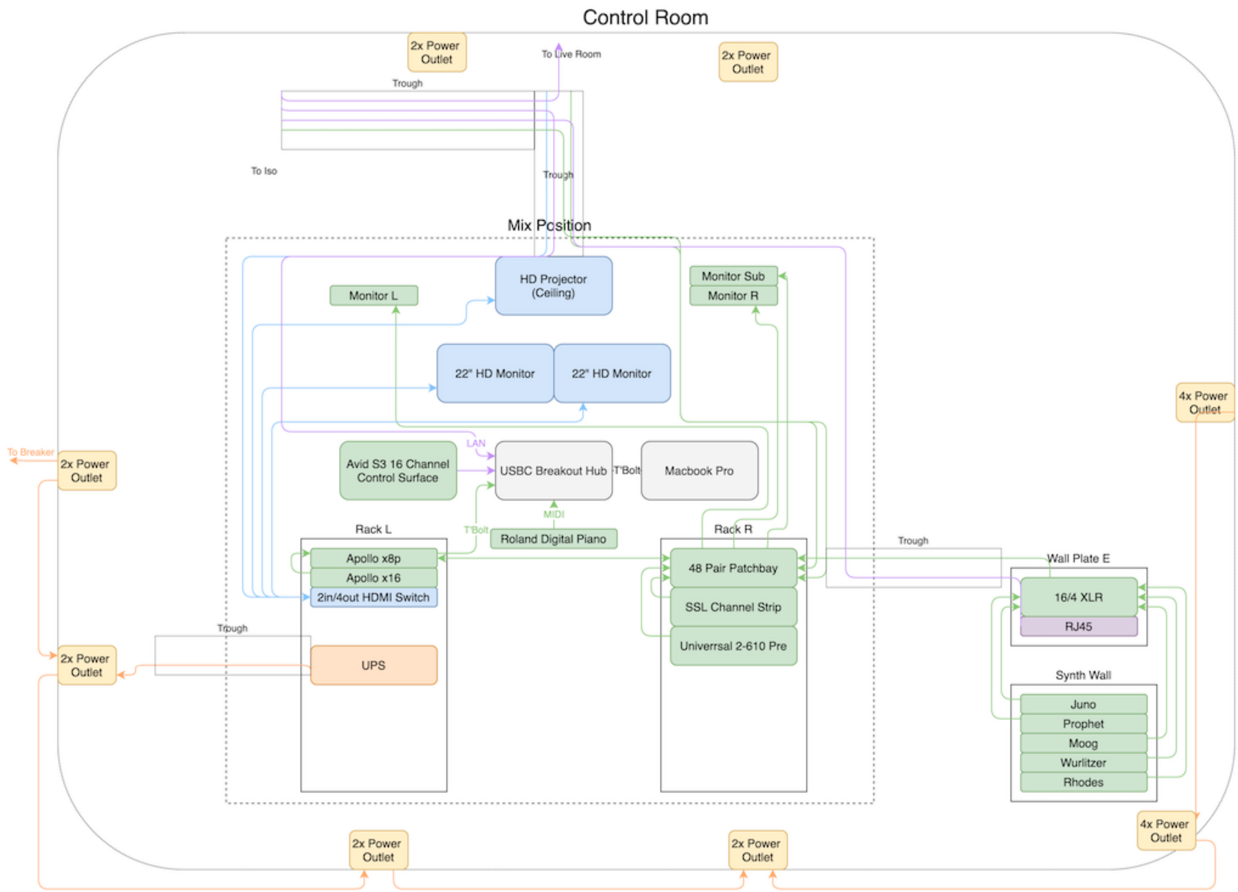


Figure 22: Control Room - Block Connections.

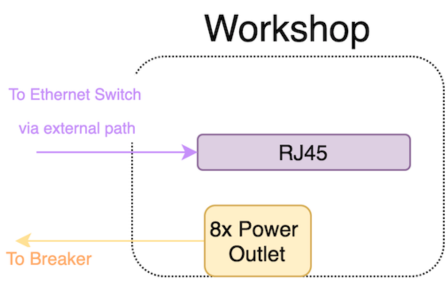


Figure 23: Workshop - Block Connections.

8 Monitoring

8.1 DSP, Crossover, Amplification

The chosen class of monitors are largely self managed, stereo output from interface into the subwoofer, which crosses internally and feeds the mains.

Should more control be required a standalone monitor management and dsp system may be used such as the dbx Venu 360.

8.2 Placement

8.2.1 LF considerations

The monitoring position is considered first by looking at the modal reponse along the centreline, at 1200mm above floor level, shown in Figure 24. To avoid modal nodes, the engineer position is suggested to be in the area between 1.6m and 2.4m setback from the front wall.

The large response from Mode 13 (90Hz) is likely an issue (especially because it is coincident with mode 12, but is seems largely unavoidable for reasonable monitoring positions. Figure 25 shows this mode has a pressure antinode on the ceiling, so could be well tamed by a tuned membrane type absorber on the ceiling.

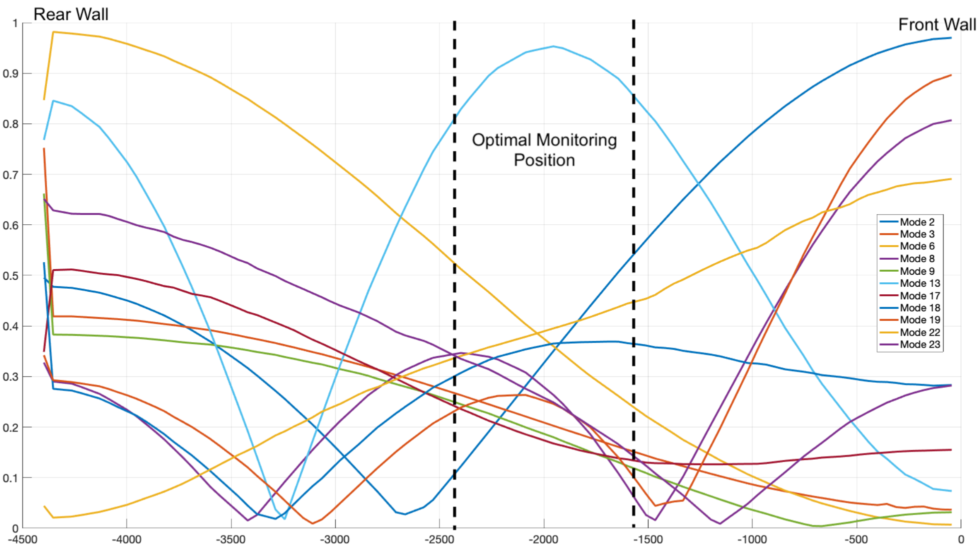


Figure 24: Modal response along the CR centreline, at 1200mm above floor level.

8.2.2 Reflection Study

Figure 26 shows early reflection geometry in the horizontal plane. The listening position is largely reflection free in this plane. Absorptive/diffusive panels at the lateral reflection points will help to tame any specular early reflections. The large diffuser on the rear wall will help to diffuse first order reflections from the rear wall.

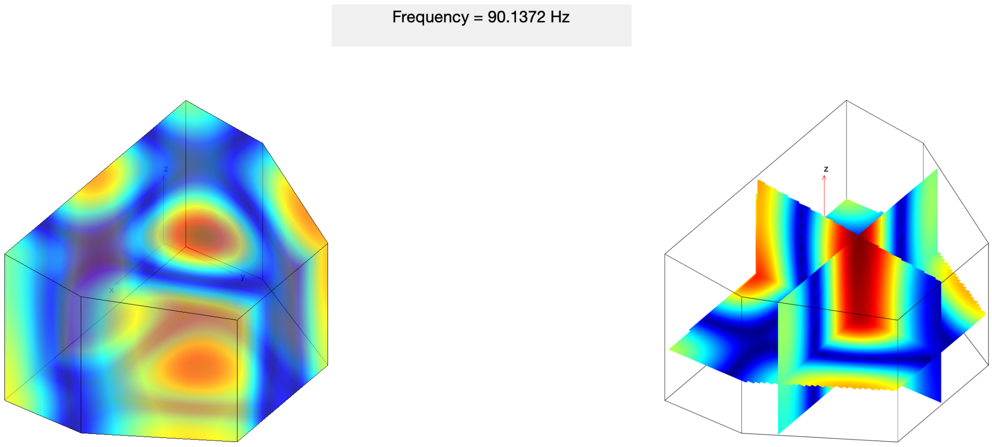


Figure 25: Mode 13 of the CR.

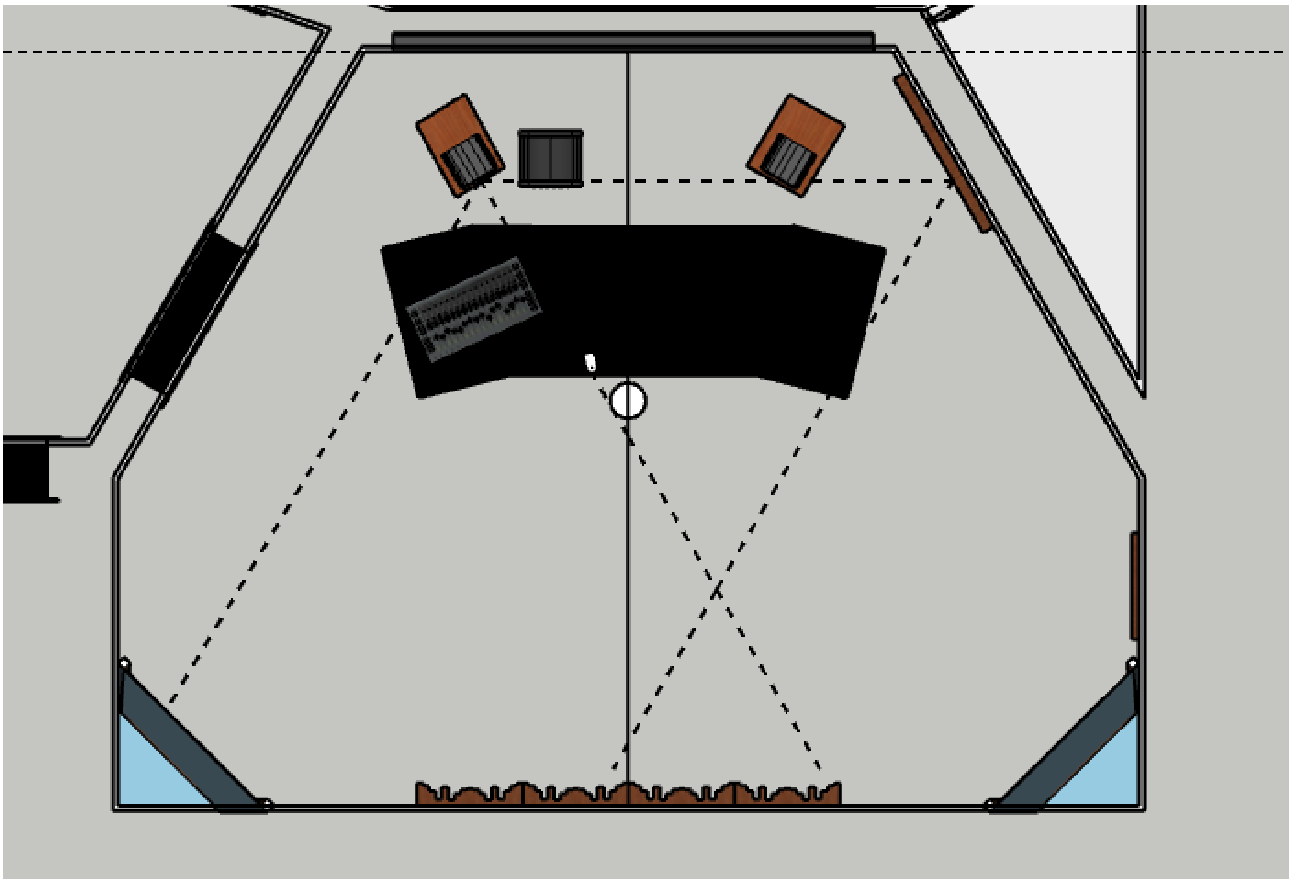


Figure 26: Early Reflections (Left speaker only, 120° throw) - Horizontal Plane.

Figure 27 shows early reflection geometry in the vertical plane. The CR glass is angled to direct specular reflections away from the listening position. An absorptive layer in the ceiling cloud will help to minimise any early reflections.

A "console" bounce exists, and poses the largest detriment to monitoring in this studio. For this studio, having a large, flat desk with lots of realestate (small control surface, no console) will be greatly beneficial for intended usage and workflow - some console bounce may be unavoidable. Potentially a rear desk hutch or false bridge could be used to strategically direct reflections away from the listener.

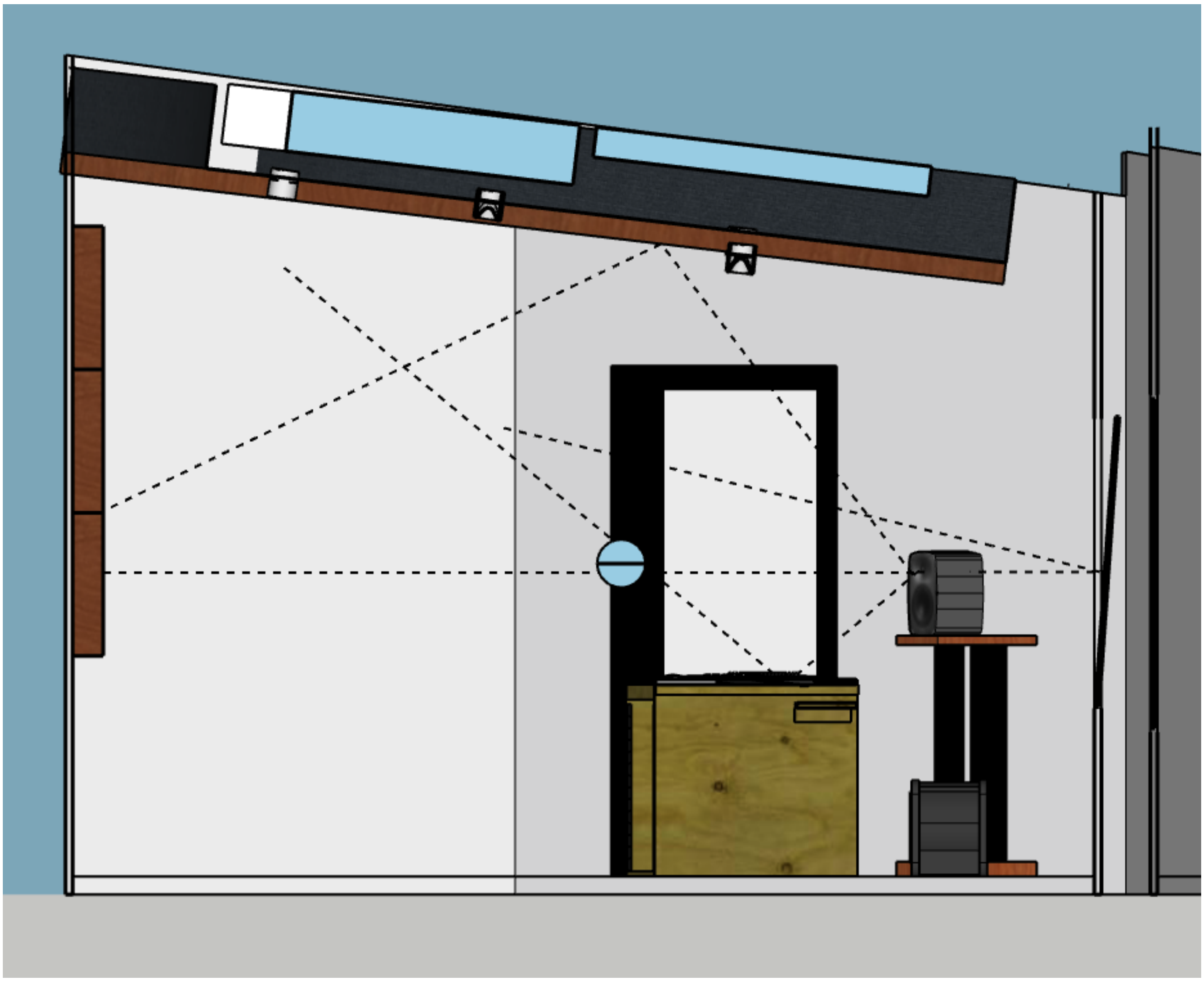


Figure 27: Early Reflections - Vertical Plane.

9 Acoustic Treatments

9.1 Control Room

The control room has a volume of $73m^3$ ($2570ft^3$). For a critical listening room, we target an RT_{60} of 0.3-0.4s. This gives $A = \frac{0.16 \cdot 73}{[0.3,0.4]} = 29 - 39$ sabins of required absorption. The proposed treatment scheme is shown in Figure 28, and with placement overview in Figure 29. Values are approximate, especially at low frequencies, where averages have been taken for membranic resonators.

Volume	RT	Total Required Absorption (Sabins)
73	0.4	29

ID	Treatment	Area	125		250		500		1000		2000		4000	
			Absorption Coefficient	Absorption	Absorption Coefficient	Absorption	Absorption Coefficient	Absorption	Absorption Coefficient	Absorption	Absorption Coefficient	Absorption	Absorption Coefficient	Absorption
A	Cloud Fill (2" 701)	13	0.44	5.72	0.68	8.84	1.00	13.00	1.09	14.17	1.06	13.78	1.10	14.30
B	RPG Modex 5" 90Hz Target	2.8	0.60	1.68	0.20	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C	RPG Modex 10" 61Hz Target	3.84	0.60	2.30	0.20	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D	Rear Corner 701, plain, 4" thick E-400]	3.64	0.87	3.17	1.14	4.15	1.24	4.51	1.17	4.26	1.18	4.30	1.28	4.66
E	BAD Expo + 2" 6pcf fibreglass board	4.08	0.55	2.24	0.80	3.26	0.92	3.75	0.80	3.26	0.78	3.18	0.70	2.86
F	Upper Wall, 701, plain, 2" thick E-400]	2.9	0.44	1.28	0.68	1.97	1.00	2.90	1.09	3.16	1.06	3.07	1.10	3.19
G	RPG Flutterfree C mount w/ Helmholtz	4.2	0.38	1.60	0.77	3.23	0.28	1.18	0.16	0.67	0.18	0.76	0.19	0.80
	Carpet	21	0.00	0.00	0.10	2.10	0.10	2.10	0.30	6.30	0.40	8.40	0.40	8.40
Total		55.46	18.0		24.9		27.4		31.8		33.5		34.2	
Estimated RT60			0.6		0.5		0.4		0.4		0.3		0.3	

Figure 28: Control Room Treatment Specification.

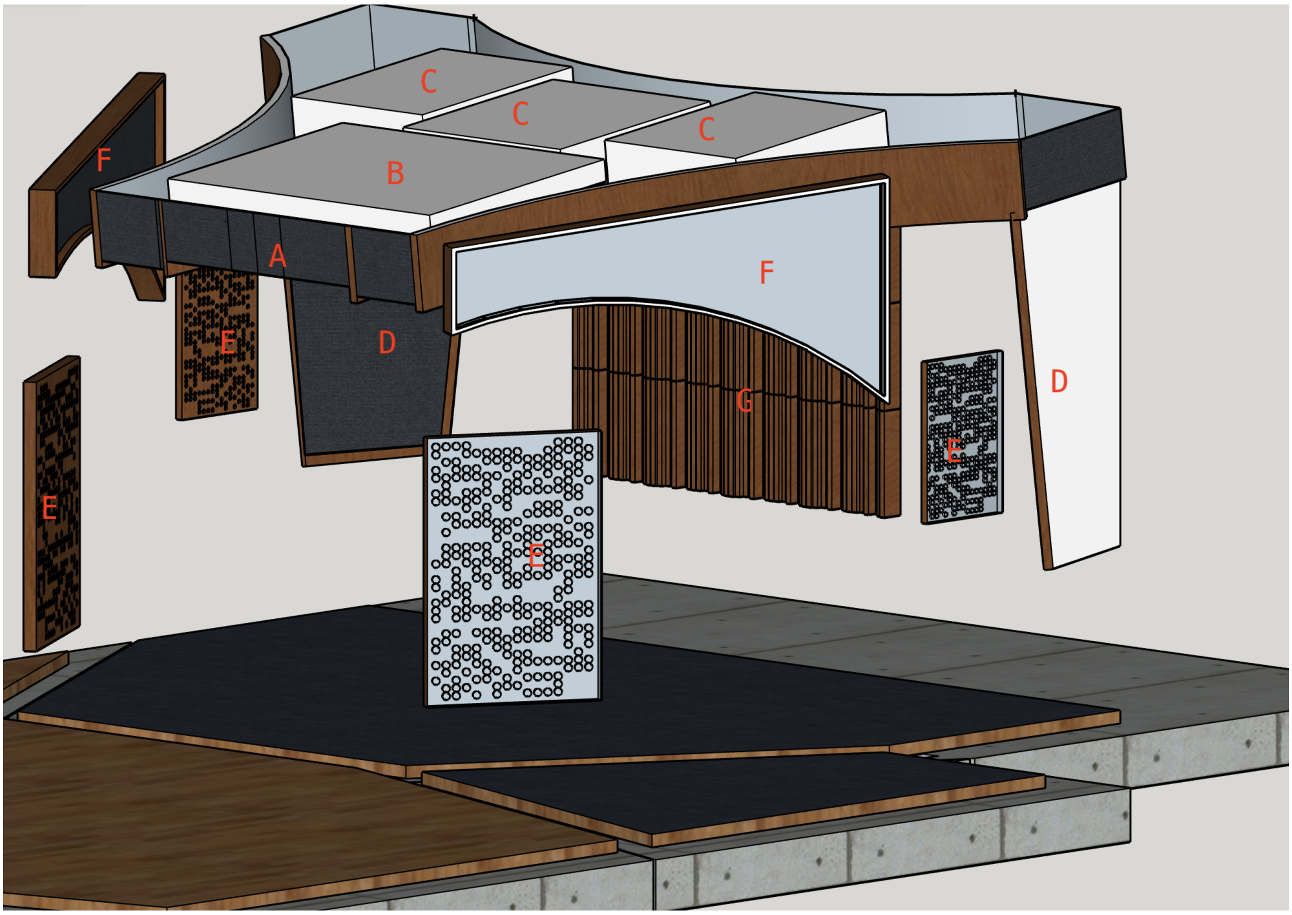


Figure 29: Control Room Treatment locations.

9.2 Live Room

The live room has a volume of $118m^3$ ($4170ft^3$). The typical program material (classical) warrants a slightly more reverberant room, though a deader room may be needed for recording other material. Thus, variable acoustics will be beneficial, with a target RT_{60} of 0.6s on the lower end, and 0.8-0.9s on the upper end. This gives the required total absorption of 32-21 Sabins (variable by 11 sabins). The proposed treatment scheme is shown in Figure 30, and with placement overview in Figures 31 and 32 .

Volume	RT	Total Required Absorption (Sabins)
118	0.6	31

ID	Treatment	Area	125		250		500		1000		2000		4000	
			Absorption Coefficient	Absorption	Absorption Coefficient	Absorption	Absorption Coefficient	Absorption	Absorption Coefficient	Absorption	Absorption Coefficient	Absorption	Absorption Coefficient	Absorption
H	Ceiling Membranic (Approx. Average)	11.45	0.50	5.73	0.50	5.73	0.20	2.29	0.10	1.15	0.05	0.57	0.01	0.11
I	Corner 701, plain, 4" thick E-400	5.24	0.87	4.56	1.14	5.97	1.24	6.50	1.17	6.13	1.18	6.18	1.28	6.71
J	Poly 28"/10" chord	4.52	0.32	1.45	0.50	2.26	0.35	1.58	0.30	1.36	0.21	0.95	0.20	0.90
K	Poly 16"6" chord	2.6	0.29	0.75	0.40	1.04	0.30	0.78	0.22	0.57	0.20	0.52	0.20	0.52
L	703, plain, 2" thick, A Mount (Variable)	12	0.17	2.04	0.86	10.32	1.14	13.68	1.07	12.84	1.02	12.24	0.98	11.76
M	Wall 701, plain, 4" thick E-400	1.6	0.87	1.39	1.14	1.82	1.24	1.98	1.17	1.87	1.18	1.89	1.28	2.05
N	Ceiling Feature Absorption	3.31	0.50	1.66	0.60	1.99	1.14	3.77	1.07	3.54	1.02	3.38	0.98	3.24
O	Tile (e.g 40mm Basotect)	2.88	0.10	0.29	0.20	0.58	0.30	0.86	0.70	2.02	0.90	2.59	0.95	2.74
Total		40.72	17.9		29.7		31.5		29.5		28.3		28.0	
Estimated RT60			1.06		0.64		0.60		0.64		0.67		0.67	

Figure 30: Live Room Treatment Specification.

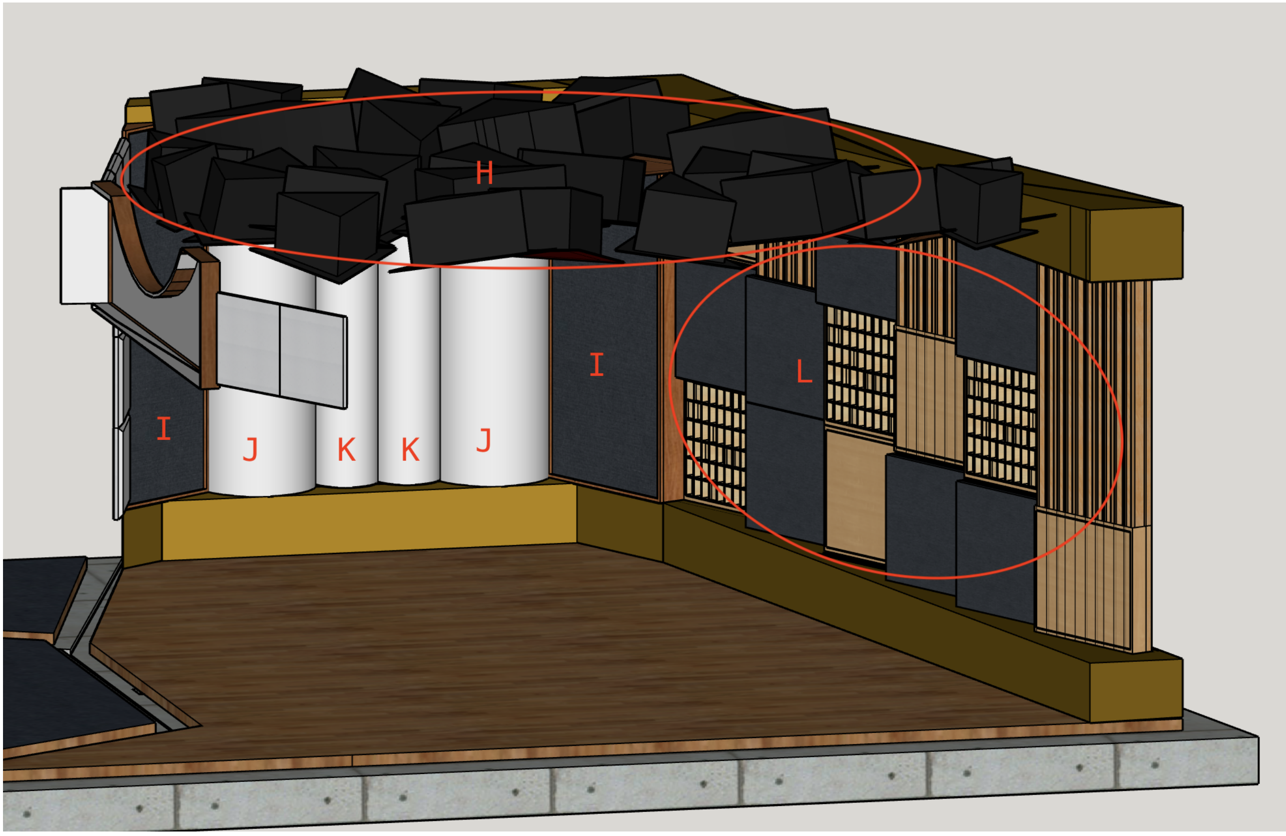


Figure 31: Live Room Treatment locations - View 1.

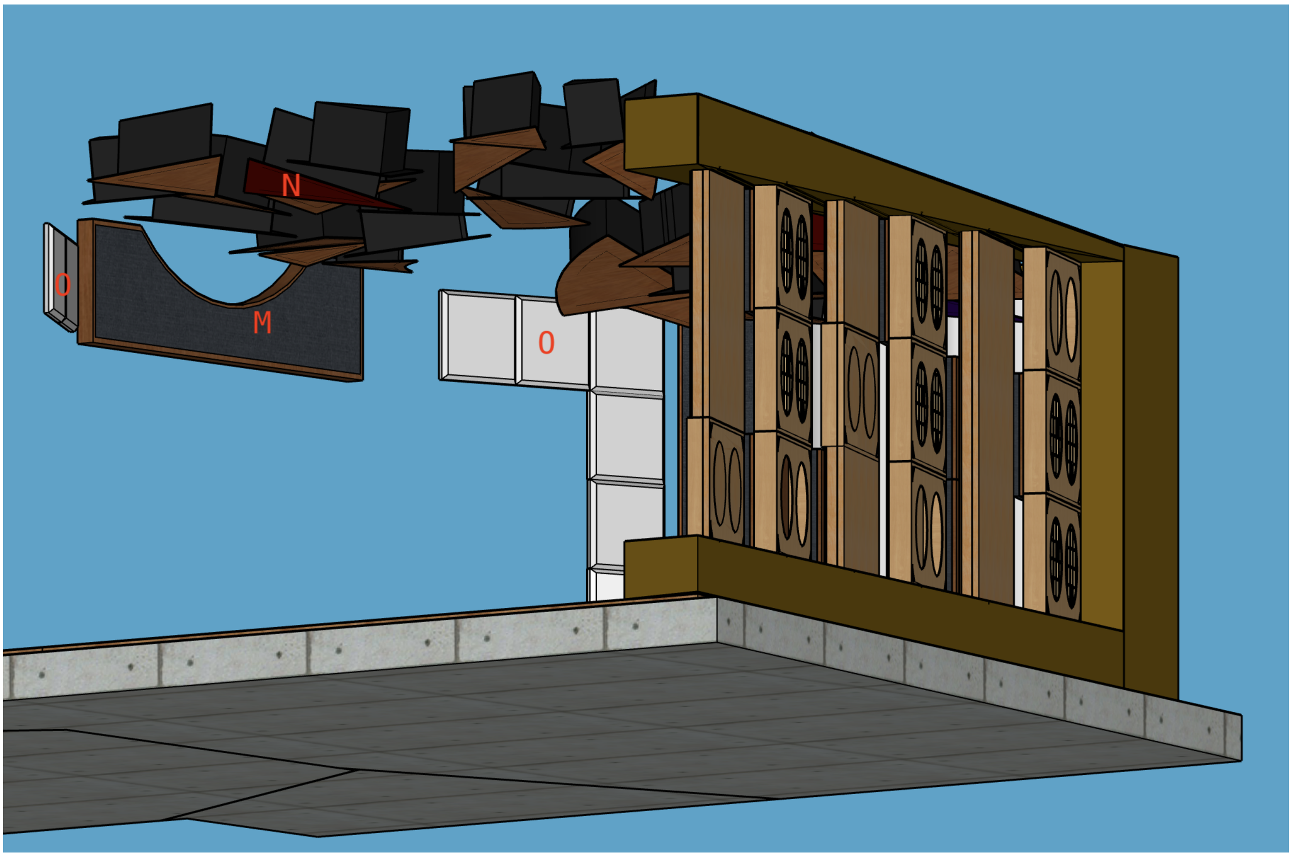


Figure 32: Live Room Treatment locations - View 2.

9.3 Predicted RT60

Figure 33 shows the predicted RT_{60} times for the control room, and the live room with the variable acoustics fully reflective and fully absorptive.

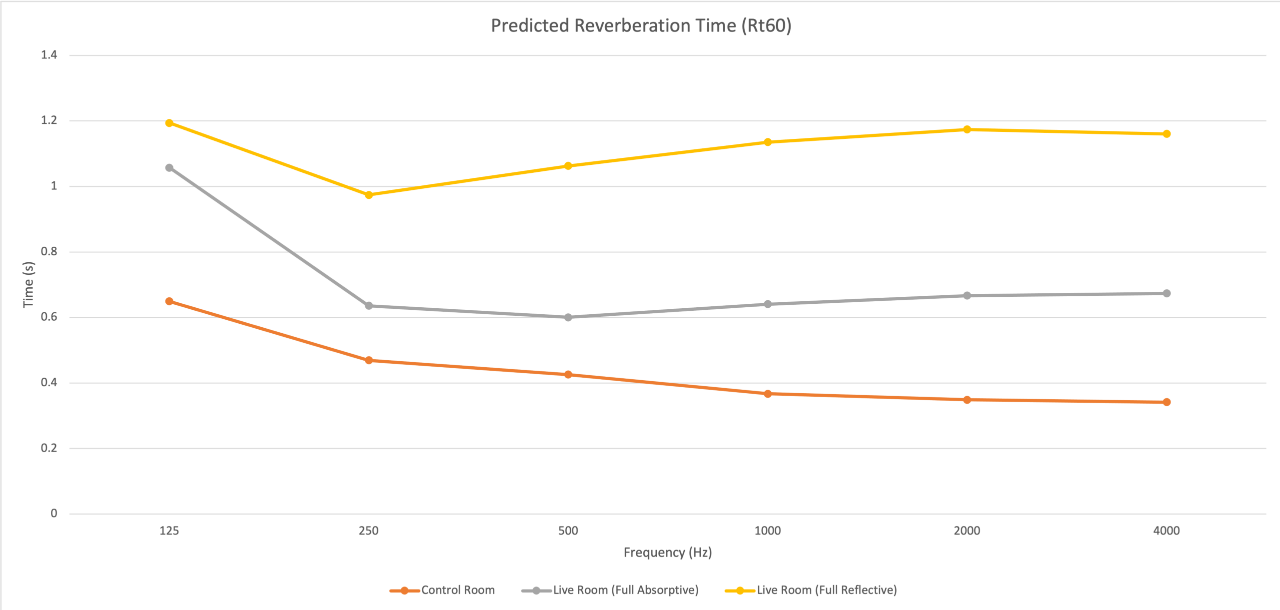
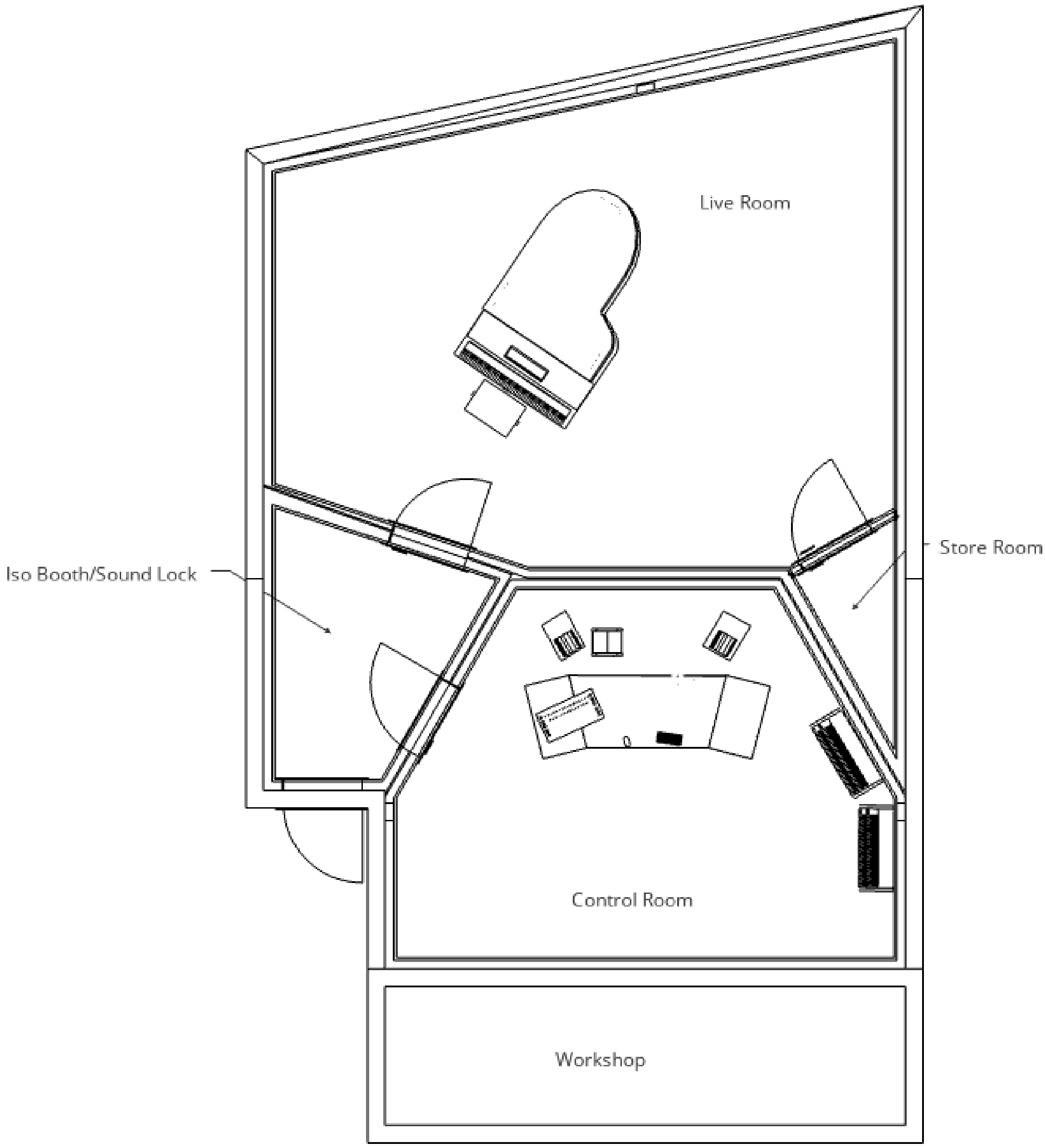
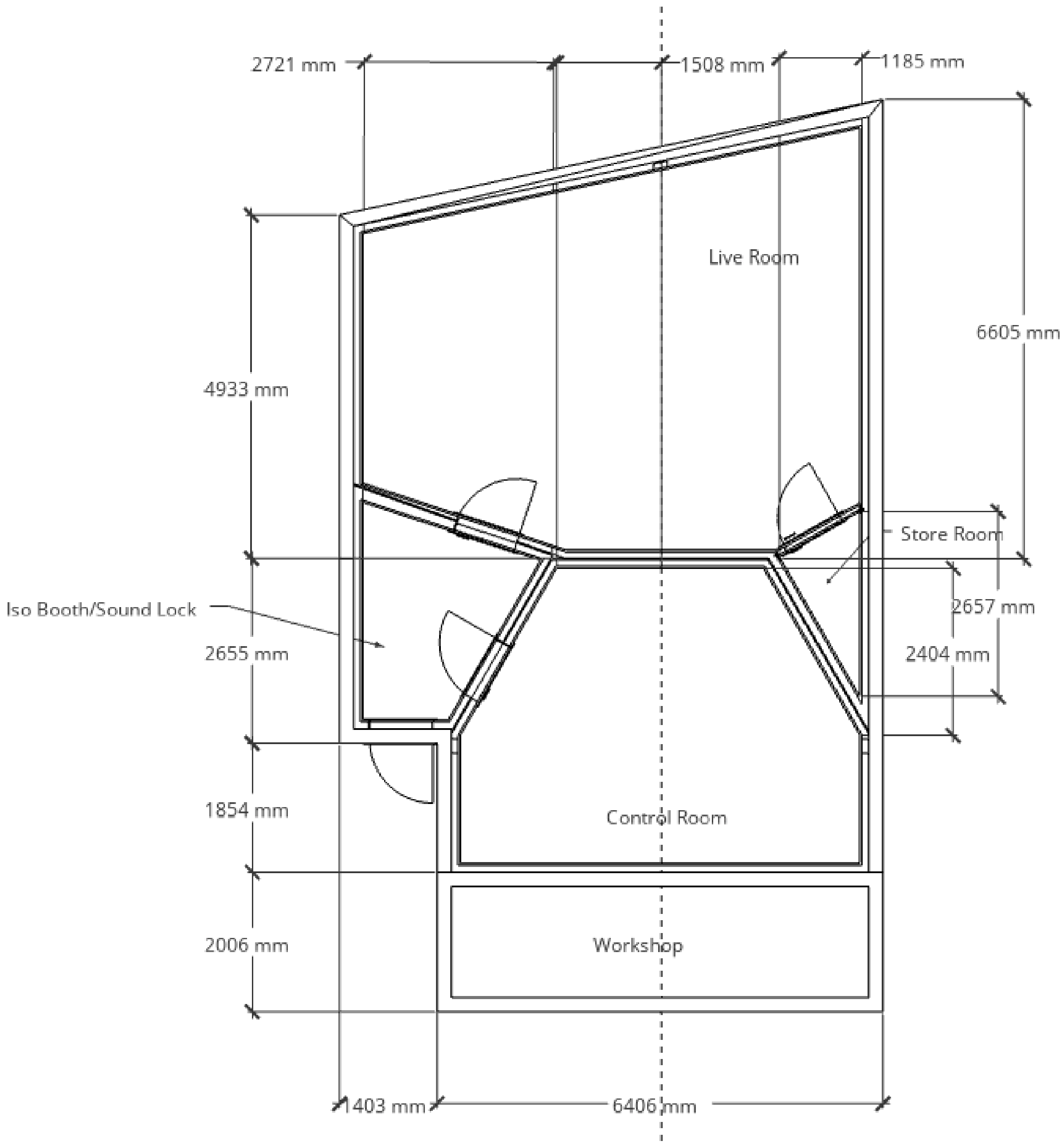
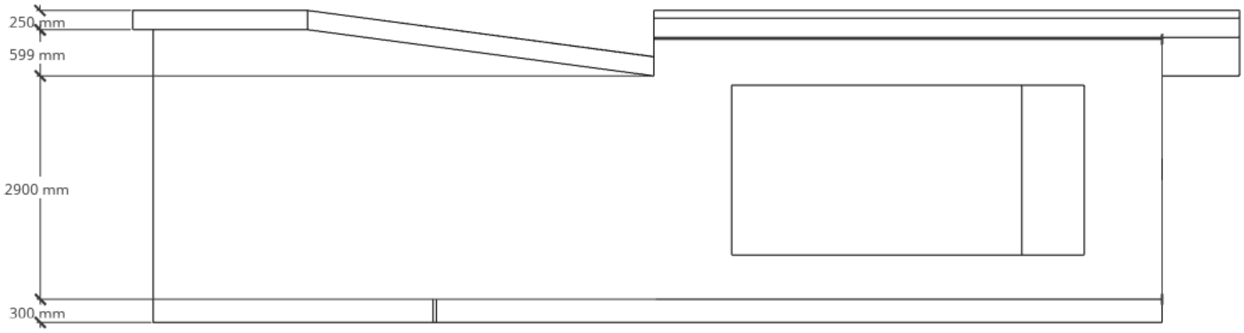


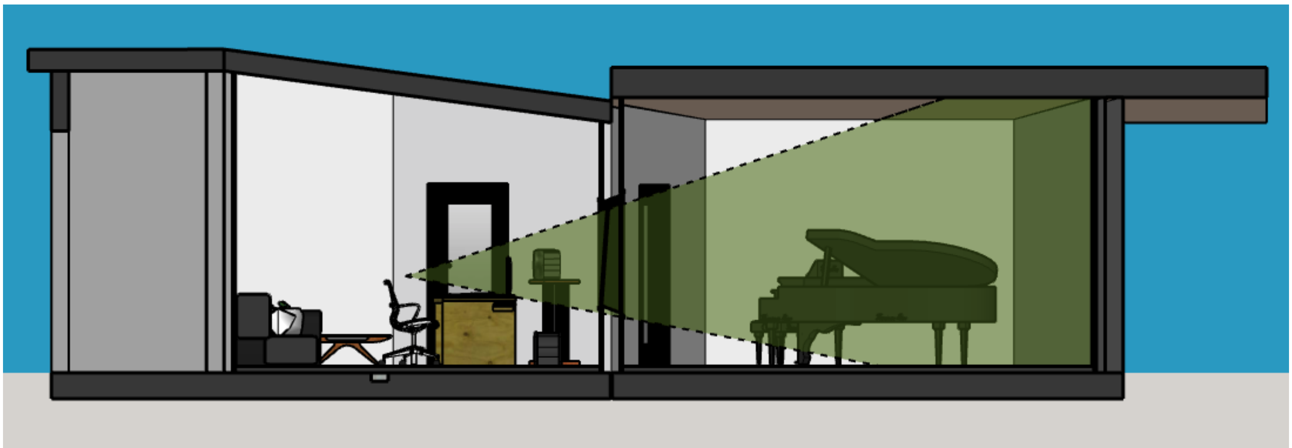
Figure 33: Predicted reverberation times.

10 Drawings, Sections and Artistic Renderings

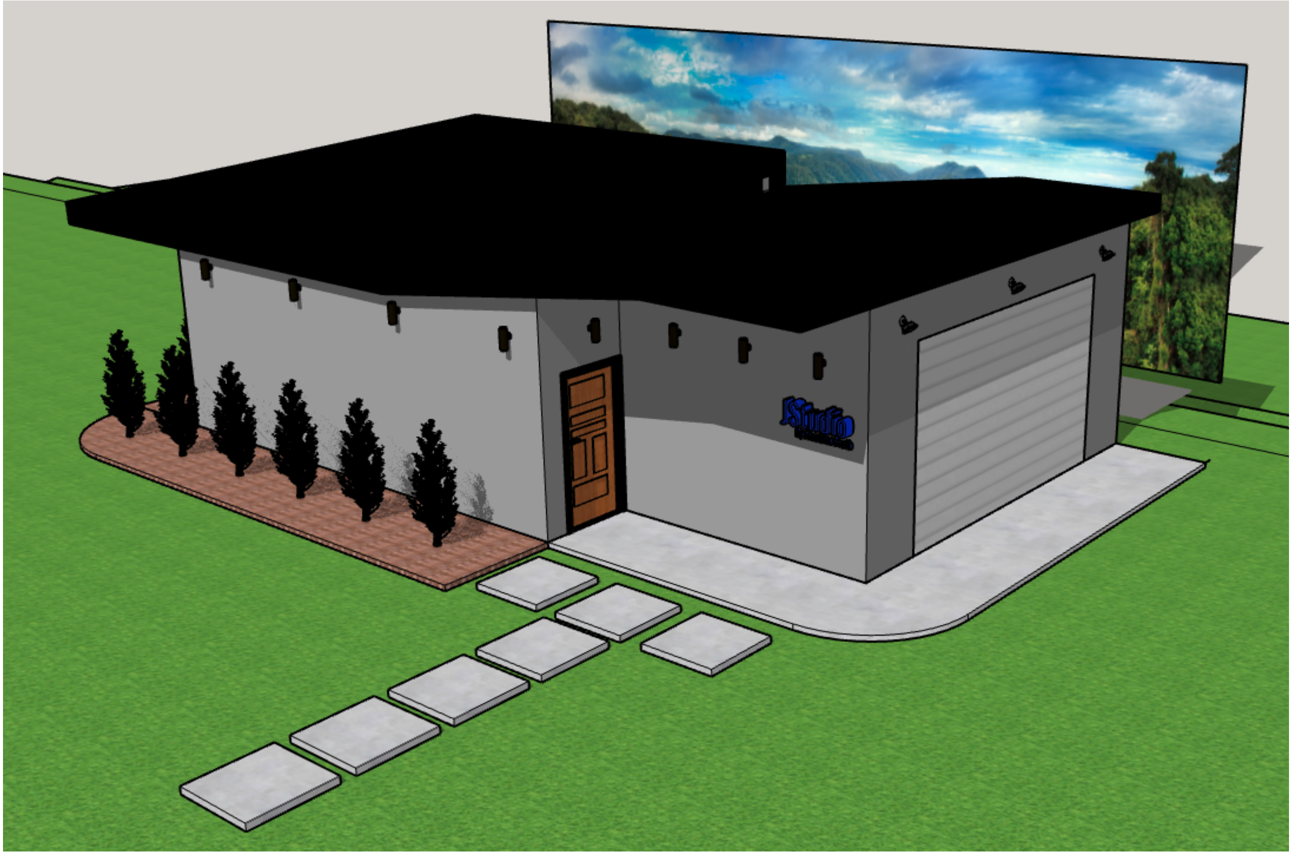


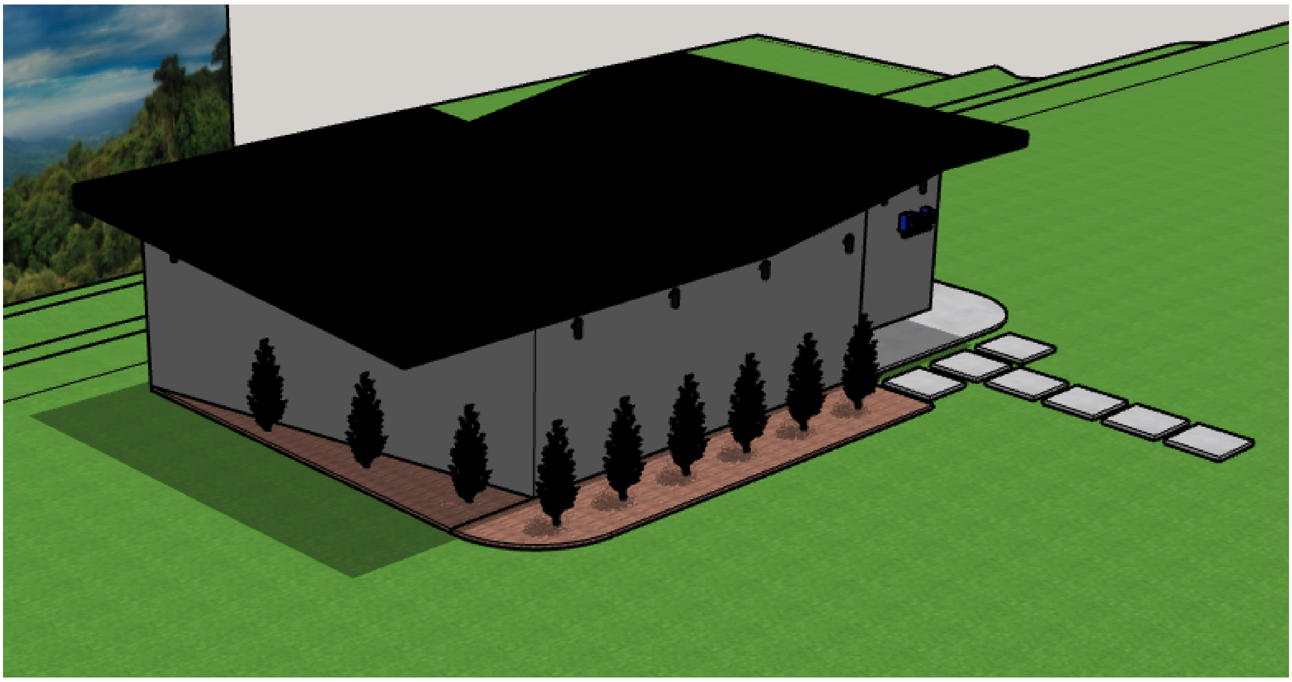

2721 mm
1508 mm
1185 mm
Live Room
6605 mm
4933 mm
Store Room
Iso Booth/Sound Lock
2657 mm
2655 mm
2404 mm
1854 mm
Control Room
2006 mm
Workshop
1403 mm
6406 mm

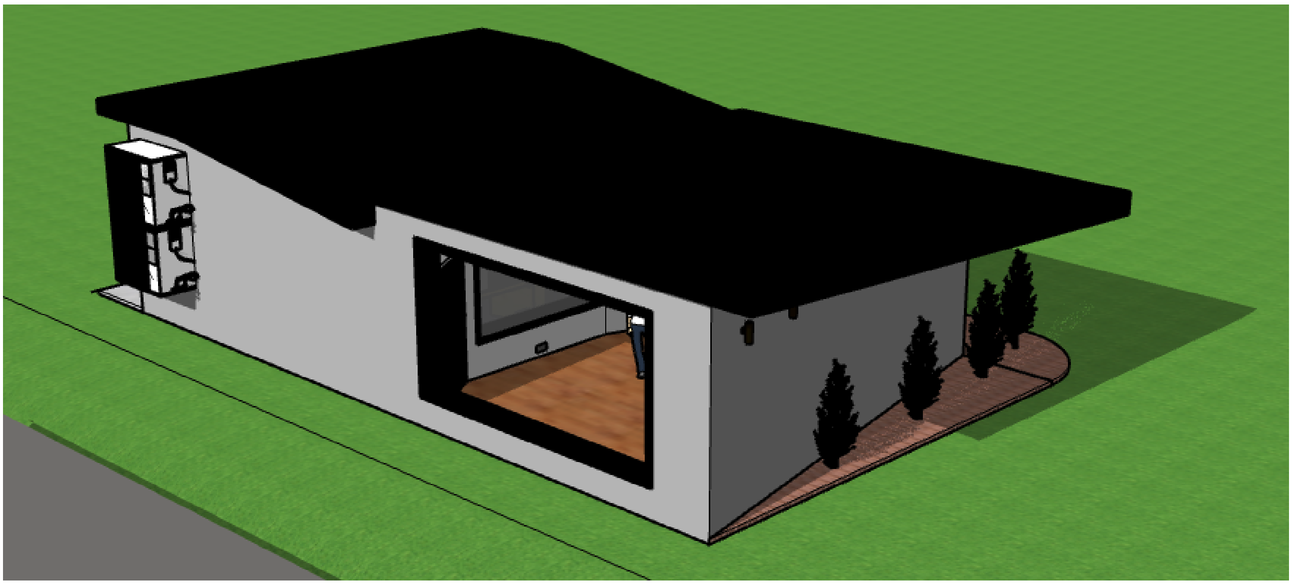

250 mm
599 mm
2900 mm
300 mm

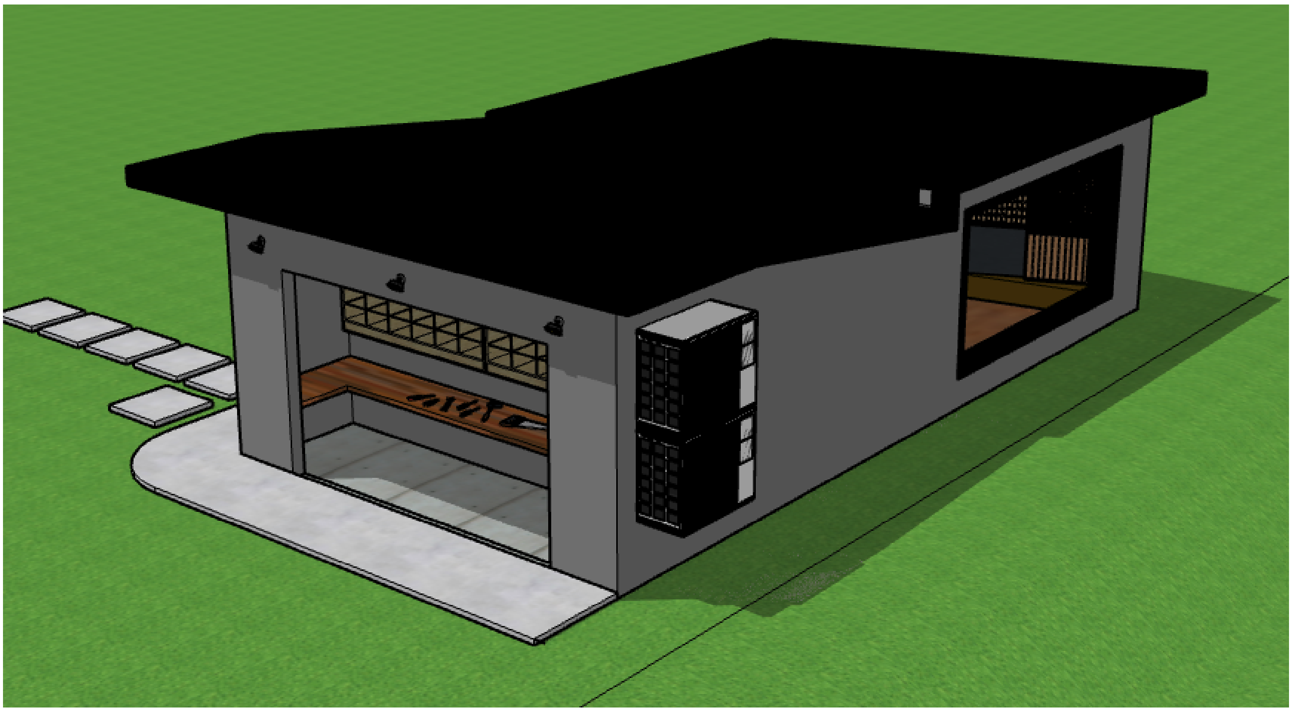


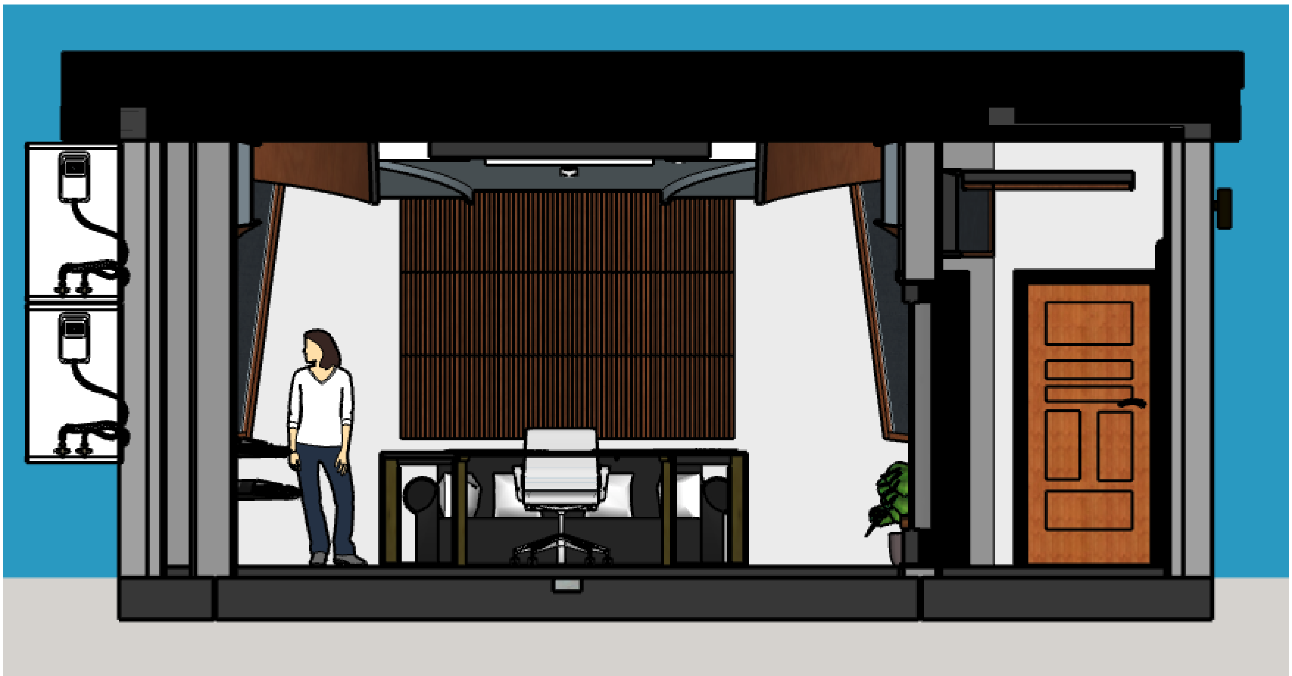

JStudio
By Jonathan South

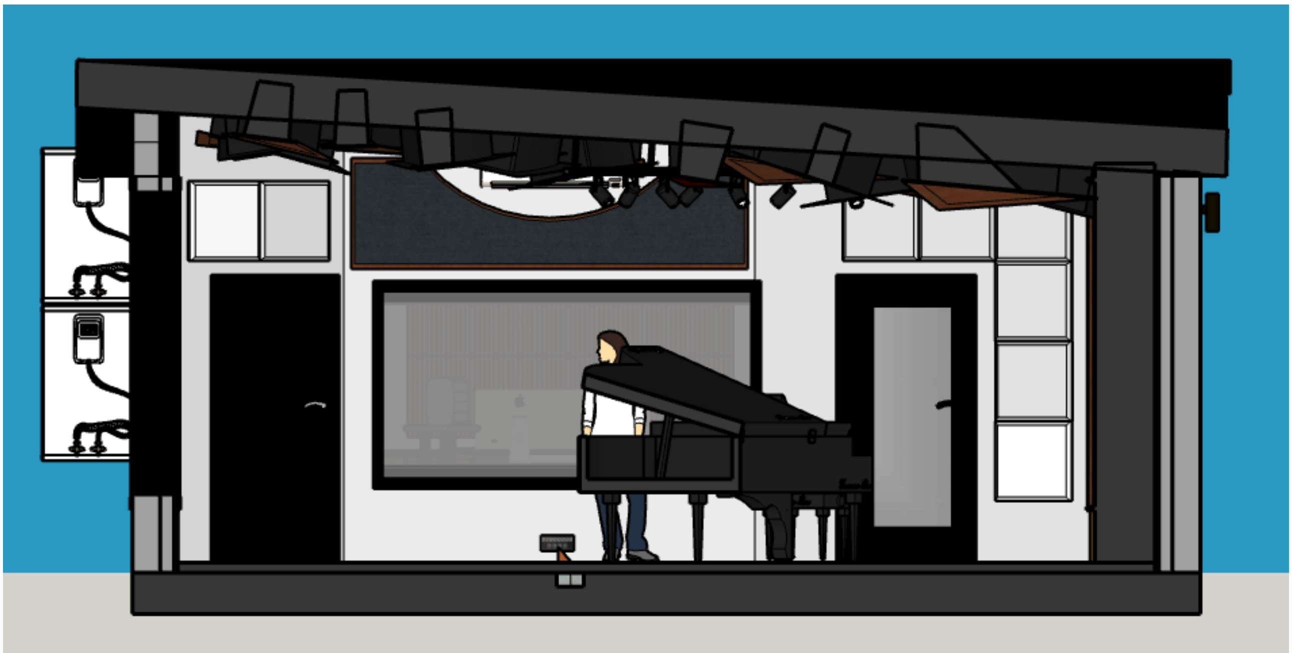


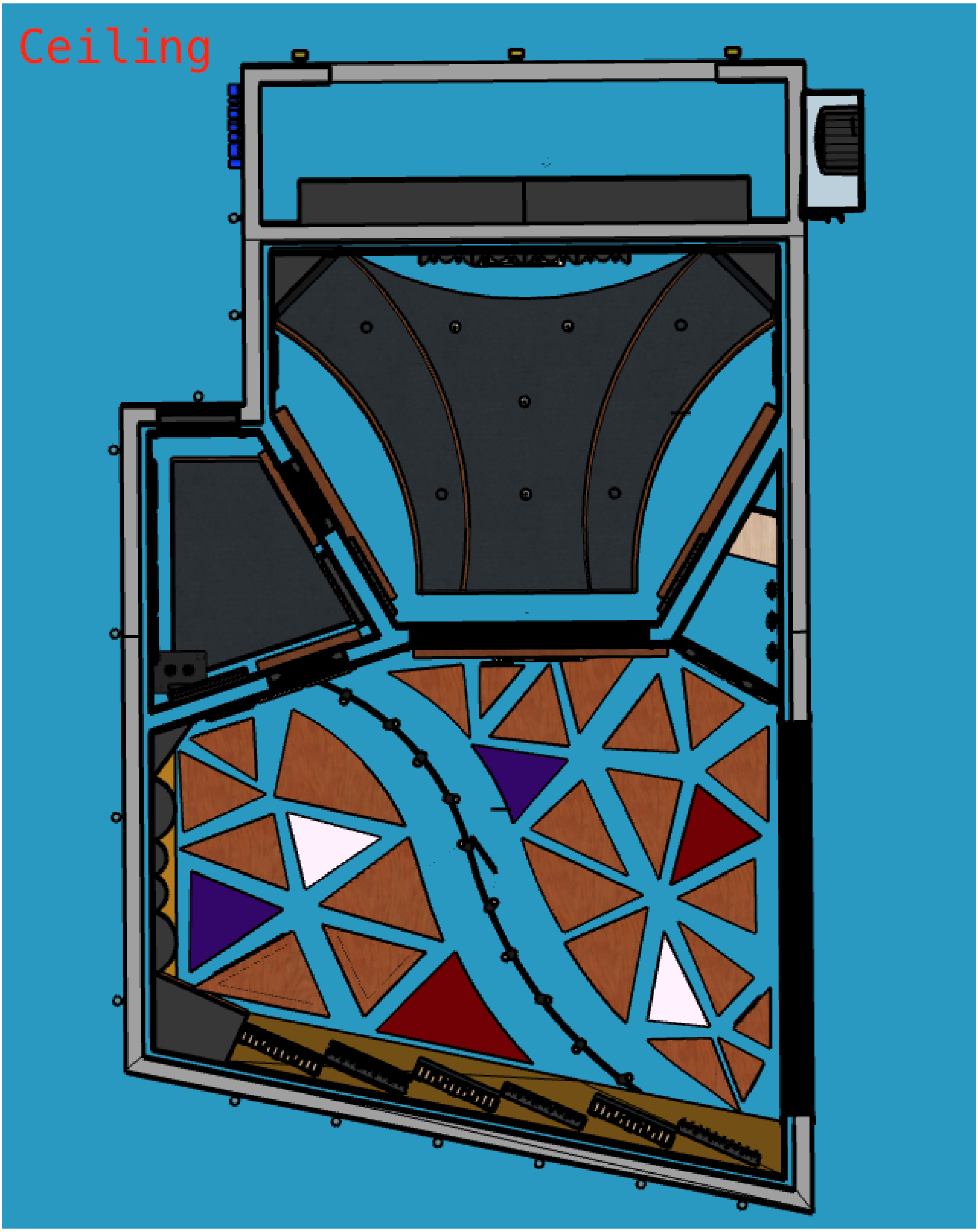


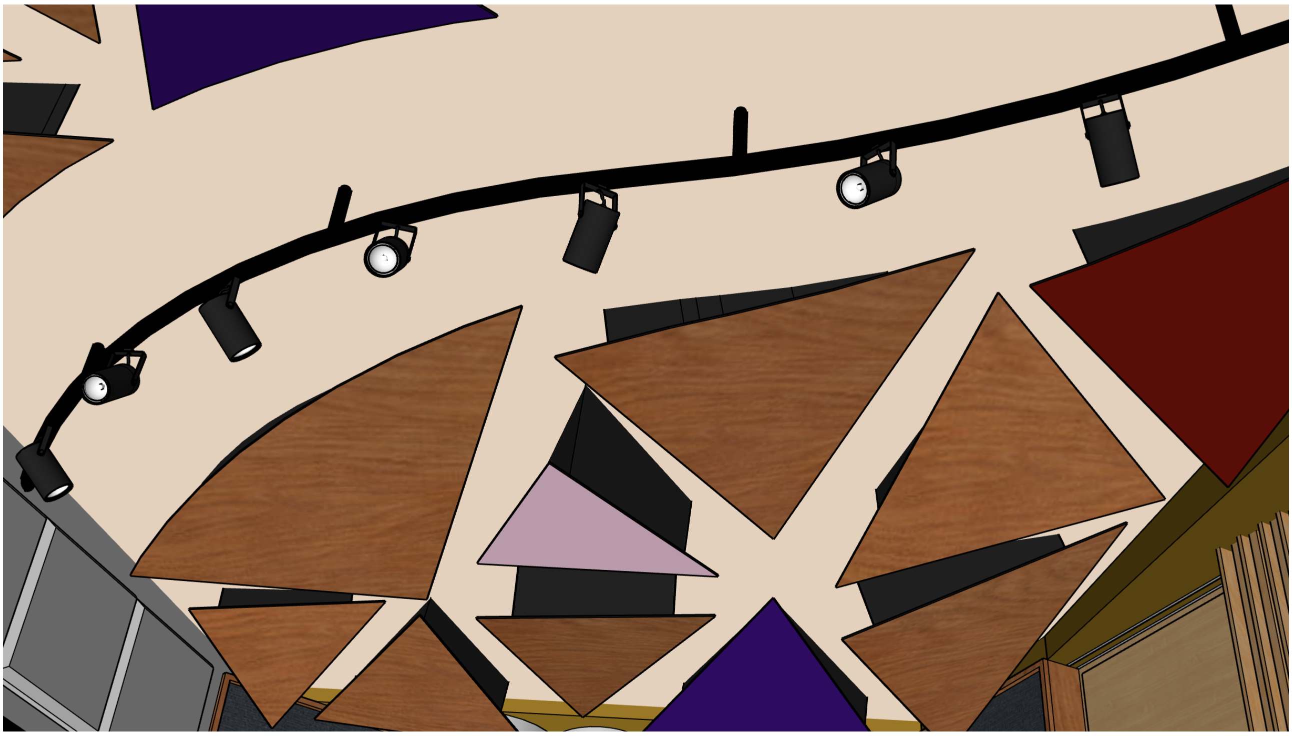


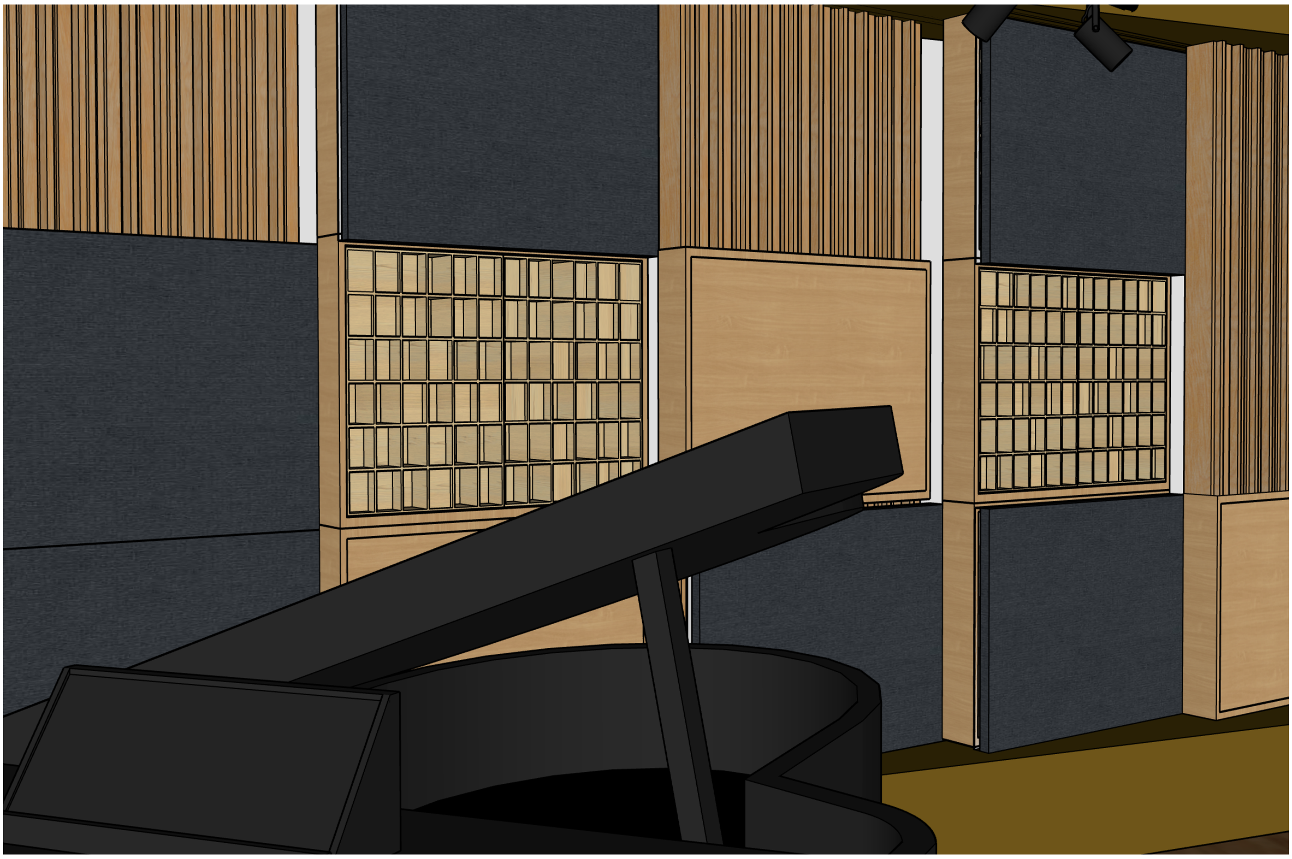







Ceiling





A Bubble Diagrams

A.1 PSK-1

- Pro's
  - Side facing CR (Per desired programming)
  - Views from CR.
  - Efficient symmetrical glass in CR.
- Con's
  - No view from LR
  - LR/Workshop Adjacency

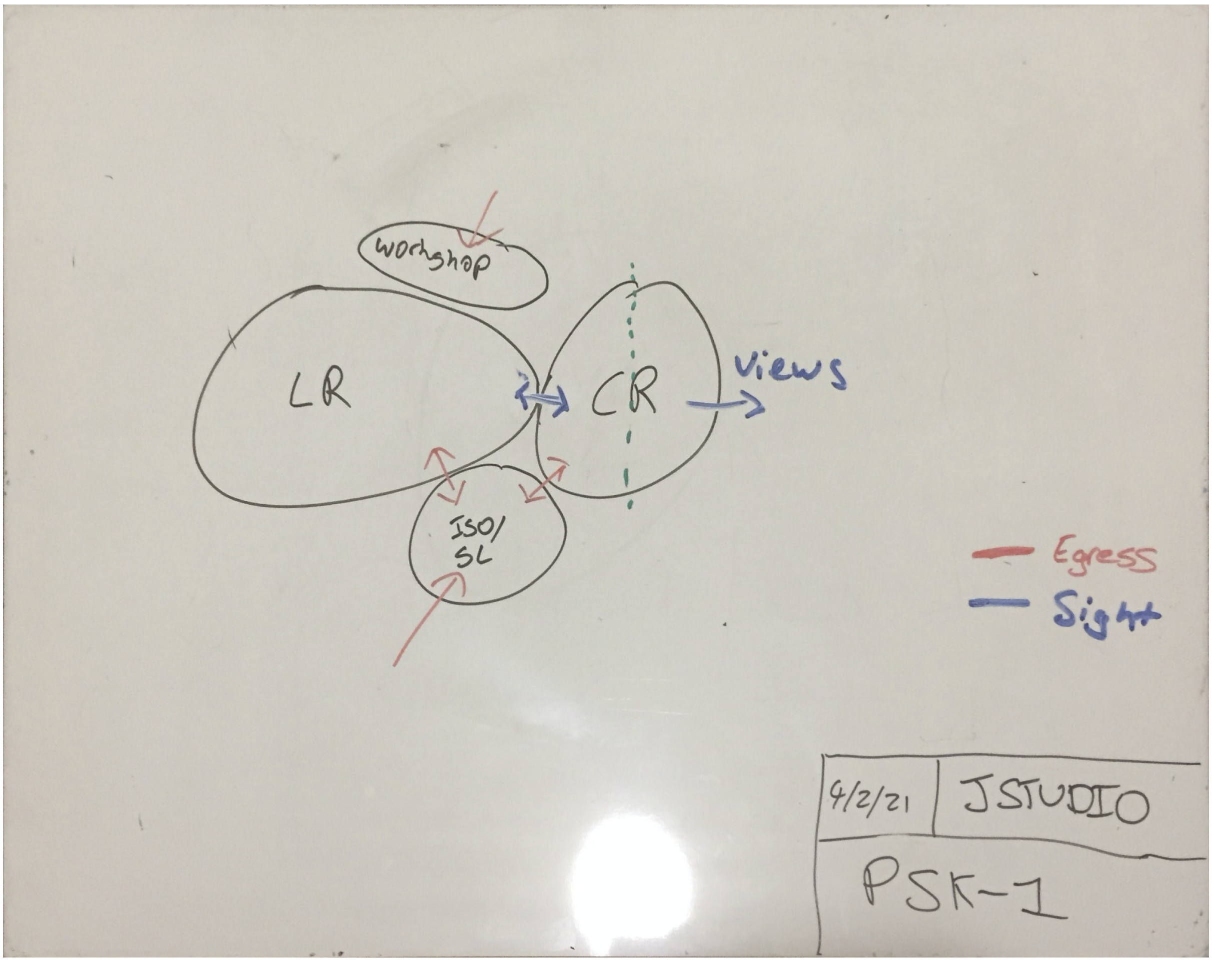


Figure 34: PSK-1.

A.2 PSK-2

- Pro's
  - Side facing CR
  - Views from LR, and CR (via LR)
- Con's
  - Asymmetric, inefficient use of glass in CR
  - LR/Workshop Adjacency

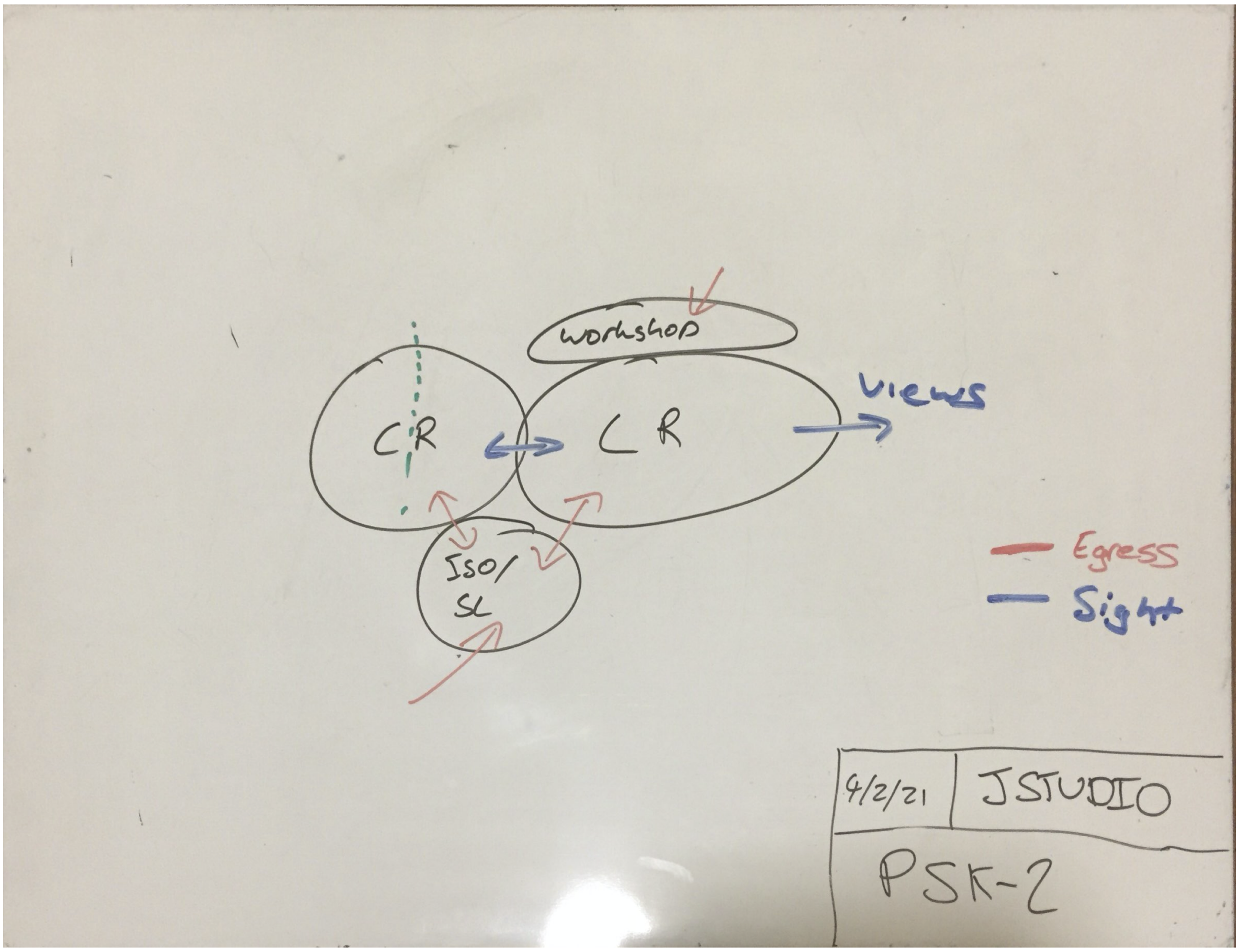


Figure 35: PSK-2.

A.3 PSK-3

- Pro's
  - Views from CR and LR
  - CR/Workshop Adjacency
  - Sidefacing CR
- Con's
  - Lots of asymmetric, inefficient use of glass in CR

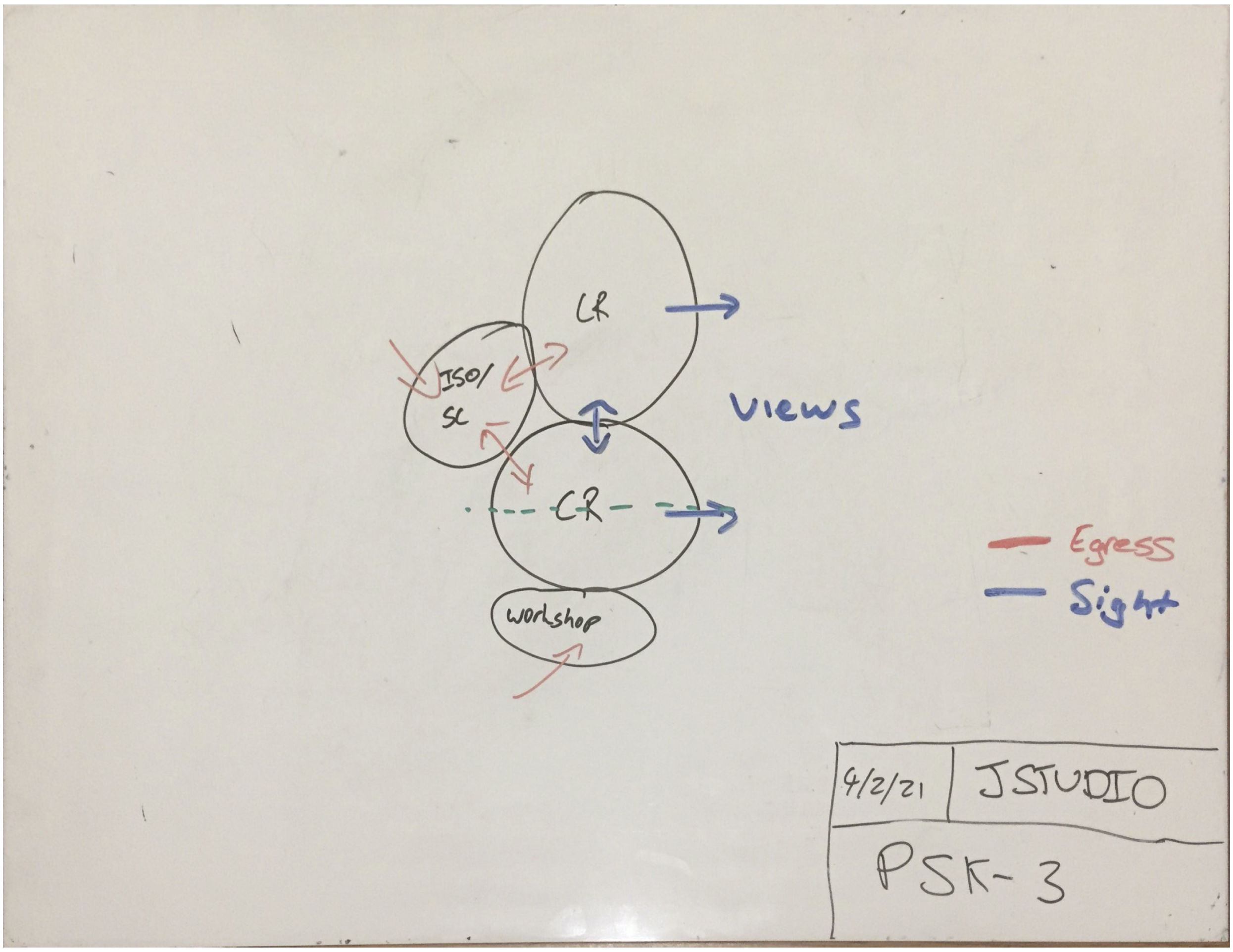


Figure 36: PSK-3.