



**Chamber Hall Threshold Design
and Acoustic Surface Shaping
with Parametric Modeling**

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Chamber Hall Threshold Design and Acoustic Surface Shaping with Parametric Modeling

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Thesis submitted to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
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in
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ABSTRACT

The architectural opportunity to develop the sound and light look of a performance venue as a space that engages and prepares the audience for a performance is one that is sadly missing from most halls. I have explored the development of this threshold as a true architectural space, one that enhances the overall experience for the audience members. And by introducing a parametric process into the architectural and acoustic development, have proposed a unique process for the design of concert halls. From physical model building to analysis by computer simulation, digital technology has undoubtedly advanced the realm of acoustic prediction. But common computer prediction programs that exist today are still essentially digitized applications of the analog model building process. Being: construct a model, analyze, make adjustments and repeat until the desired results are achieved.

By implementing a parametric approach to model building it allows for design changes and the significance of those changes to be recognized in real time, an invaluable tool in the development of a sound-sensitive space. Utilizing the 3D software Rhinoceros and its scripting plug-in Grasshopper, it becomes possible to easily visualize crucial first-order reflections relative to surfaces that can be controlled and manipulated in very precise ways. This software is becoming more popular amongst architects and designers, and the prediction process will be an extension of this software into the field of acoustics. By using software already in the design vernacular, there is a seamless transition between design and analysis, making for a more cohesive project.

ACKNOWLEDGEMENTS

I would like to thank my committee members Michael Ermann, Patrick Clay and Randy Ward for their support throughout the duration of my thesis and for their efforts and contributions not only to this project but to my education and career as well.

Additional thanks to Jonathan Grinham and David Rife for helping me conquer the software.

I would also like to thank my friends and family for helping me get where I am today, with special thanks to Charles Schilb for keeping me sane and always reminding me that there is a light at the end of the tunnel.

Thank you all.

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SOUND AND LIGHT LOCKS

The typical role of the sound and light lock in a performance venue is purely pragmatic; its purpose being to allow occupants into the interior of the hall while keeping out light and noise that may enter from the lobby. As a result these spaces are usually characterized by efficiency at every design decision.

This is detrimental to the overall performance experience because these spaces are the threshold through which we are first exposed to the hall beyond their doors, and as such they should be given as much attention as the performance space.

The space we enter has the potential to either calm or excite, create tension or release, but it must always prepare us for entry into the theatre. Unfortunately in most cases it is reduced to a hallway or closet.

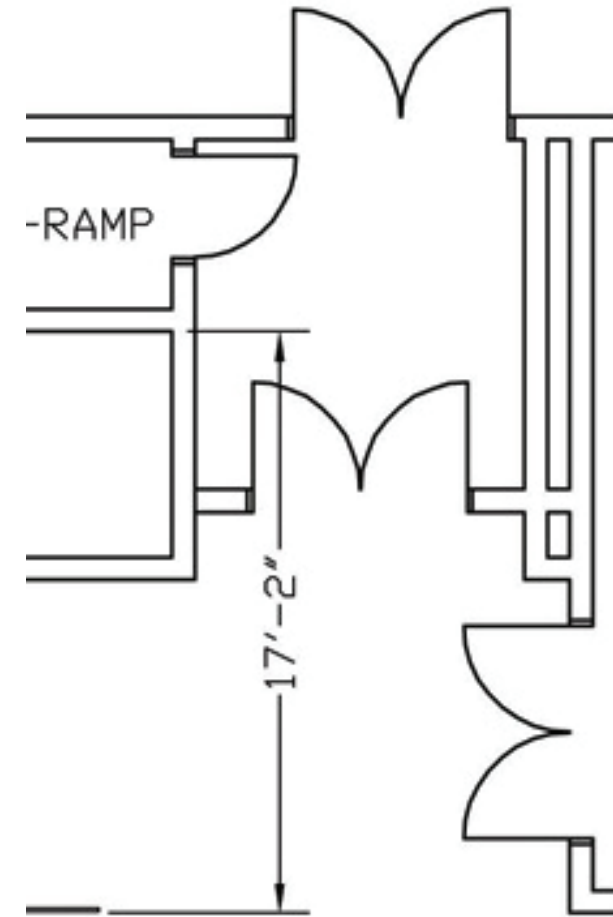


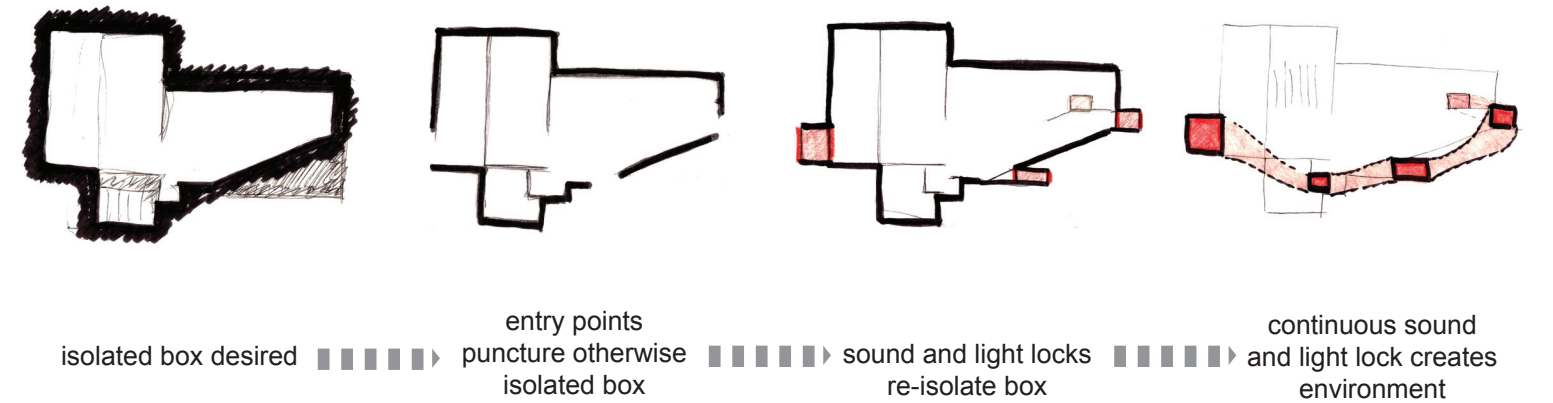
Image 1 - typical plan of sound and light lock



Image 2 - corridor type sound and light lock

One of the goals in acoustics is to create a contained volume of sound. This contributes to the reverberance of the hall and enhances the overall sound quality. But there must be a way to enter, so we introduce doors and hallways and puncture the contained volume, allowing for sound to escape and light and noise to infiltrate.

Typically, we would combat this with the sound and light lock. But instead of creating separate, disparate volumes at every entry point, I have proposed connecting and expanding these volumes to create an environment that one wants to experience, a far cry from the pragmatic, efficient vestibules of most theatres.



The canyons of the American southwest have served as a natural source of inspiration for the atmosphere of the threshold as one navigates this venue. Their shapes naturally filter light in dramatic fashion, and one must wind through their crevices, the unknown at every turn.

Similar ideas have permeated the development of the thresholds for the chamber music hall. The dramatic filtering of light and the meandering of circulation heightening the anticipation of the eventual entry into the formal performance space.



Image 3 - Antelope Canyon, AZ





SURFACE SHAPING

The intimate nature of the chamber music hall suggests balcony seating that remains close to the performers and integral to the volume of the hall.

The sweeping, draping form of the tiers provide convex balcony fronts that diffusely reflect sound back toward the main audience floor; each providing space for approximately thirty patrons.



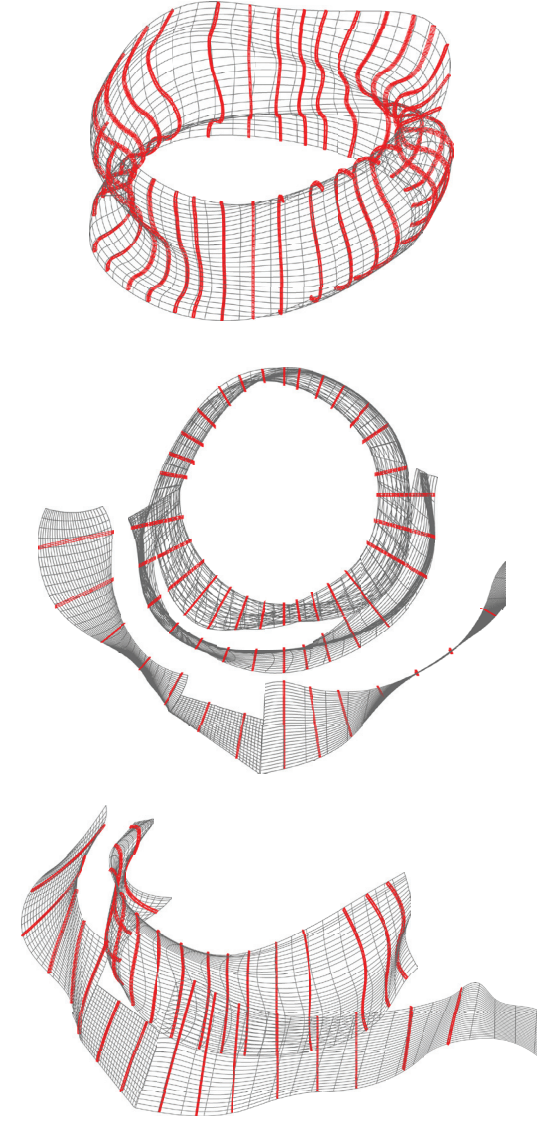
balcony rendering



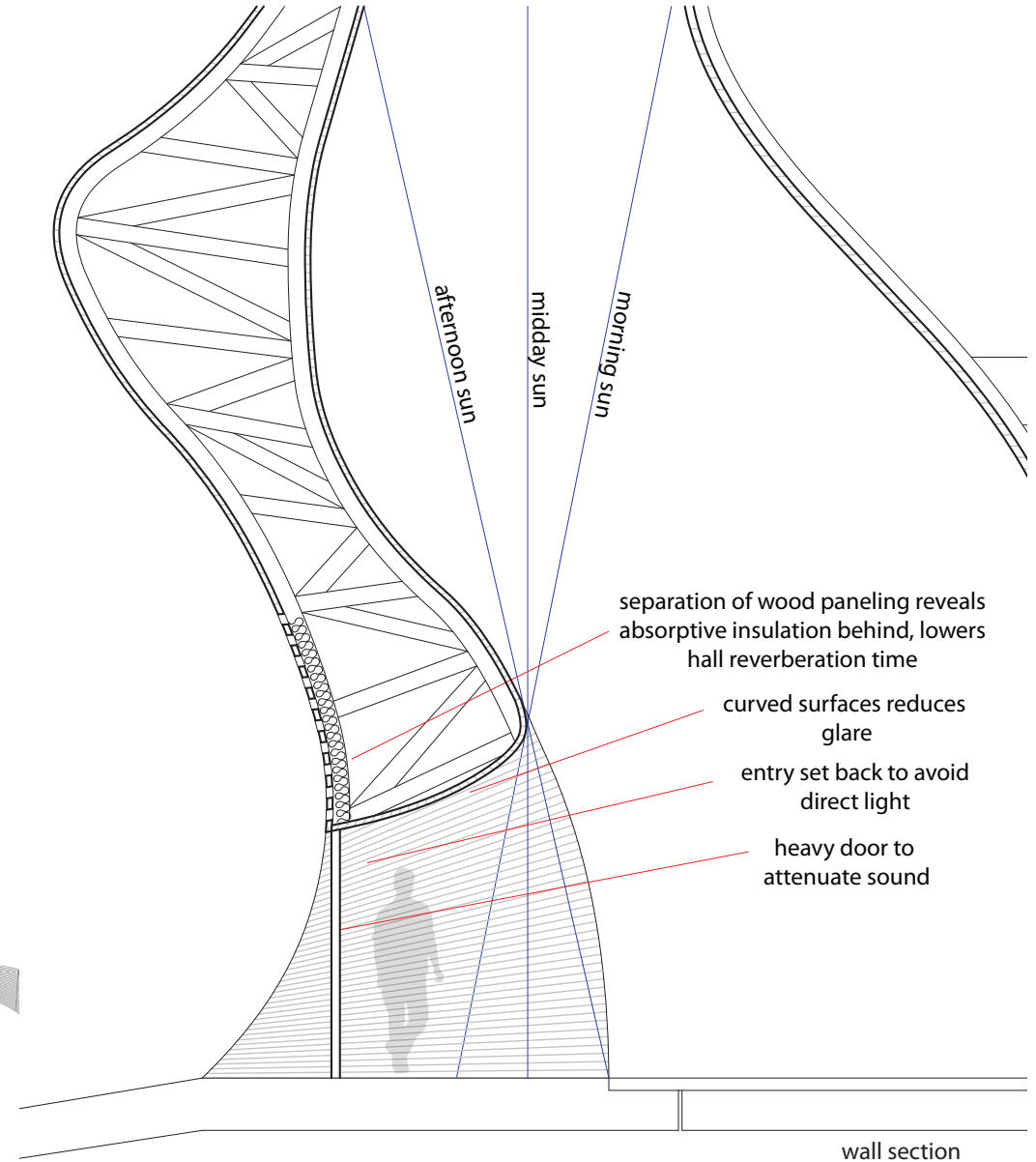
3D print

As the canyon-like circulation space continued to develop, the form of the space became more about the way one inhabits the space and less about the pragmatic duties of the sound and light lock.

To mitigate the functional sacrifices made for the sake of form, the role of attenuating sound and filtering light is handled through careful placement of thresholds, locating them on the concave sides of wall curvatures to block light from above; and through detailing of the actual entryway, carefully controlling material and thickness for sound attenuation.



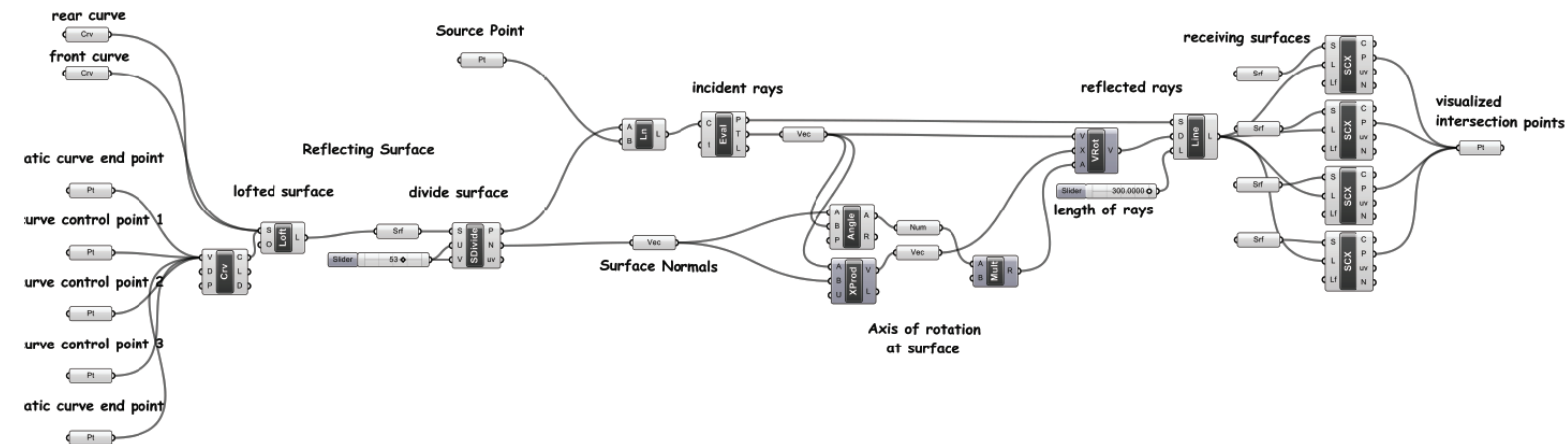
structural diagram



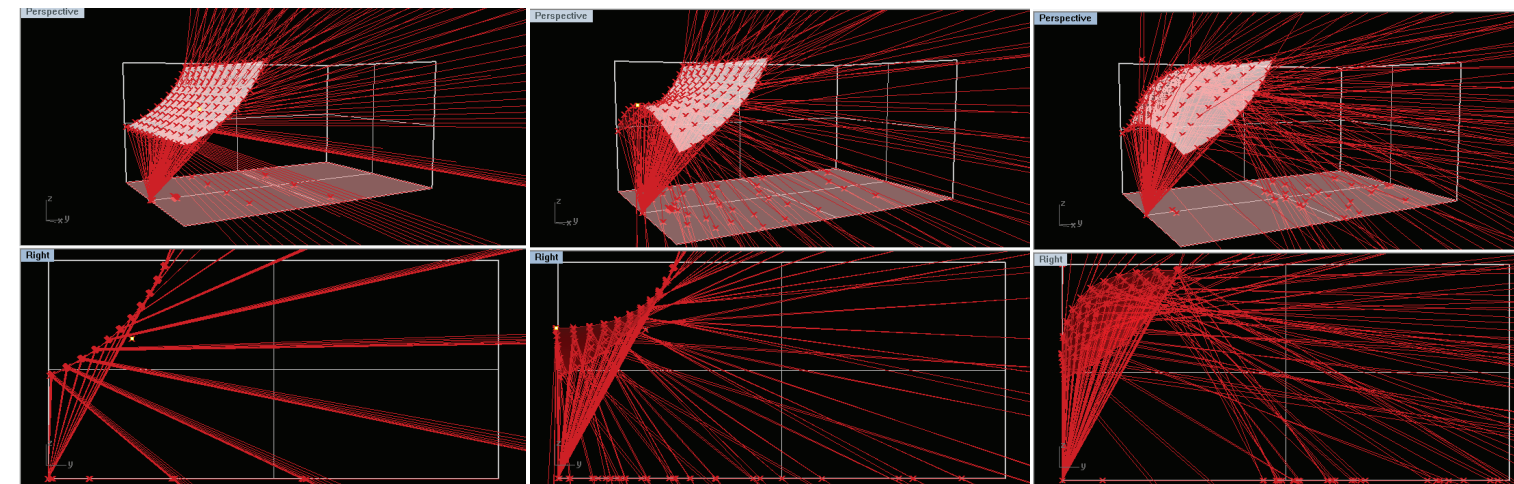
wall section

PARAMETRIC APPROACH

The general concept of parametric modeling can be described as developing a model based on a series of variables (or parameters) versus modeling with discrete entities. In the case of architectural design, this means establishing a sequence of relationships that dynamically create form versus modeling fixed geometries. Architecturally this has many implications, with designers finding new ways to utilize the process every day. Surface paneling, constraint-based modeling and project feasibility are just some of the ways that parametric tools are being integrated into the architectural process. Understanding the software first from a design standpoint has allowed me to be able to recognize the potential of this tool in other applications. And there is a strong case to introduce parametrics into the field of acoustics. By using parametric modeling to operate within the digital realm shared by both design and analysis we can introduce acoustic parameters into an architectural model to control the shape of key surfaces in sound critical spaces.

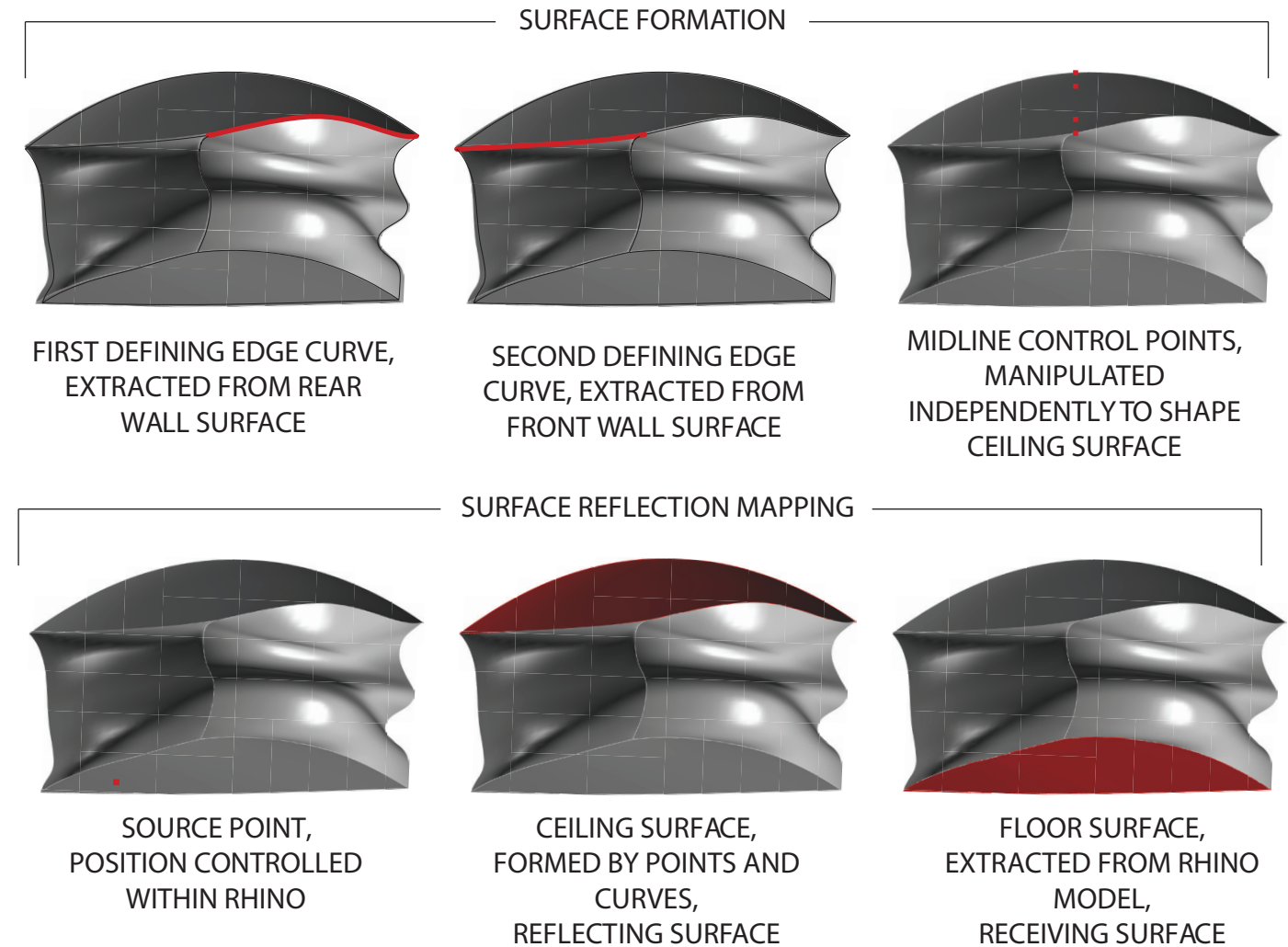


grasshopper definition



first-order reflection mapping with simple surface manipulation

At its simplest, the prediction model consists of three inputs: one source point, one surface that will be reflecting rays from the source point, and another surface that will be receiving rays from the reflecting surface. These three basic components can be built in Rhinoceros and imported into the Grasshopper definition, where the reflections will be calculated and mapped in the Rhinoceros window. The significance of the parametric nature of the process becomes clear as you begin to manipulate the input parameters in Rhinoceros. Since the surfaces are linked to the script in Grasshopper, when you modify any of the input components in Rhinoceros, the reflections that are mapped change accordingly. For example, rotating of one of the surfaces or moving the position of the source point will correspond to a real-time translation of the reflections.



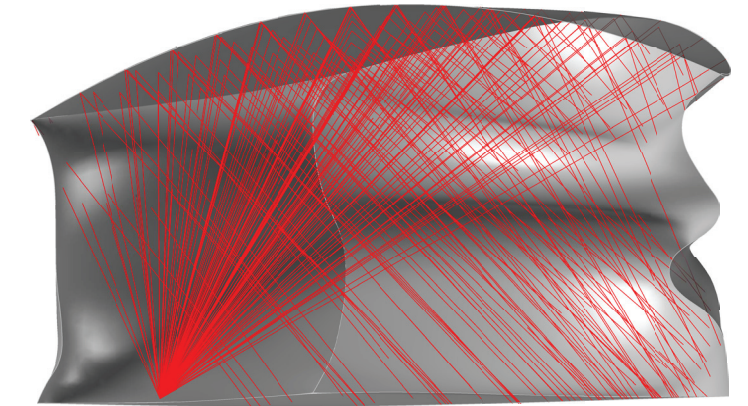
descriptions of Grasshopper input parameters

While the ray tracing of simple geometries may be straight forward, with the experienced acoustician being able to easily identify a successful hall over an inappropriate one, building technologies are advancing and architects are pursuing more complex forms in their design. Acoustic prediction of these buildings becomes much more complicated and this is where the parametric tools become most valuable. By conducting analysis within the very software that is developing these complex geometries there is a high degree of efficiency to the process of mapping reflections that is relevant to both the architect and the acoustician.

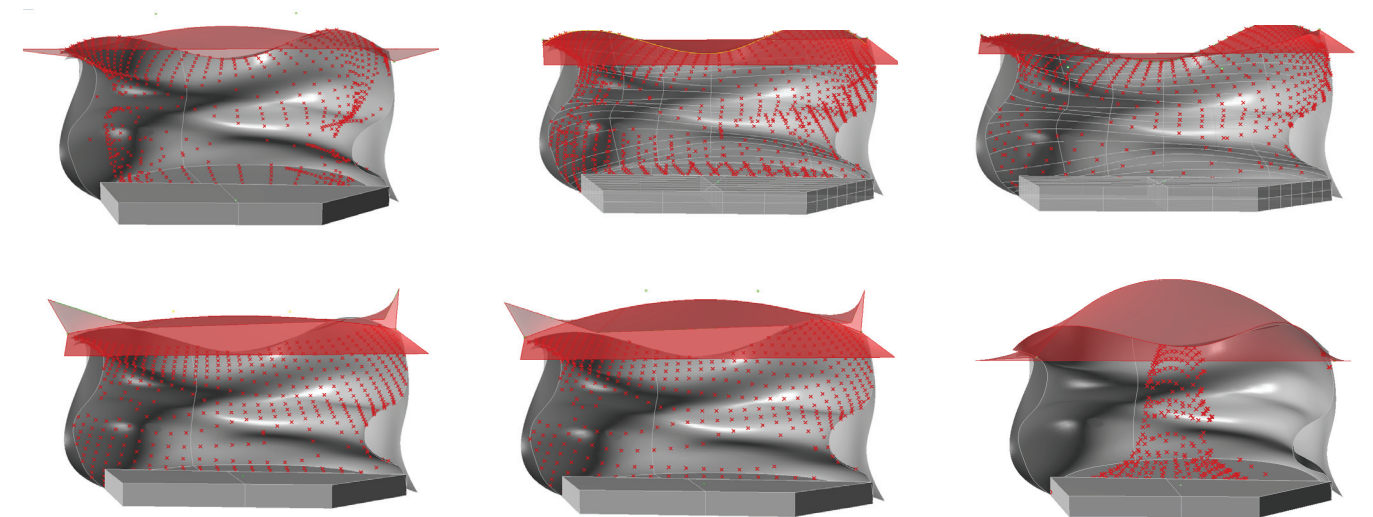
The Grasshopper definition becomes even more powerful as the surfaces decompose into their constituent parts, allowing a greater degree of parametric control over the surfaces. Where there once was a single surface, that surface can be rebuilt based on two curves that are lofted together. Then the surface can be built and rebuilt by way of manipulating the curves. To add another degree of control we can build the curves as a series of points, each point being able to move independently and thus generating a seemingly infinite series of surfaces.



hall interior surfaces

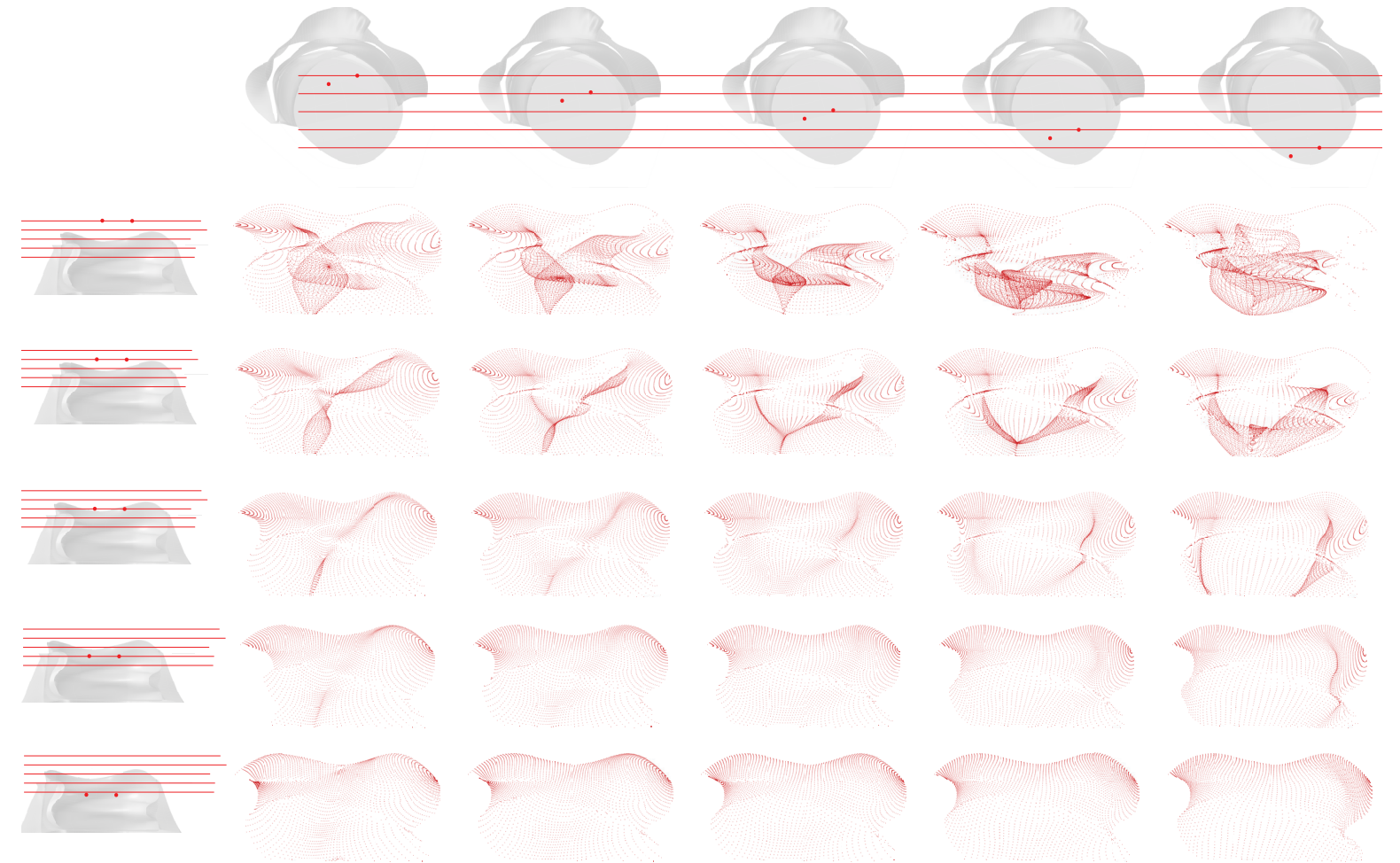


grasshopper generated ray diagramming



ceiling studies with mapped first-order reflections

This is where the true power of this tool lies; in its ability to produce many iterations very quickly. Change the orientation, size, position, or curvature of any of the input variables and the consequences of those design changes are immediately visualized. And the more parameters that are controlled in Grasshopper the greater the possibility to generate unique solutions.

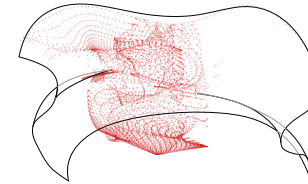


first-order reflections from ceiling surface organized by position of surface control points

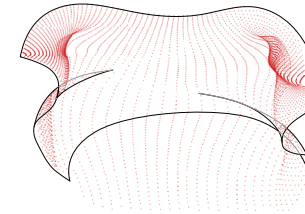
By implementing a systematic approach to the manipulation of the variable control points, successful patterns become clear. Knowing which moves have the most significant positive change on the configuration of the hall, those critical surfaces can be identified and used to make design decisions.

In this series the shaping of the ceiling was studied, specifically how its shape would affect reflections to the main audience floor. The visualization of the resulting reflections dictated the eventual geometry of the hall.

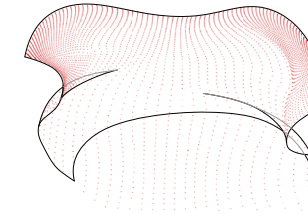
CENTER FOCUSING



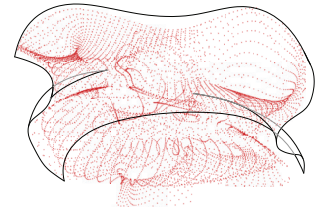
EDGE FOCUSING



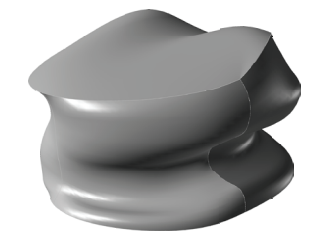
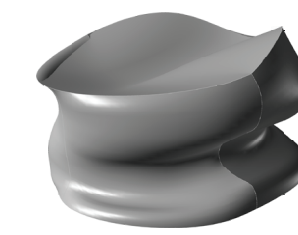
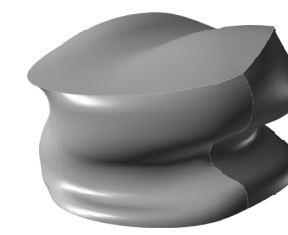
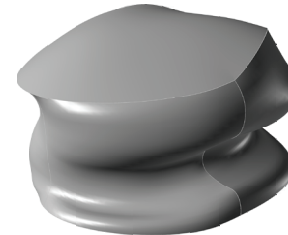
TOO FEW REFLECTIONS TO AUDIENCE



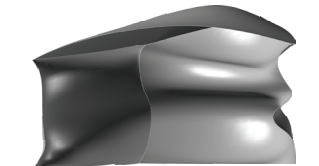
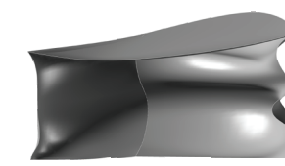
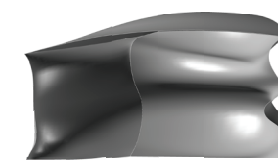
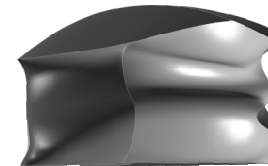
APPROPRIATE REFLECTIONS



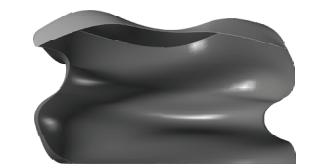
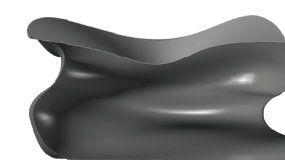
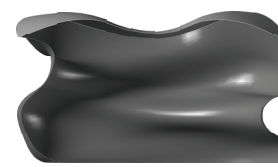
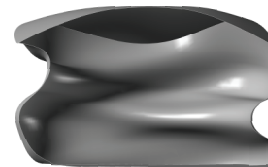
mapped reflections



perspective

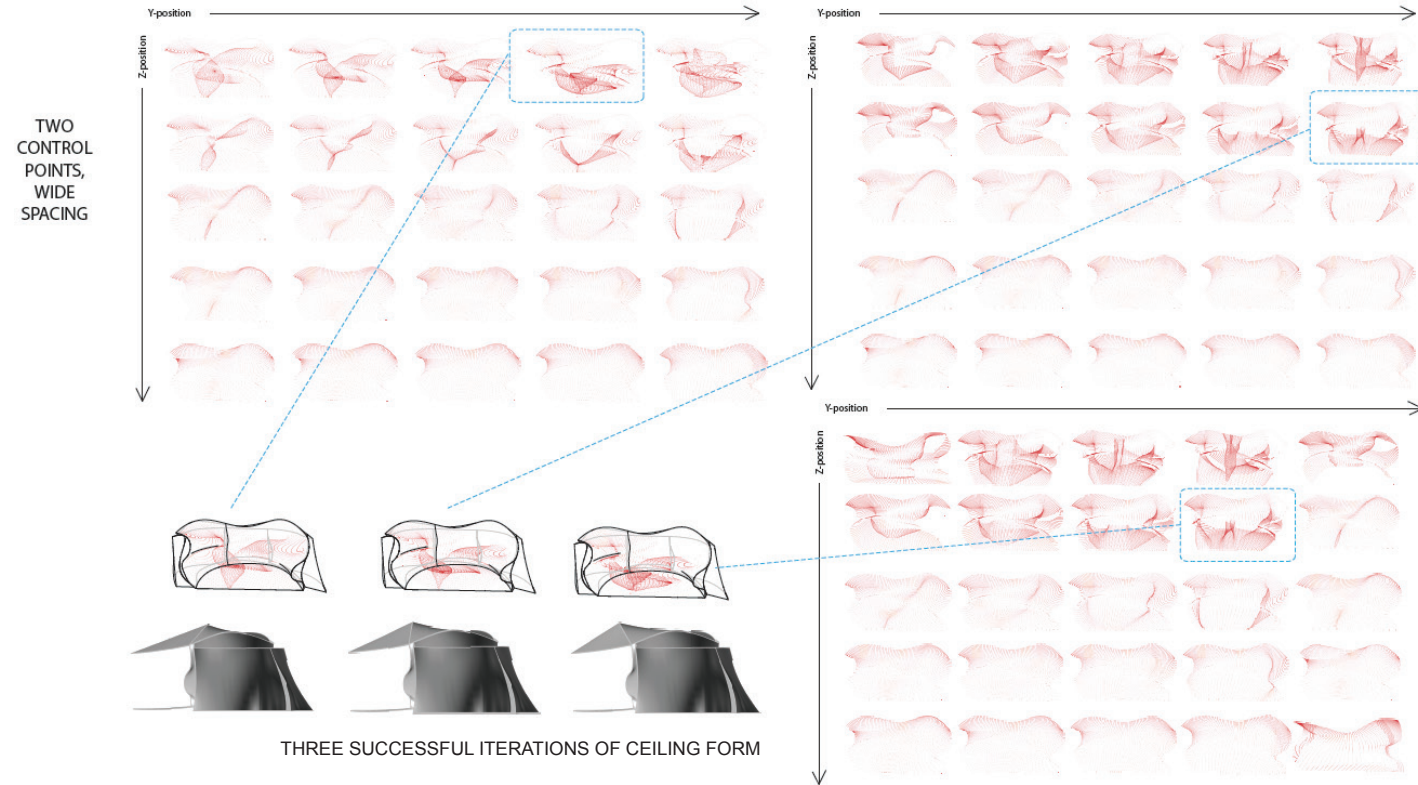


transverse section



longitudinal section

MAPPING OF CEILING REFLECTIONS BASED ON CONTROL POINT POSITION



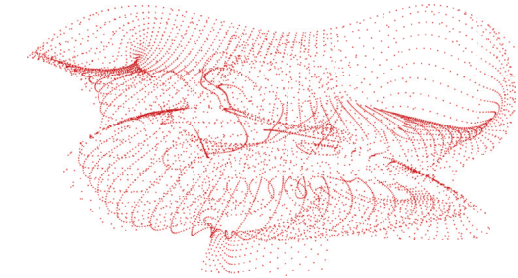
Pulling from a wide array of reflection mapping studies, organized by placement of the surface control points, I was able to identify those ceiling configurations that were most successful and use this information to come to the final ceiling form.

TWO CONTROL POINTS, NARROW SPACING

THREE CONTROL POINTS, VARIABLE SPACING



Initial Hall Surfaces



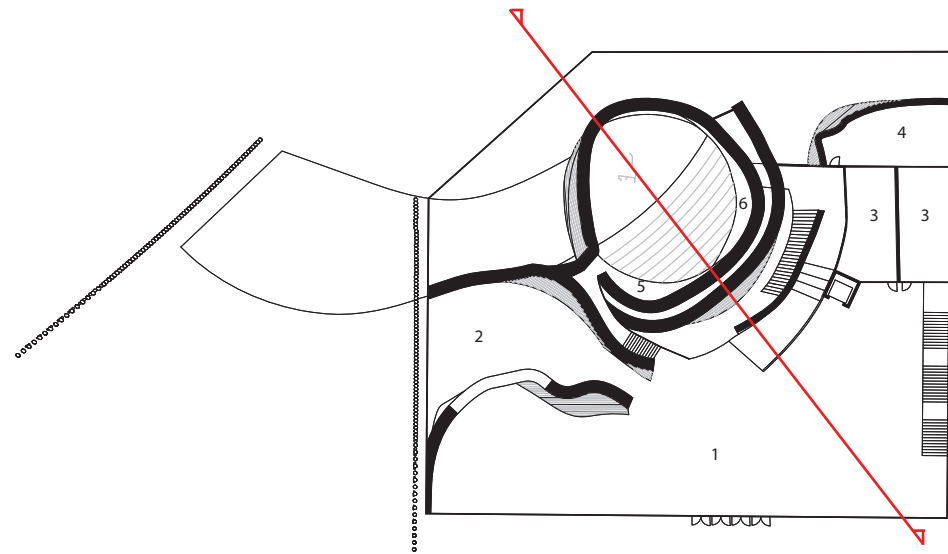
Final Reflection Mapping



Final Hall Ceiling

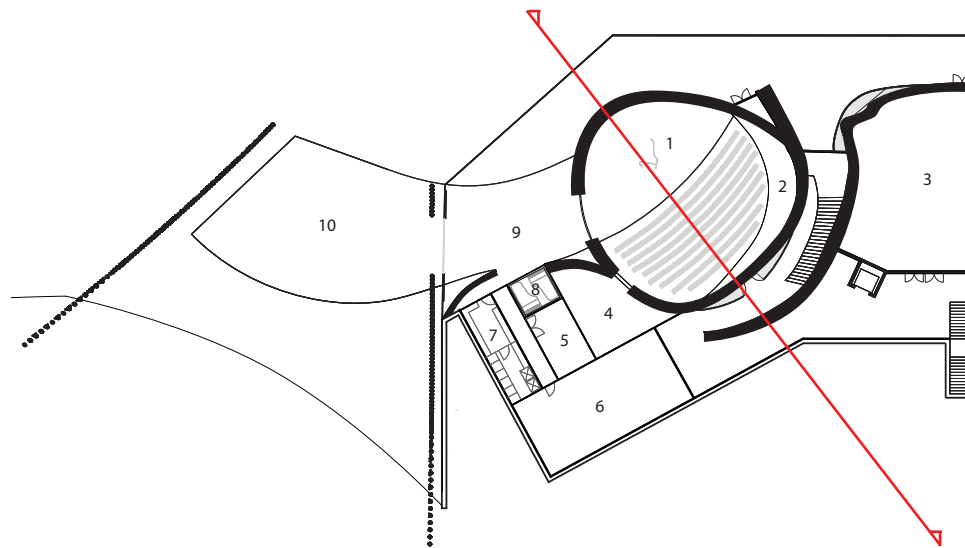






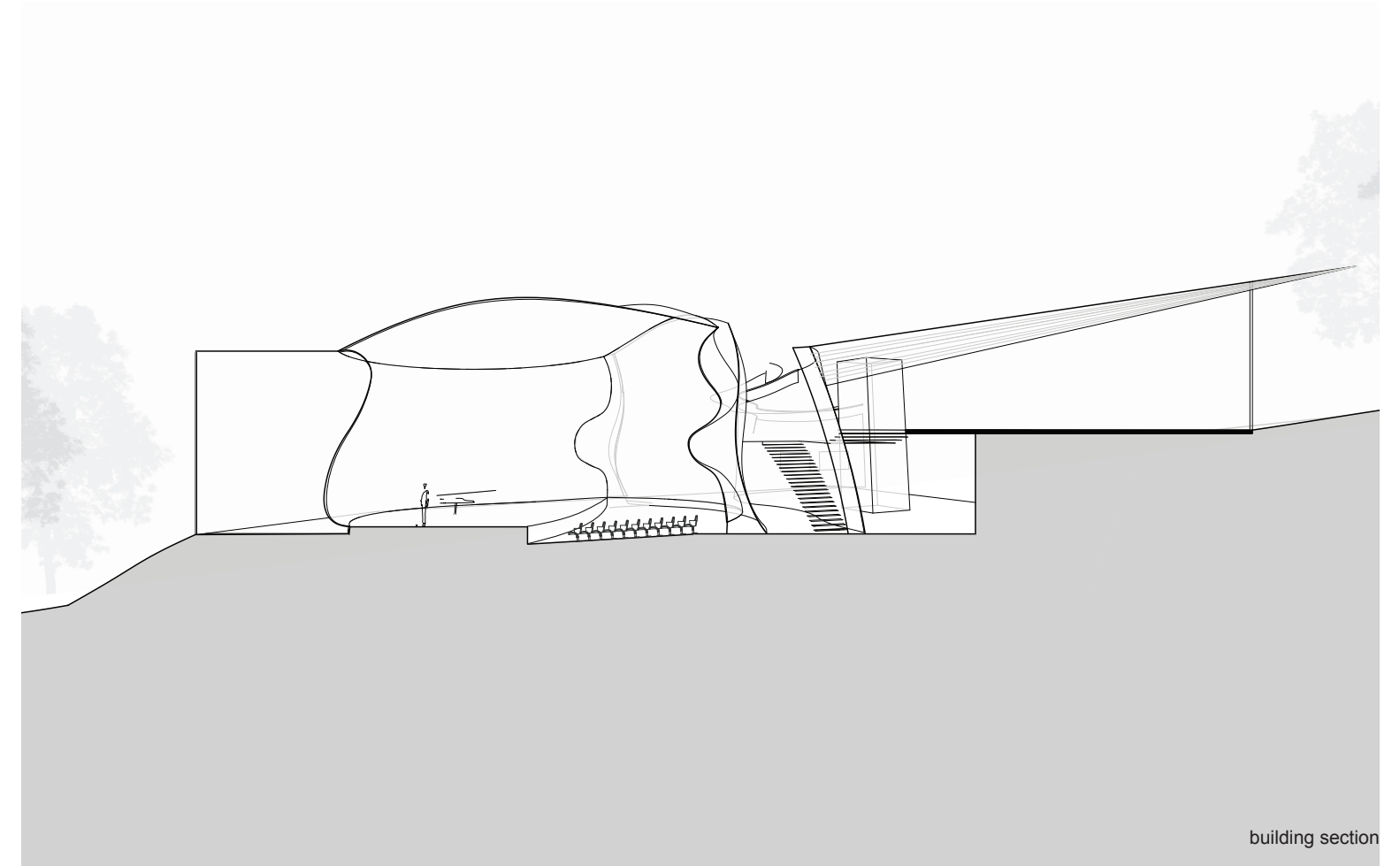
- 1. Lobby
- 2. Ticket Booth and Office
- 3. Restrooms
- 4. Storage
- 5. Upper Balcony
- 6. Lower Balcony

lobby level plan



- 1. Chamber Hall Stage
- 2. Lower Balcony
- 3. Green Room
- 4. Tech Booth
- 5. Instrument Storage
- 6. Mechanical Room
- 7. Dressing Rooms
- 8. Piano Storage
- 9. Side Stage
- 10. Amphitheater Stage

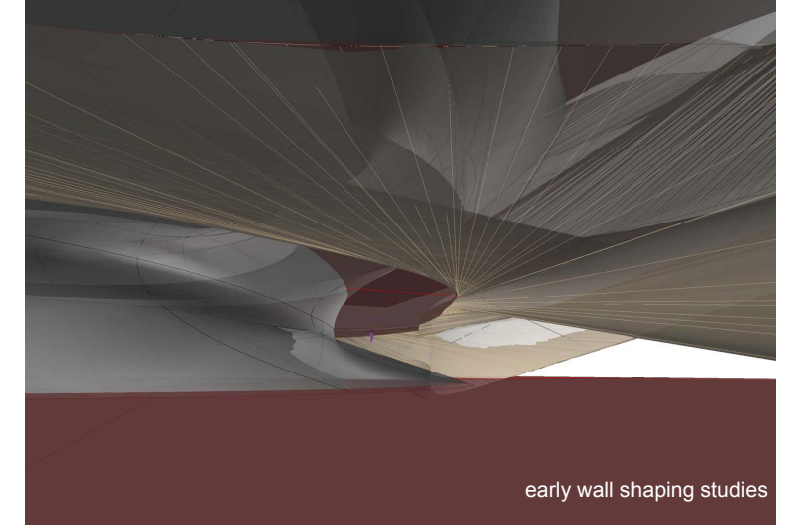
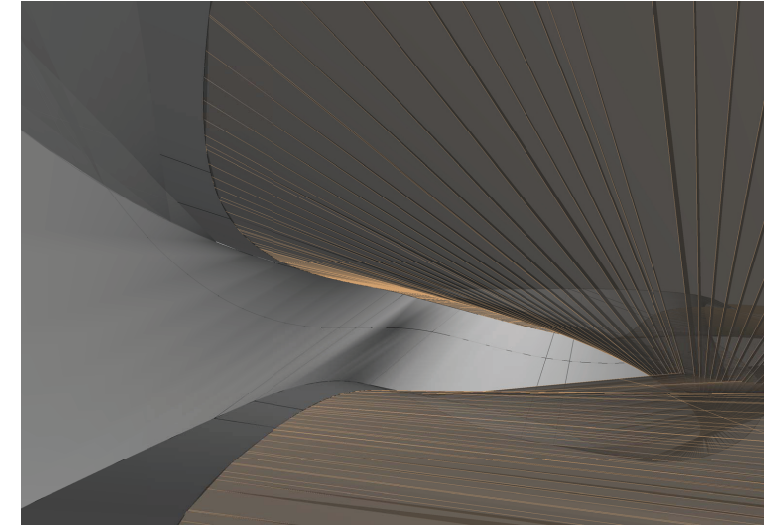
stage level plan



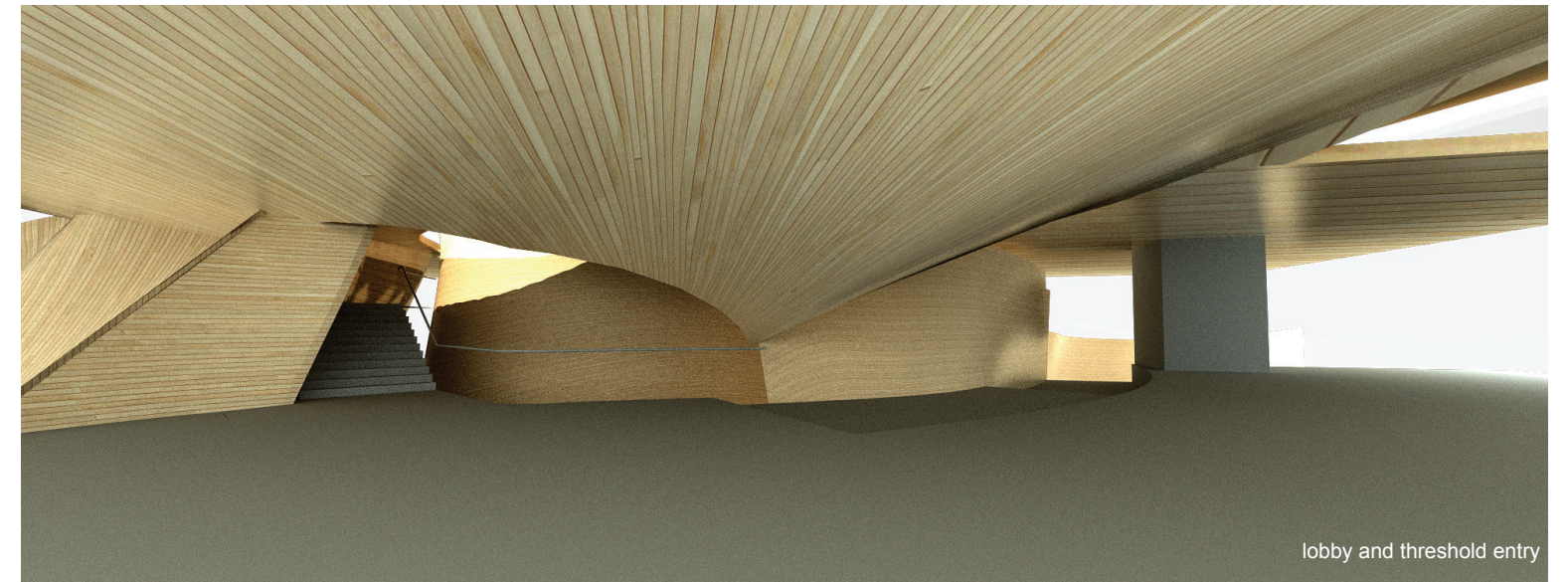
building section

TENSION AND RELEASE

The architectural idea of tension and release has informed several aspects of the building design in a variety of ways. In one manifestation of the concept, theater patrons pass through the lobby where the ceiling surfaces undulate and drop compressing the space from a grand lobby space down to human scale. In the threshold spaces the curvilinear walls come together and pull apart as theater-goers wind their way through the canyon like space. These spaces contribute to the larger idea of the threshold acting as a preparatory experience, a series of rises and falls before the eventual entry into the chamber hall, the final release.

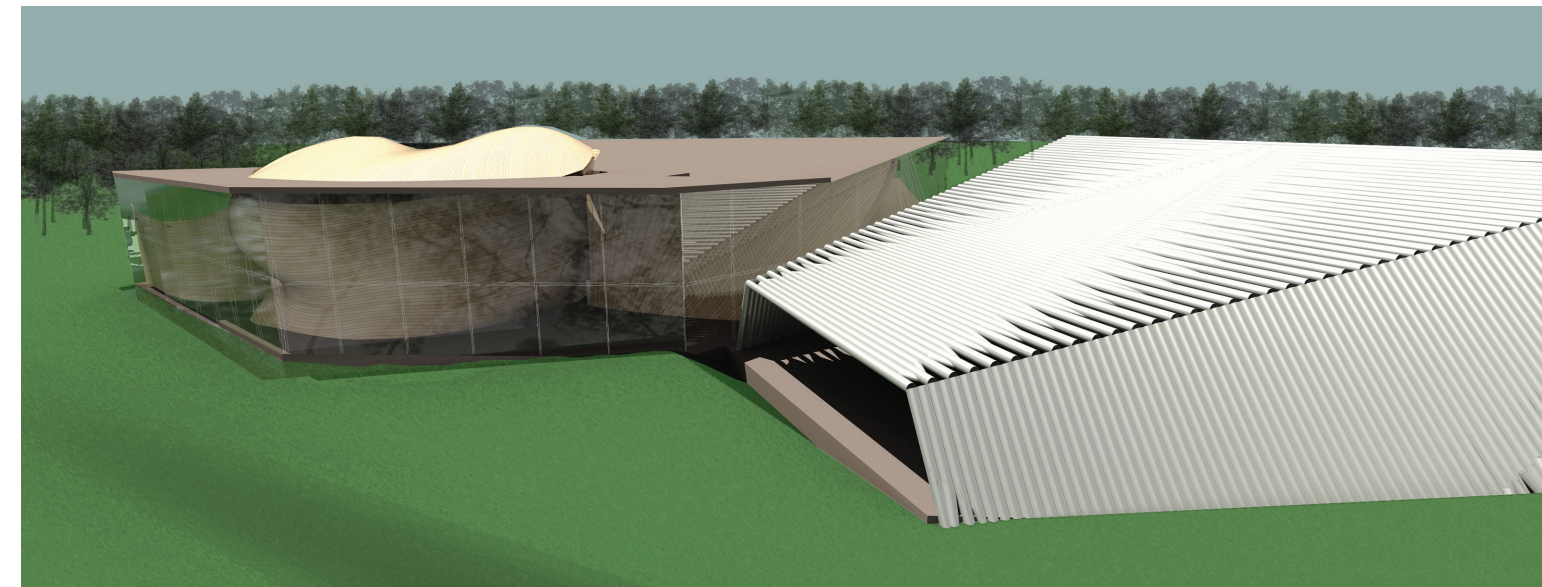


early wall shaping studies



lobby and threshold entry

In a second application of the tension-release concept, the surfaces of the amphitheatre comprised of individual members, work both together and against each other in such a way as to form a unique surface; embodied by moments of tension and release. Characterized by the overall density of material, the aesthetic expression of the surfaces speaks to both the acoustic behavior and the architectural form.

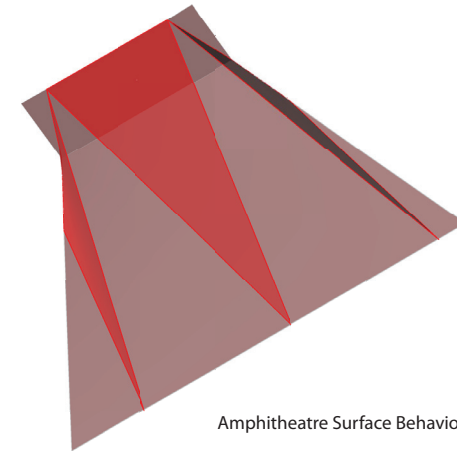


amphitheatre and chamber hall exterior

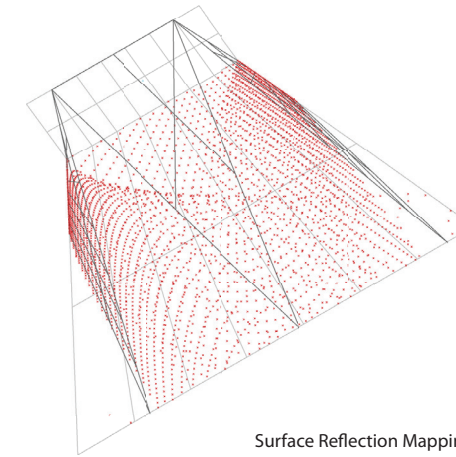
AMPHITHEATRE DESIGN

In a tangential application of the Grasshopper software, the scripting tool is used to shape the enclosure of a covered outdoor amphitheatre. The application here was to be able to maximize the number of useful reflections while minimizing the amount of material overhead.

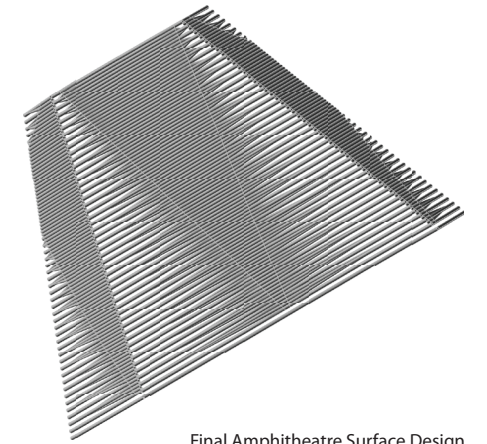
Inputting the general shape of the amphitheatre surfaces, we can divide said surface into a series of discrete linear elements. But by skewing the way this surface is divided we can create an uneven distribution of material. This allows us to build up material in some places and take away material in others. Meaning that we can eliminate material where it does not add to the acoustic quality of the amphitheatre. This same process is applied to the side surfaces, and both come together to create an even distribution of sound across the amphitheatre with minimal material.



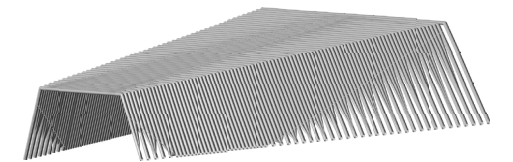
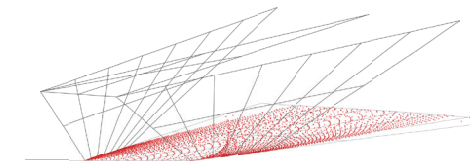
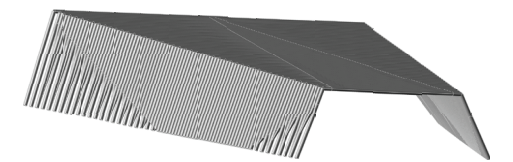
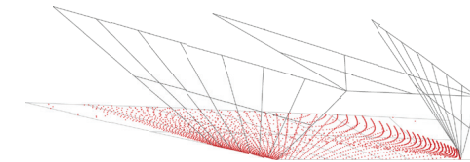
Amphitheatre Surface Behavior



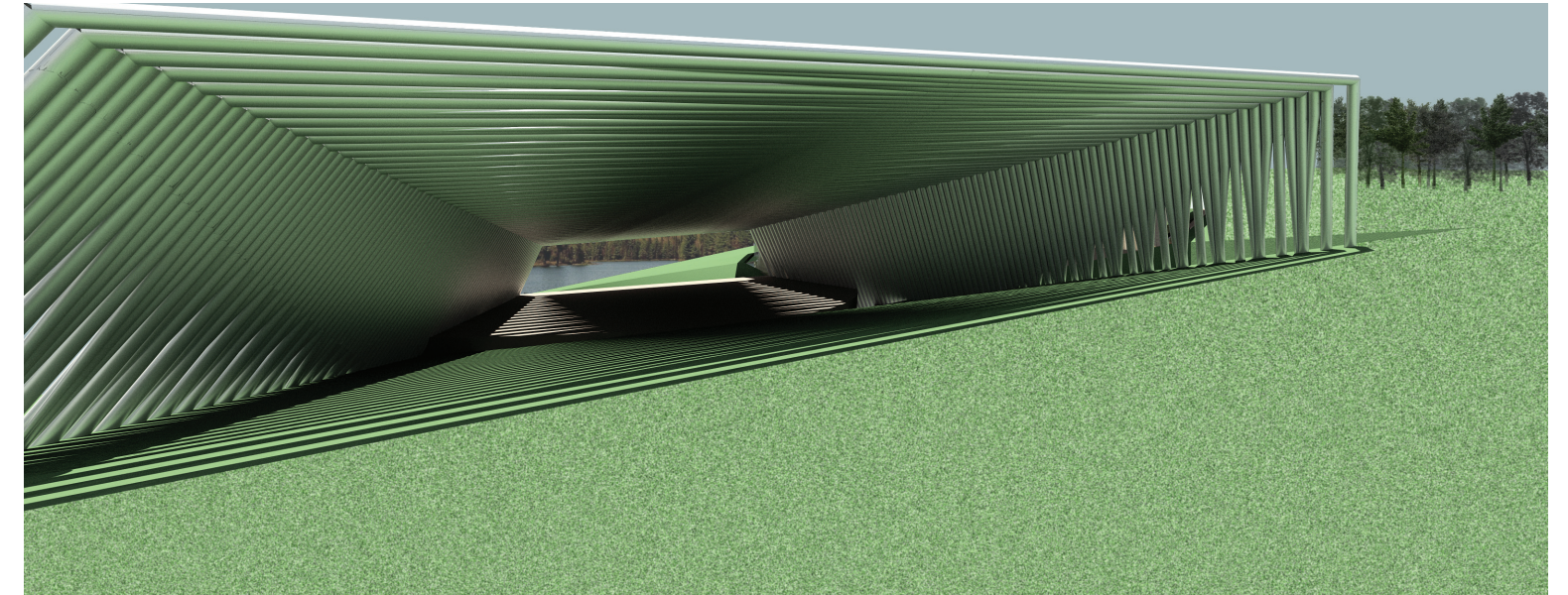
Surface Reflection Mapping



Final Amphitheatre Surface Design



Working with a set source position and the natural slope as it exists on the site, the Grasshopper script is used to identify those points on the overhead and side surfaces where reflections from the stage are going to be most important in directing sound to the audience. After identifying these points as “attractor points” the surface is divided relative to its proximity to these points. For example, where the incident sound rays are striking the surface in a location crucial for ample reflections, the surface is dense and provides maximum reflections.



final amphitheatre surfaces

CONCLUSIONS

While this project was mostly characterized by architectural design through rational acoustic analysis, the final building forms are also imbued with a great deal of intuitive architectural form-finding, influenced by the sculptural architecture of some of the most dramatic natural spaces on the planet. The successful synergy of these two seemingly contradictory processes resulted in a wholly unique architectural resolution to the acoustic cliché of the sound and light lock. In addition to furthering my own design solutions, the parametric process developed has the potential to change the way in which both architects and acousticians approach the design of modern theatres and concert halls; providing a designers with a holistic process and the possibility for a more cohesive design.



DESIGN REFERENCES

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Egan, David M. *Architectural Acoustics*. 1st ed. New York: McGraw-Hill, 1988. Print.

Izenour, George C. *Theater Design*. 2nd ed. New Haven: Yale University Press, 1996. Print.

IMAGE REFERENCES

Image 1.

<http://www.sicoinc.com/docs/dimensions/Theatre/Insta-Theatre-Plan.jpg>

Image 2.

<http://www.umaec.umich.edu/projects/Hill/photos.html>

Image 3.

<http://beautifulplacestovisit.com/canyons/antelope-canyon-arizona-united-states/>

APPENDIX A - ACOUSTIC STUDIES

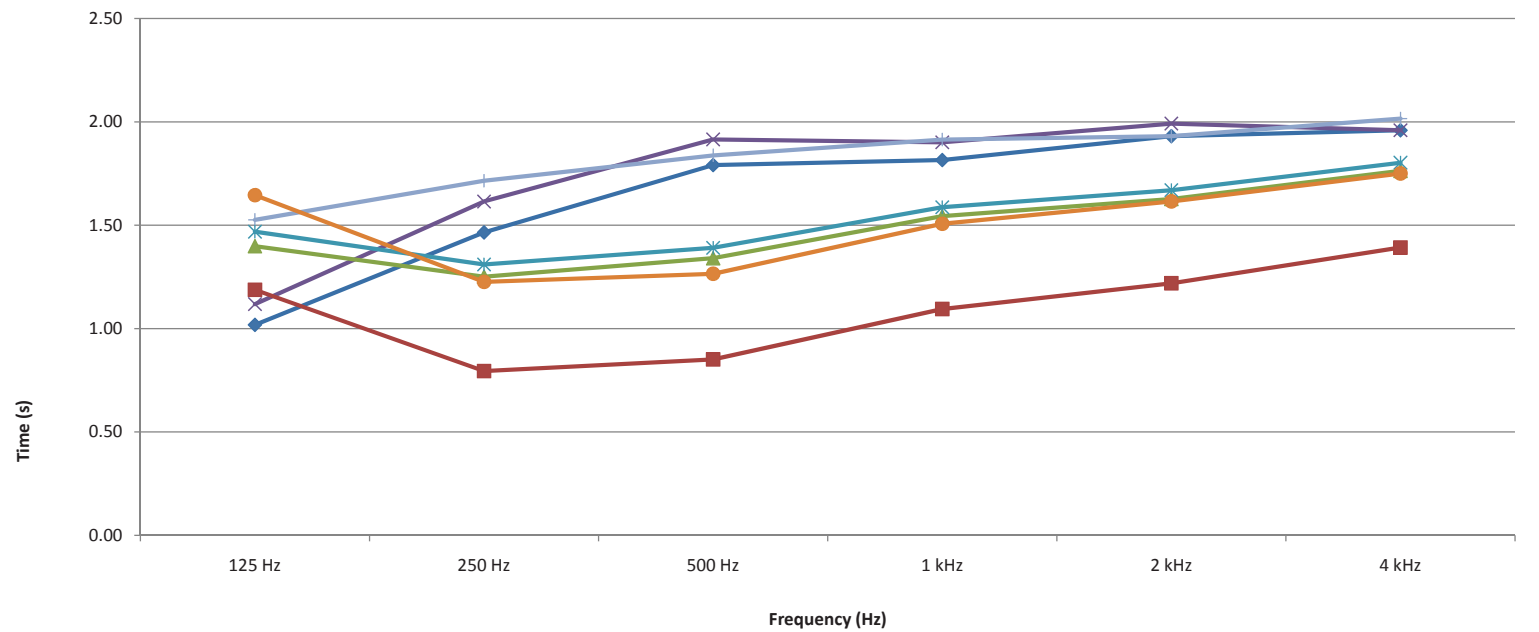
Chamber Salon

Volume: 114,000 cu.ft.
 Total Area: 3.347 sq.ft
 Stage Area: 2.075 sq.ft.
 Audience Area: 1.271 sq.ft.

Seating Capacity: 320
 Main Floor: 240
 Balconies: 80

Height: 43 ft.
 Width: 68 ft.
 Depth: 70 ft.
 L/W Ratio: 1.03

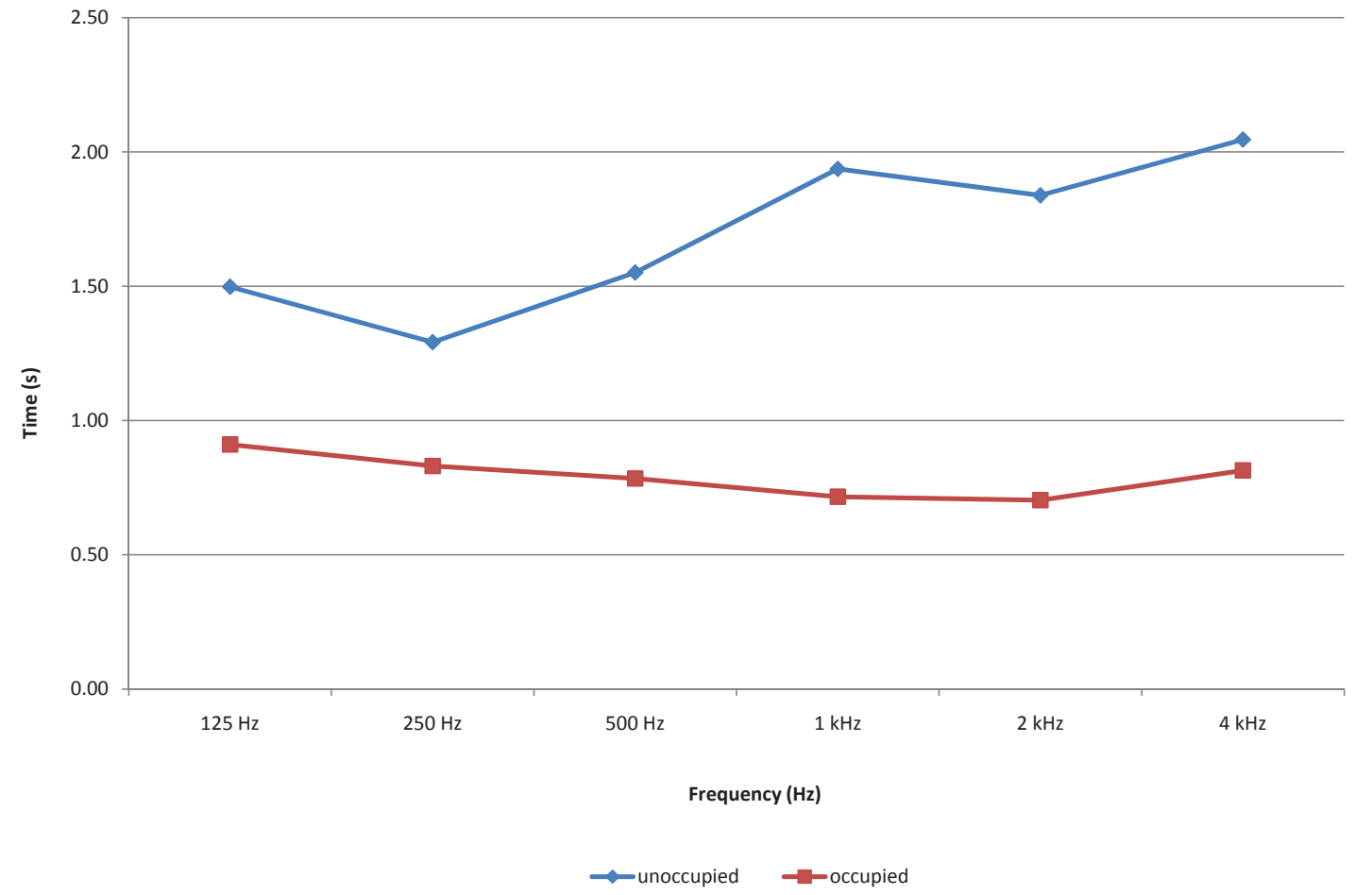
Reverberation Time (Target 1.4-1.7s)



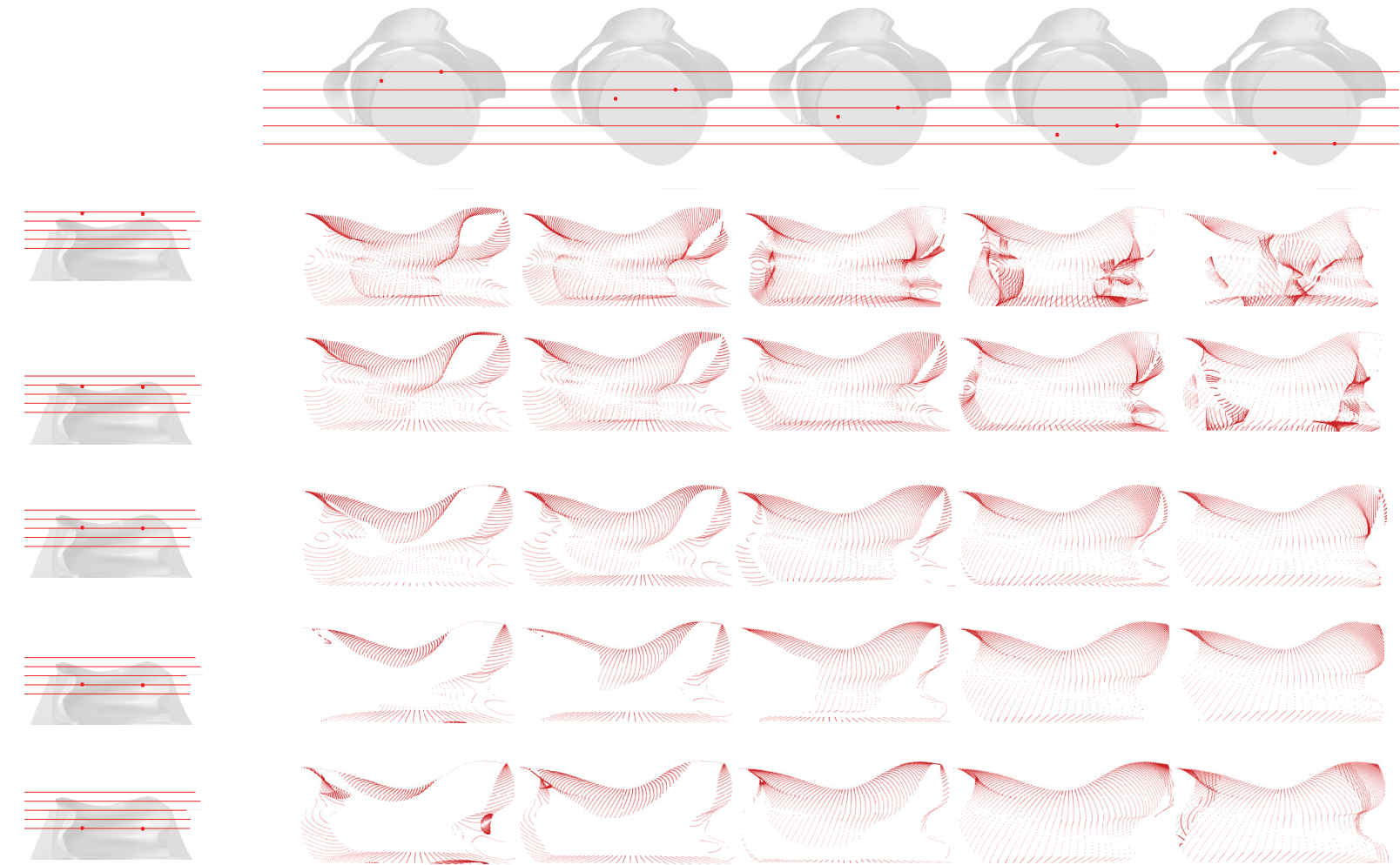
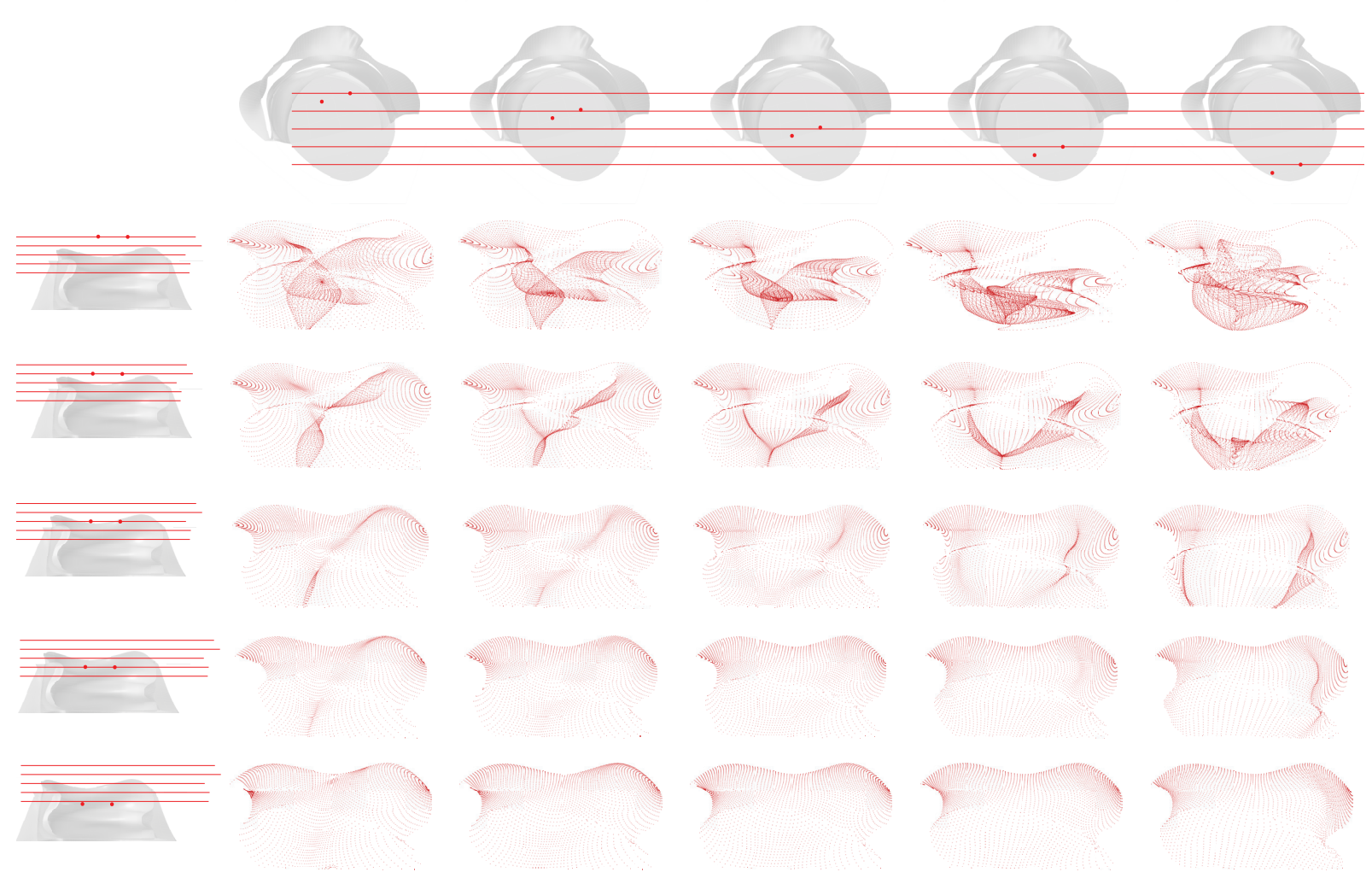
- ◆ 1/4" Wood walls, ceilings, stage, occupied
- ◆ 1" Wood walls, ceilings, stage, occupied
- ▲ 20% absorptive walls, wood ceiling, stage, occupied
- 50% absorptive walls, wood ceiling, stage, occupied
- ✕ 1/4" Wood walls, ceilings, Concrete stage, occupied
- Absorptive Audience Wall, 1" wood Stage wall, wood stage, occupied
- ✱ 30% absorptive walls, wood ceiling, stage, occupied

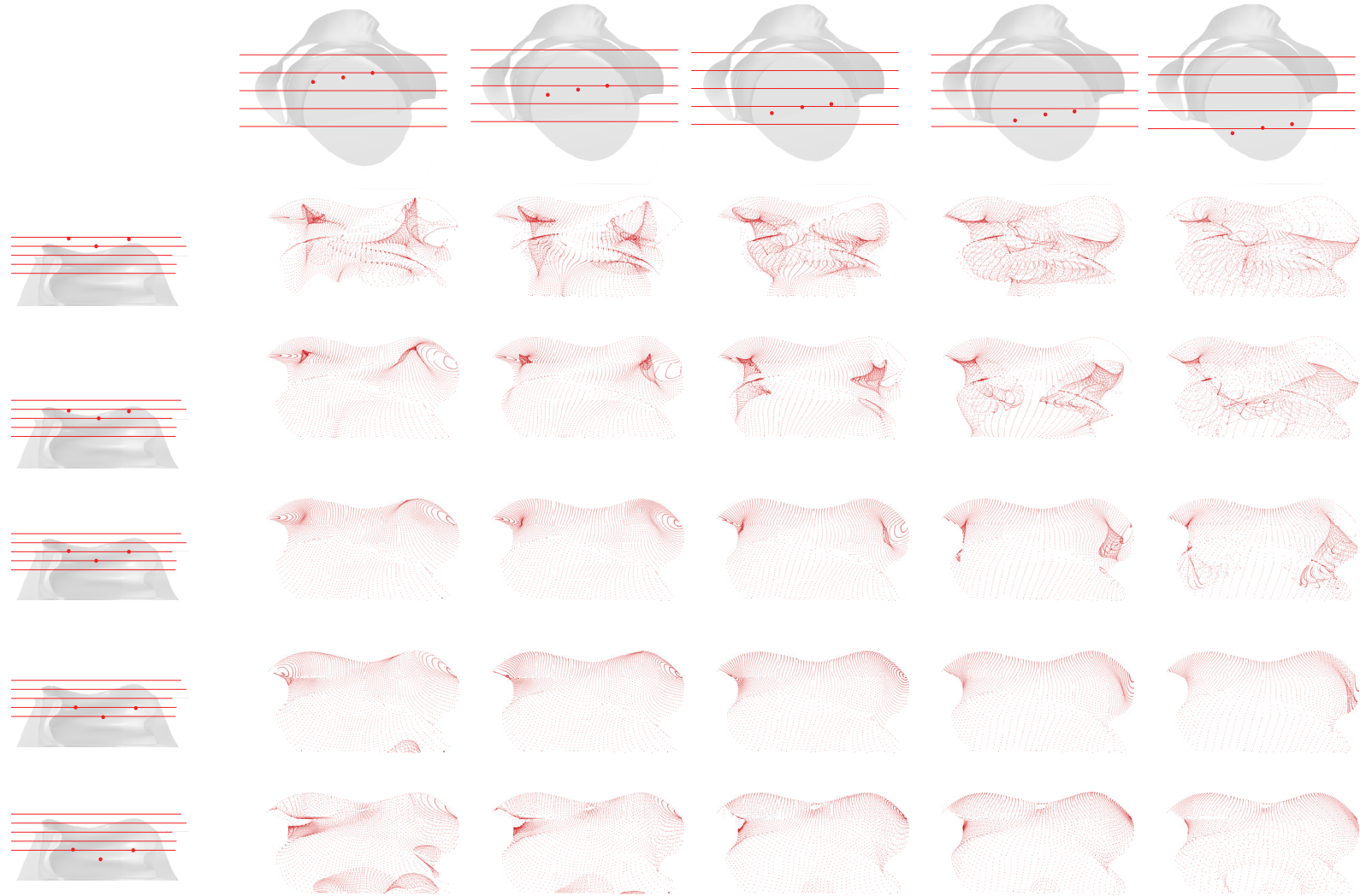
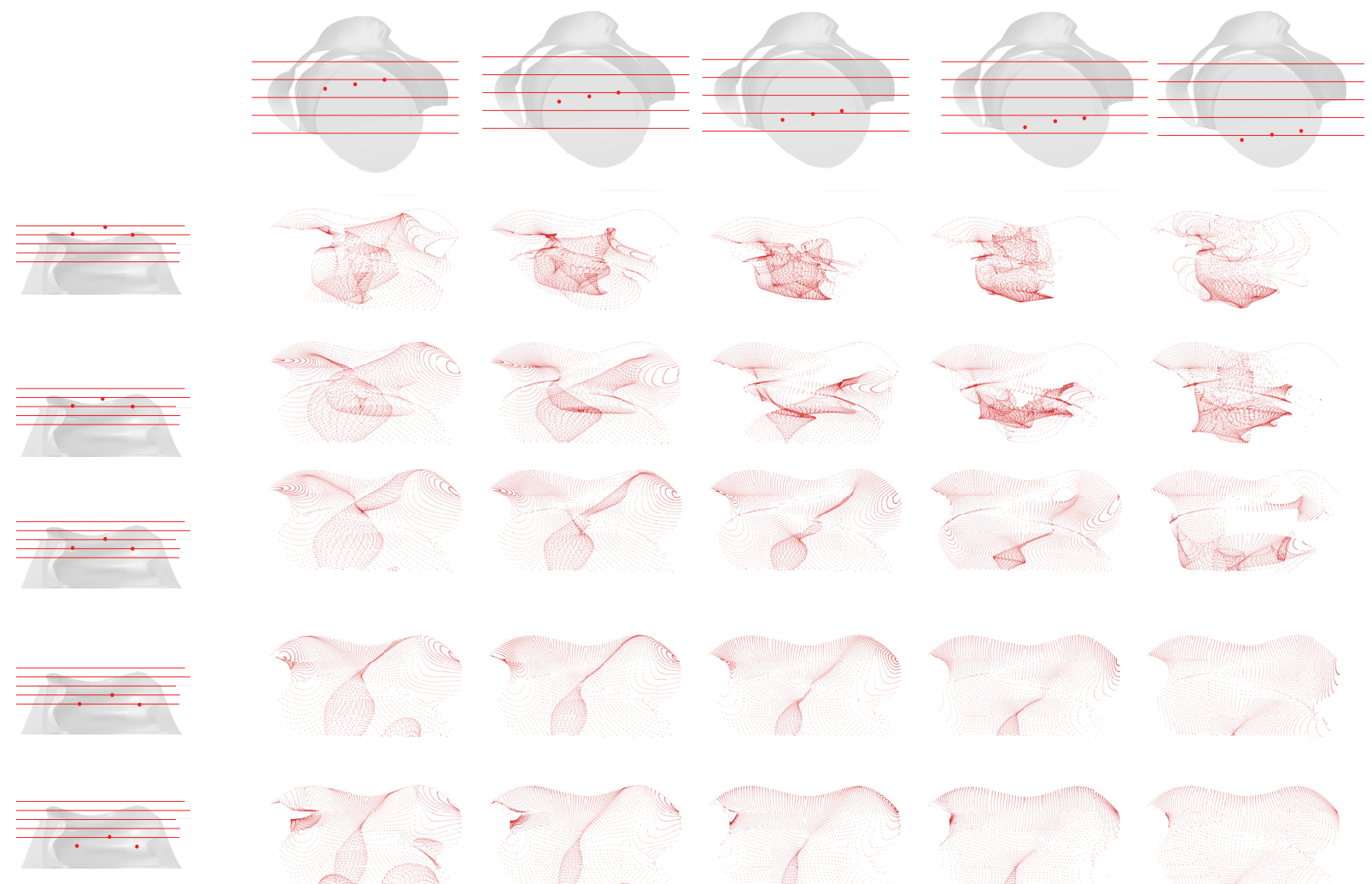
Green Room
Volume: 35,535 cu.ft.
Total Area: 2,360 sq. ft.
Banquet Seating: 200
Lecture Seating: 300
Height: 15ft.
Width: 41 ft.
Depth: 61 ft.
L/W Ratio: 1.48

Reverberation Time



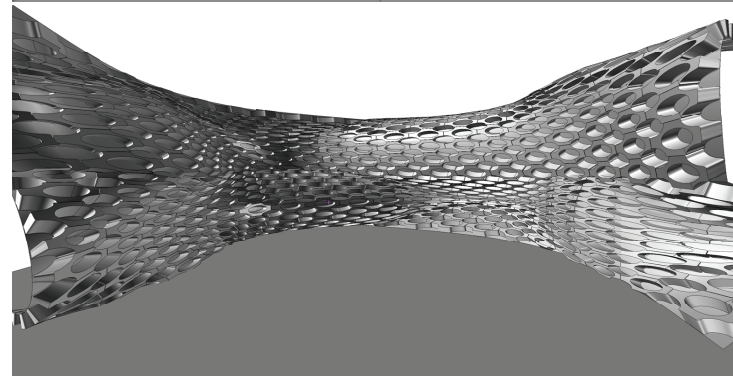
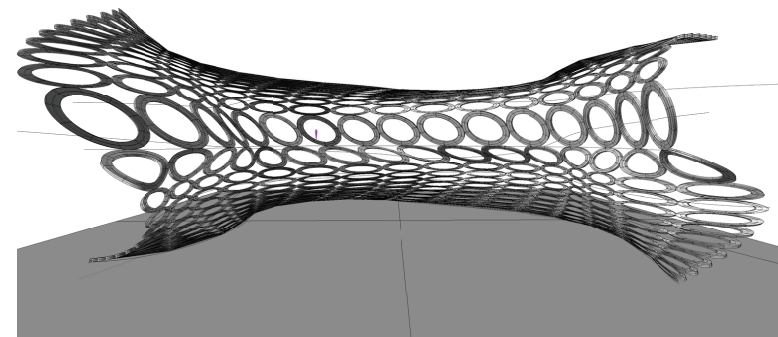
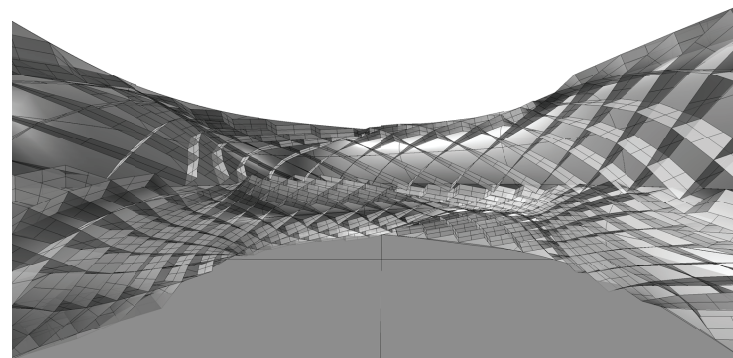
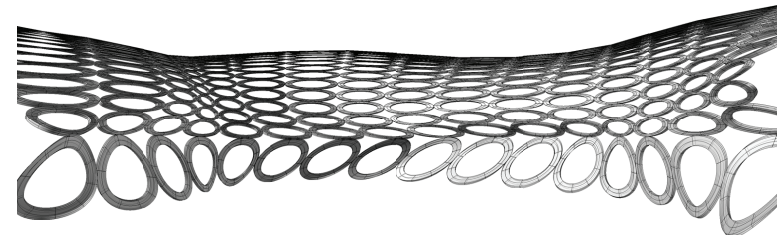
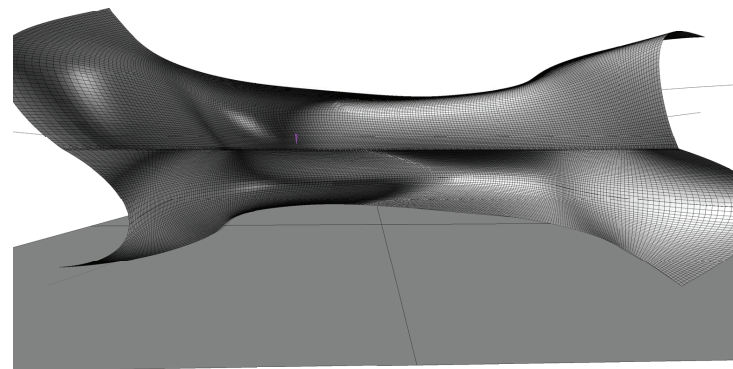
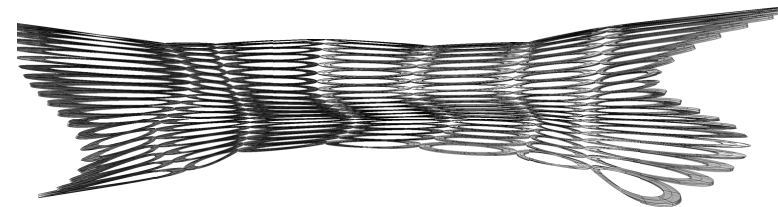
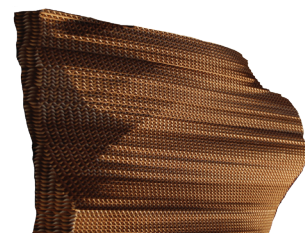
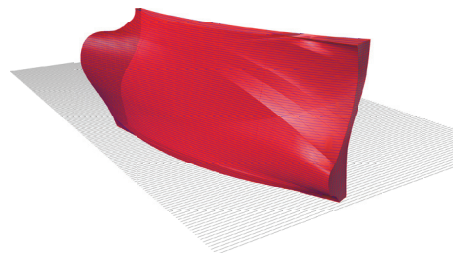
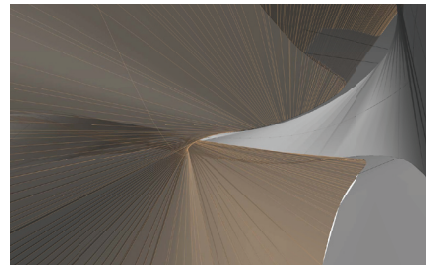
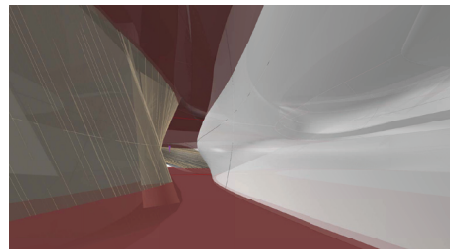
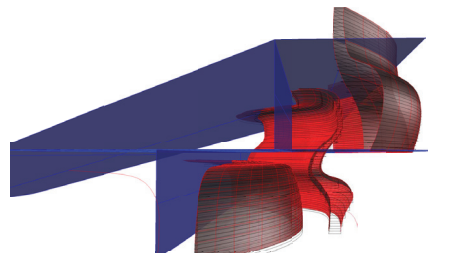
APPENDIX B - SUPPLEMENTARY GRASSHOPPER STUDIES



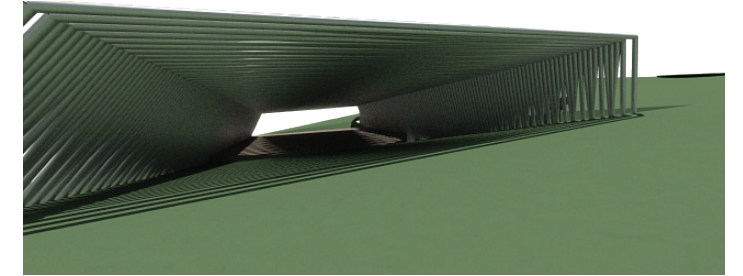
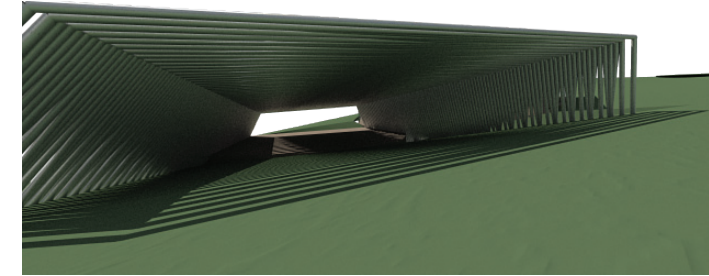
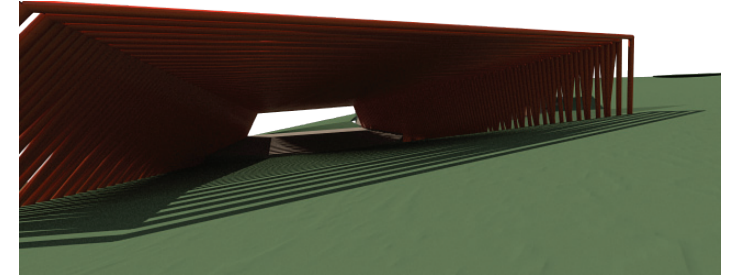
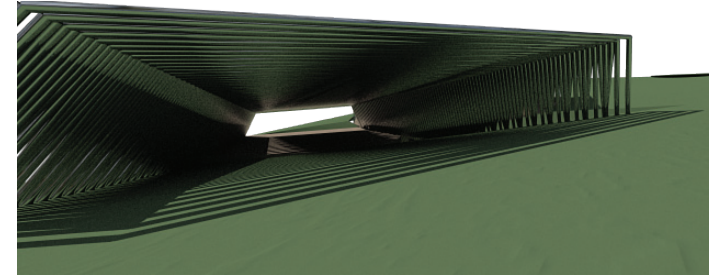
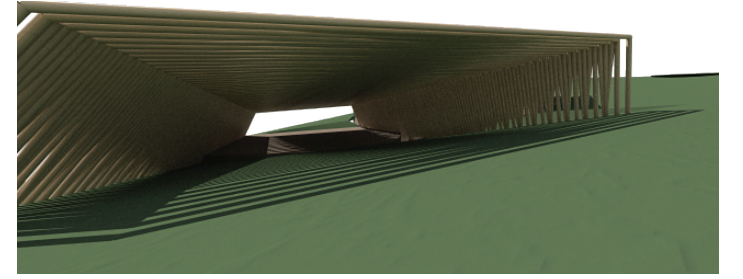
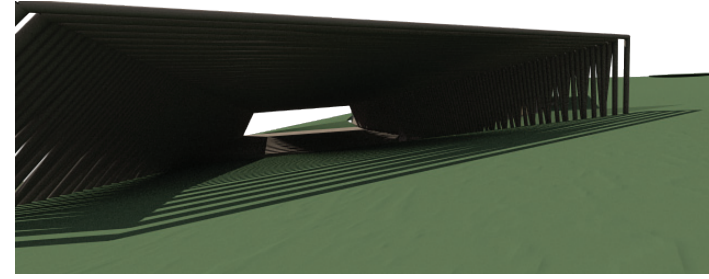
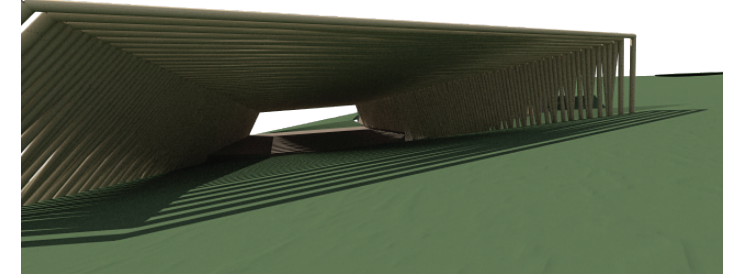
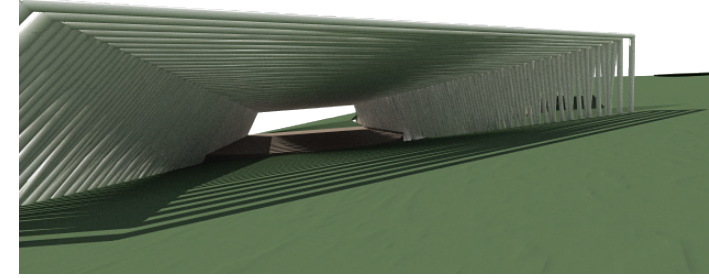
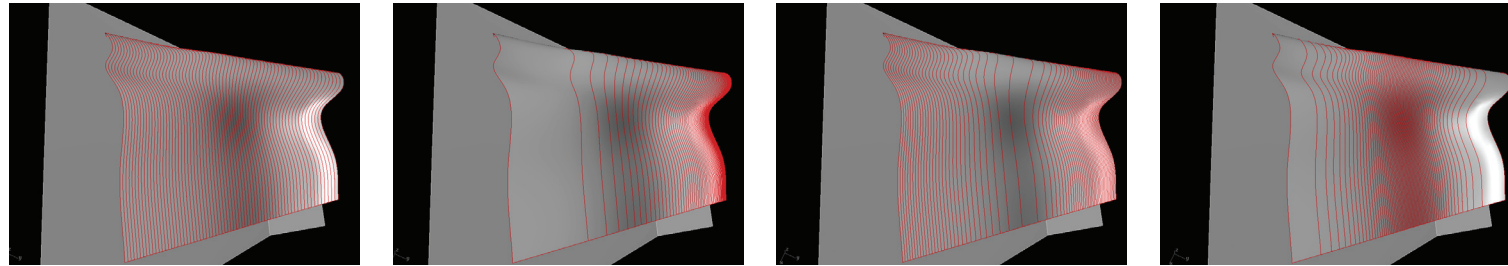
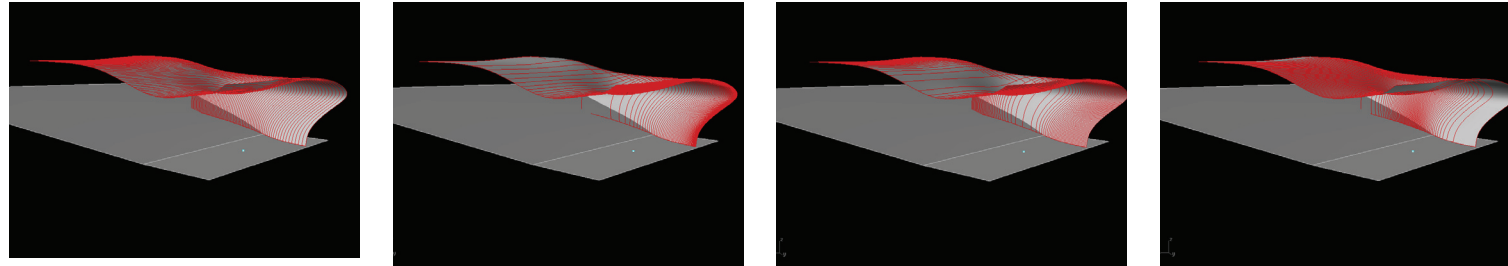
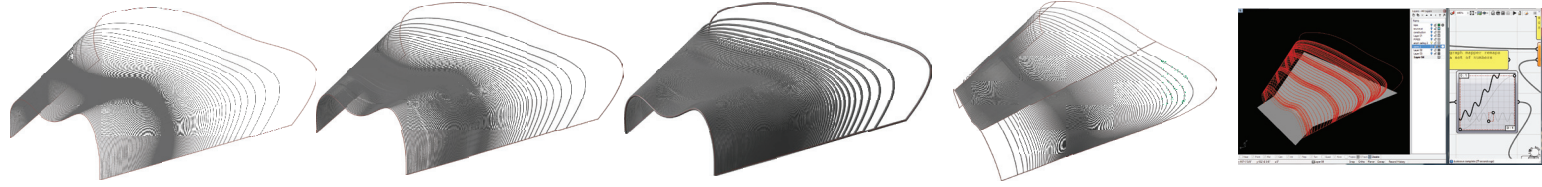
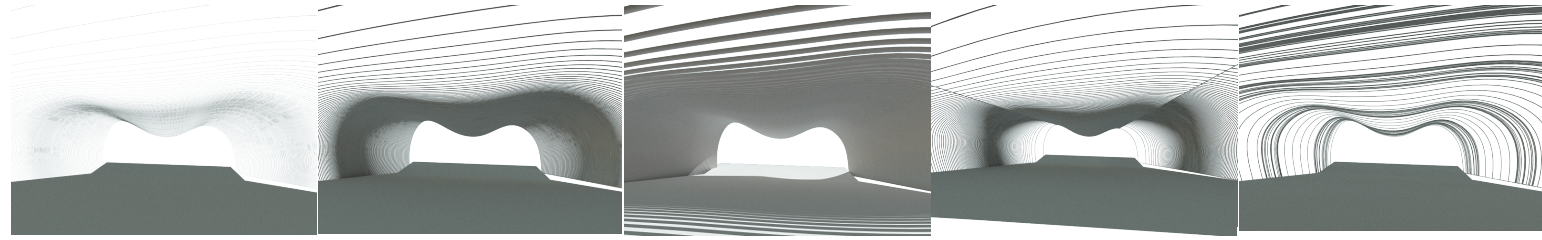


APPENDIX C - SUPPLEMENTARY DESIGN STUDIES

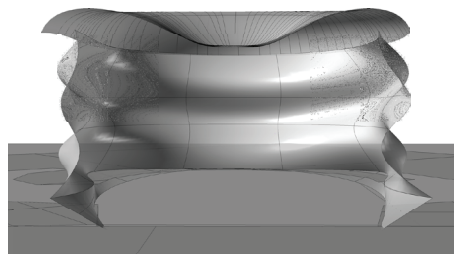
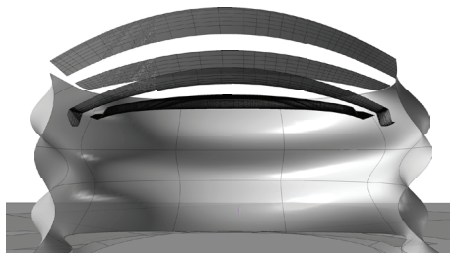
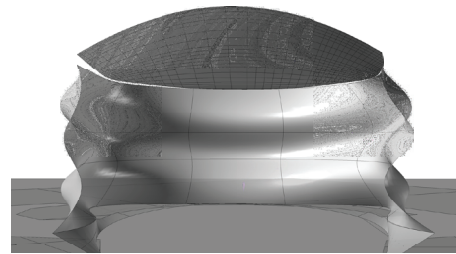
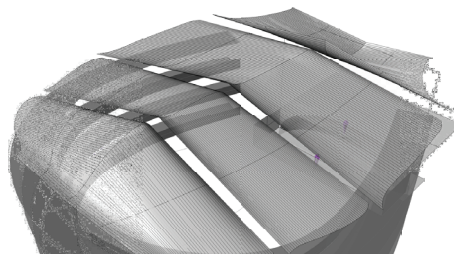
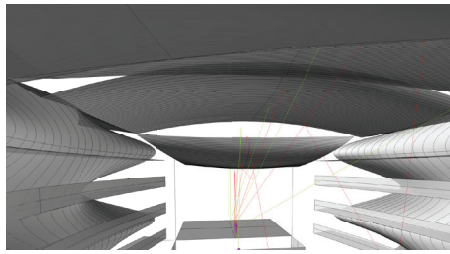
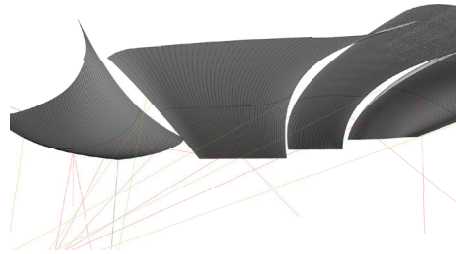
WALL STUDIES



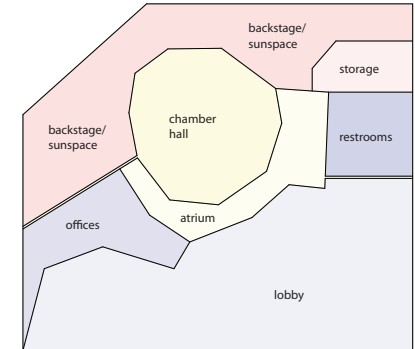
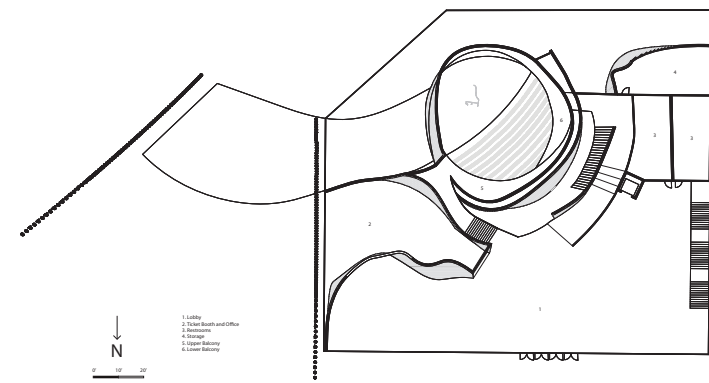
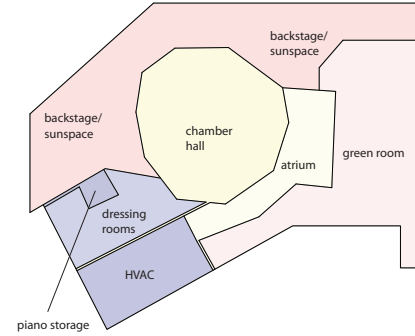
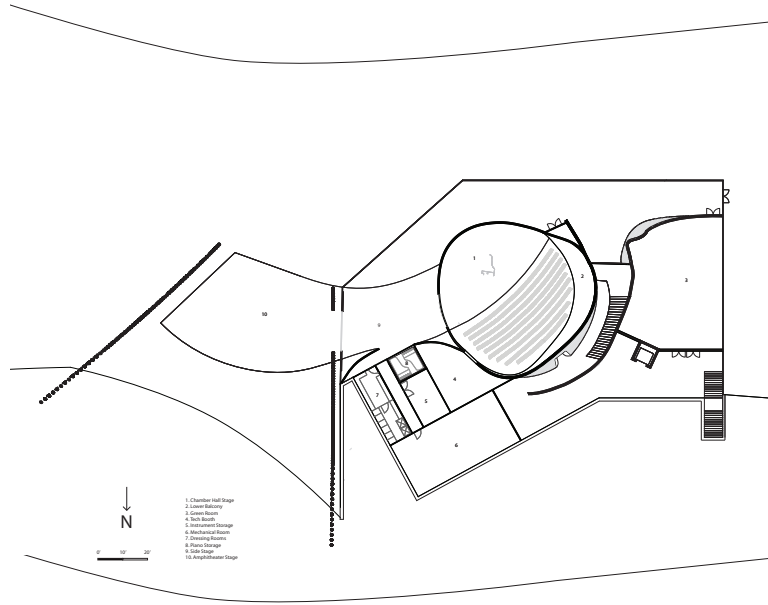
ADDITIONAL AMPHITHEATRE STUDIES



ANALOG CEILING STUDIES



APPENDIX D - ENERGY MODELING



ADJUSTED SCHEDULE

		OFFICE	PIANO STORAGE	CHAMBER HALL	GREEN ROOM
WEEK	SU	--	12a - 12a	--	--
	MO	9a - 5p	12a - 12a	--	9a - 5p
	TU	9a - 5p	12a - 12a	11a - 3p	9a - 5p
	WE	9a - 5p	12a - 12a	11a - 3p	9a - 5p
	TH	9a - 5p	12a - 12a	9a - 5p	9a - 5p
	FR	9a - 5p	12a - 12a	9a - 11p	9a - 12p
	SA	--	12a - 12a	9a - 11p	9a - 12p

"DARK" SCHEDULE

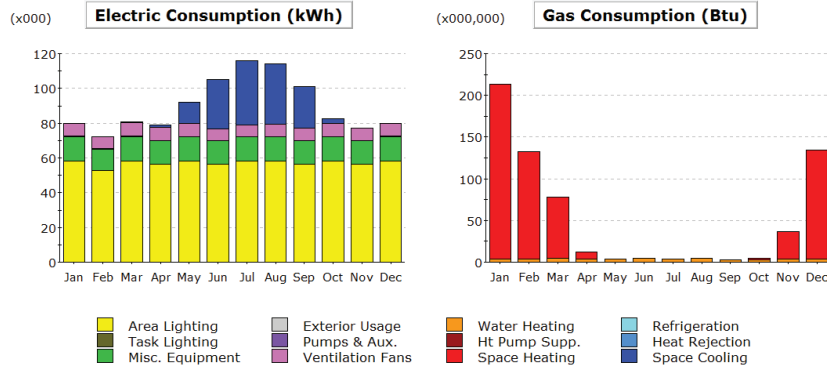
		OFFICE	PIANO STORAGE	CHAMBER HALL	GREEN ROOM
WEEK	SU	--	12a - 12a	--	--
	MO	9a - 5p	12a - 12a	--	--
	TU	9a - 5p	12a - 12a	--	--
	WE	9a - 5p	12a - 12a	--	--
	TH	9a - 5p	12a - 12a	--	--
	FR	9a - 5p	12a - 12a	--	--
	SA	--	12a - 12a	--	--

TYPICAL SCHEDULE

		OFFICE	PIANO STORAGE	CHAMBER HALL	GREEN ROOM
WEEK	SU	9a - 5p	12a - 12a	9a - 5p	9a - 5p
	MO	9a - 5p	12a - 12a	9a - 5p	9a - 5p
	TU	9a - 5p	12a - 12a	9a - 5p	9a - 5p
	WE	9a - 5p	12a - 12a	9a - 5p	9a - 5p
	TH	9a - 5p	12a - 12a	9a - 5p	9a - 5p
	FR	9a - 5p	12a - 12a	9a - 11p	9a - 12p
	SA	9a - 5p	12a - 12a	9a - 11p	9a - 12p

Annual schedules consist of a 3 month season of minimal use on the "dark" schedule, a 6 month season of "average" use on the adjusted schedule, and a 3 month "festival" season, characterized by one week a month of higher than average use.

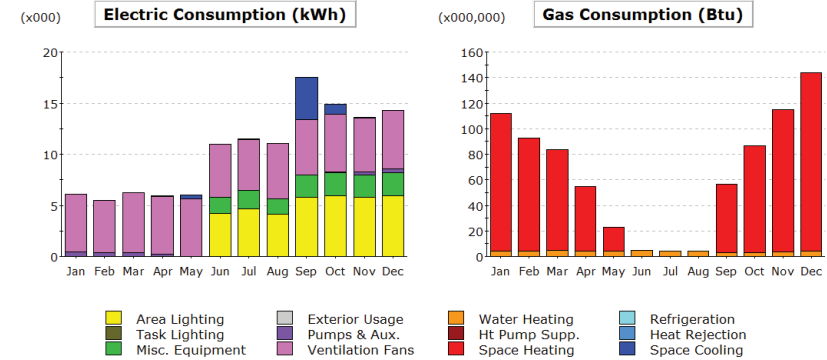
Typical Schedule (Baseline)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	0.6	1.3	12.3	28.2	37.3	35.0	23.8	3.0	-	0.0	141.5
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	7.6	6.8	7.8	7.6	7.6	7.0	6.7	7.3	7.3	7.6	7.1	7.6	88.0
Pumps & Aux.	0.4	0.4	0.4	0.2	0.0	-	-	-	0.0	0.1	0.3	0.4	2.2
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	13.9	12.5	13.9	13.4	13.9	13.4	13.9	13.9	13.4	13.9	13.4	13.9	163.1
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	58.2	52.6	58.2	56.3	58.2	56.3	58.2	58.2	56.3	58.2	56.3	58.2	685.2
Total	80.1	72.3	80.9	78.9	91.9	105.0	116.1	114.3	100.8	82.7	77.1	80.0	1,080.1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	208.98	128.66	73.45	7.56	0.25	-	-	-	-	1.08	33.34	130.92	584.24
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	3.98	3.88	4.65	4.21	3.92	4.61	4.01	4.24	3.16	3.20	3.41	3.87	47.13
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	212.96	132.54	78.10	11.77	4.17	4.61	4.01	4.24	3.16	4.27	36.74	134.79	631.38

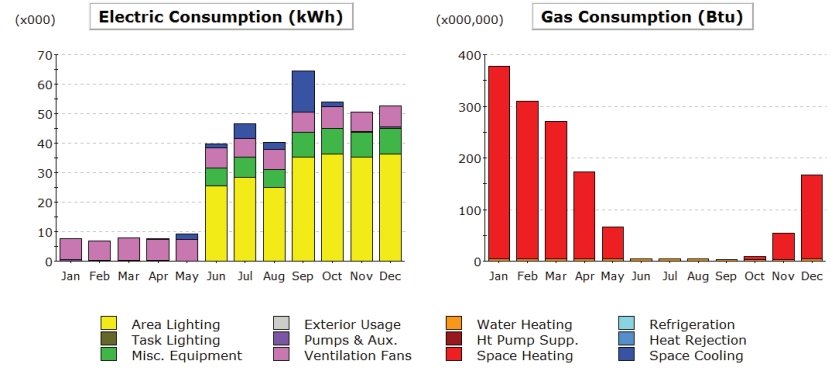
Office and Piano Storage only



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	0.00	0.02	0.38	0.00	0.07	0.01	4.13	0.94	0.10	0.04	5.70
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	5.64	5.08	5.83	5.64	5.65	5.22	5.01	5.42	5.45	5.64	5.27	5.64	65.49
Pumps & Aux.	0.43	0.39	0.38	0.25	0.02	-	-	-	0.00	0.08	0.29	0.39	2.24
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	1.58	1.76	1.55	2.18	2.25	2.18	2.25	13.76
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	4.19	4.67	4.10	5.77	5.96	5.77	5.96	36.44
Total	6.08	5.47	6.21	5.91	6.05	11.00	11.51	11.08	17.54	14.88	13.61	14.29	123.64

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	107.70	88.33	78.61	50.62	18.90	0.01	0.03	0.03	53.44	83.59	111.61	139.86	732.73
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	4.15	4.02	4.77	4.29	3.96	4.61	3.99	4.23	3.17	3.25	3.50	4.00	47.93
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	111.84	92.35	83.38	54.91	22.86	4.63	4.02	4.26	56.61	86.84	115.11	143.86	780.67

Adjusted Schedule



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	0.06	0.21	1.85	1.29	5.01	2.31	14.02	1.51	-	-	26.26
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	7.24	6.52	7.48	7.24	7.26	6.70	6.43	6.95	7.00	7.24	6.76	7.24	84.05
Pumps & Aux.	0.43	0.39	0.38	0.25	0.02	-	-	-	0.00	0.08	0.29	0.39	2.24
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	6.09	6.78	5.96	8.38	8.66	8.38	8.66	52.91
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	25.58	28.47	25.03	35.20	36.37	35.20	36.37	222.21
Total	7.68	6.91	7.92	7.70	9.12	39.66	46.68	40.25	64.60	53.86	50.63	52.66	387.68

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	373.1	306.3	266.5	169.0	62.7	0.1	0.1	0.0	0.1	6.1	51.0	162.3	1,397.4
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	4.0	3.9	4.7	4.2	3.9	4.6	3.9	4.2	3.2	3.2	3.4	3.9	47.2
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	377.1	310.3	271.2	173.3	66.6	4.7	4.0	4.2	3.3	9.3	54.5	166.2	1,444.6