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Renovation Study of Musical Space and Pipe Organ

An Interactive Qualifying Project Report
Submitted to the Faculty
of the
Worcester Polytechnic Institute

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Degree of Bachelor of Science in
Civil and Environmental Engineering

By

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Abstract:

The Great Hall of Alden Memorial is the primary venue for musical performance on campus. This project measured the acoustical properties of this space and made recommendations for optimising the space for musical performance, in the context of choral, organ, and orchestral works. This project also analyzed the performance of the original pipe organ in the hall, and suggested several methods of improving this performance.

Introduction

The Great Hall of Alden Memorial is the primary performance space for the larger musical groups on campus. These groups include Glee Club, Alden Voices, Concert Band, Jazz Band, and the Orchestra. This hall is also used for other activities, such as musical theatre, and the occasional concert organized by Soccomm's MSEC. Currently, the hall has acoustical properties that are ill suited for any of these applications. The purpose of this project has been to analyse the needs of these various groups in a performance space and, based on the current acoustical properties of the hall, evaluate and recommend several solutions to optimise the acoustics of the hall. Another goal of this project has been to make recommendations to improve the function of the pipe organ in the hall. Several options were explored, and recommendations for each developed.

Current State of the Great Hall

Measurement of the acoustical properties of a space requires specialised tools to obtain precise data. The usual values measured in an acoustical survey include the reverberation time (RT60), the noise reduction coefficients of the surfaces and materials in the room, and a real-time analysis (RTA). The RT60 measurement is a measure of how long sound reflects around a space indistinctly: this is not a measurement of echo. A broad-spectrum sound such as pink noise is generated, and when it is stopped, the time is measured for the sound pressure level (SPL) in the room to drop by 60 dB. NRC's are available in tables based on the material and square footage of the surface in question. An RTA is performed by generating a known broad-spectrum noise, usually pink noise, and then using a reference microphone to measure the relative amplitudes of frequencies across the audible spectrum. Additionally, software exists that allows the entire acoustical performance of a space to be simulated, based on inputs of room dimensions and materials. This software is developed by the BOSE company under the name Modeler®. I was unable to obtain the specialised equipment needed to measure the RT60, and obtained an estimate based on the "hand clap test". I estimate that the RT60 of the great hall is roughly 0.5 seconds. The RTA was performed using equipment borrowed from WPI's LnL club. The results are shown in Figure I. Very noticeable in this figure is the attenuation of frequencies from 20 Hz to 250 Hz.

Physically, the great hall is a large proscenium arch theatre, with a floor plan roughly described by a rectangle. The floor is uncovered wood, the walls are wood panelling, supported by furring approximately every 2'. The wood panelling is 12' in height, above which the walls are plaster. The windows on both sides have curtains of a canvas-like material, stitched at 100% fullness. The ceiling is plaster in the central division, with sound-absorbing tile on the angled sides. At the front of the room is the stage, with a large velvet curtain, stitched at 100% fullness. At the rear of the room, there is a balcony. The front-facing walls of the balcony have all been treated with sound-absorbing foam, approximately 1" thick. Most of the time, the floor is open space, but during performance, seating is placed throughout the hall, and a portable shell is used behind the performing group.

All of these material descriptions are not specific: they were made by look, feel, and tape measure. the plans on file at Plant Services are the plans from the 1990 renovation of the building. At this time, only minor cosmetic restoration was performed in the great hall. Because of this fact, the plans had little detail on the construction details and materials used in the original 1940 construction. These plans were useful in providing scale views of the hall for use by Greg and Elliot, whose work will be described later. However, to analyse the response of the materials, I needed information on what was behind the surfaces, and specifically what materials were used. The Worcester department of Building Inspection and Code Enforcement only had a floor plan of the first floor. The WPI Archives had flyers and handbills from the dedication and rededication ceremonies, but no plans. Also, the original architect for the hall is no longer in business. It seems as if all copies of the original plans have been lost. Obviously, plant services would not allow me to drill into walls or remove panels to find out what materials and techniques were used, so these are the best estimates available.

In addition to actual measurements of the hall, plans obtained from plant services of the hall, both section views and floor plans, were sent to Elliot Baskas of BOSE. I was put in contact with Elliot through both members of LnL, and Greg Martiros, the local Allen Organs representative. Elliot was going to use these plans, as well as pictures of the hall from all angles (Appendix A) to form a simulation of the room using Modeler®. This simulation would allow us to obtain more precise data on the acoustics of the hall, as well as experiment with various changes in materials on walls. Unfortunately, Elliot was not able to complete this simulation before the completion of this IQP, so the data is not included here. However, the data and simulation will be available if the recommendations of this paper are implemented in the future.

In addition to the objective acoustical measurements of the hall, there are subjective measurements to be considered. Both from my personal experience performing in the hall, as well as others experience, the hall has been described as "dead", "it sounds like the sound stops a foot in front of your face," and "no life, but an annoying echo".

The pipe organ in the great hall suffers from several elements of poor design. Most of the problems stem from the location, size, and design of the wind chests. As seen in the photos in appendix A, the swell and choir divisions of the organ are set back from the opening to the great hall by almost ten feet. The ceiling of the room containing the pipework is significantly higher than the top of the façade. The louvers of the wind chests of the great and swell divisions are pointed up into the ceiling, instead of out into the room. The room is wider than the façade. These factors combine to trap most of the sound energy produced by the organ inside the pipe room. What sound energy does escape from the pipe room is highly directional, being focused directly across the hall. This causes a significant drop-off in volume of the organ at any point more than about fifteen feet towards the rear of the room from the stage.

Additionally, Organs should be at least twice a year: once at the beginning of spring, once at the beginning of fall, and additionally before any major performance, if the organ is used often. A major overhaul should be performed once every twenty to thirty years. I could find no record of any maintenance being performed on the organ, other than tuning once a year since the organ was installed by the Aeolian-Skinner company in 1940. Even these tunings are less than adequate: there are several ranks with notes grossly out of tune. Because of these difficulties, it is obvious that changes need to be made to the organ.

Musical Needs

During the course of this project, I spoke with directors and members of the various large ensembles that perform in the great hall to help establish a better idea of the needs of the groups that use the hall. Additionally, I studied several books on acoustics to gain information about how materials affect acoustical response. These books were exceptionally helpful: they not only provided information on materials, but also on ideal values for acoustical measurements based on intended use. Tables summarizing these recommended values can be found in figures II and III. Because of the size of the space, smaller groups such as the Medwin String Quartet and Vocal Performance Lab rarely if ever perform in the great hall. Mostly it is the larger groups such as the choral ensembles or the concert band or orchestra. Based on these groups, as well as the presence of the pipe organ, the ideal RT60 time would be around 1.5 to 2.0 seconds. Also, a much flatter response curve than is currently generated by the room is desireable for better hearing music as it is meant to sound.

The first step in achieving this acoustical performance is to remove all of the sound absorbing material from the rear wall and ceiling. These materials are the primary contributors to the "deadness" of the room. Removing this will increase the response time. To further increase it, it might be necessary to devise a system of storing the curtains behind some kind of rigid baffle, to minimise their sound absorption.

However, simply transforming the hall into a reflective box is not the entire solution. Both the wood panelling, and the glass of the windows act as selective dampers for low frequency sound. To minimise this effect, the wood panelling should be supported by more closely spaced furring strips. Wood surfaces help to add to the warmth of the room's sound, but it needs to be rigidly supported to avoid a loss of low-end frequencies. Also, since the floor plan is almost a rectangle, the walls are parallel. This creates a problem with distinct echo, which is distracting and irritating. To avoid this, some kind of diffusion pattern should be set up on opposite walls. Triangular, cylindrical, and quadratic diffusers are all options. These patterns disperse incoming sound in all directions, aiding warmth and reverberation, and eliminating echo, which is caused by sound being reflected directly back towards the source.

Increasing the reverberation time would make the room more unsuitable for use with other types of music, such as a rock concert. However, the types of music performed where reverberation is not expected are usually electronically amplified. The proper use of amplification can overcome the natural acoustics of a space, allowing the hall to still be used as a venue for concerts not quite large enough to fill Harrington Auditorium, even after redesign for a primary use of acoustical music.

The specific choice of materials to be used for diffusion is a difficult one. The decision can be made easier through the use of the Modeler® software. By giving the program the size and shape of the room, we can try many different materials and shapes before making a large investment in material and installation costs.

Pipe Organ

Previously, I described why the pipe organ in its current state does not perform up to its potential in the space. There are two main options to consider: reconstructing the organ, or replacing the organ. If the organ is rebuilt, it will need to be moved to a new location, as well as have a major overhaul covering the past sixty-five years of sub-par maintenance. The cost of this approach approaches the cost of a new organ. This leaves the replacement option.

Organ building is a highly specialised field. Because of this, pipe organs are expensive to build, as well as maintain. Most organisations that own large organs have an endowment or trust of some kind just to pay for the maintenance of the organ. Because of this, computerised organs have become a viable alternative for many locations. There are pros and cons to each kind of organ, and I believe that, while a traditional wind instrument would be the best solution musically, for this school and this space, a digital organ is the most practical solution.

Organists are notoriously picky musicians. They will often refuse to play an organ of not exactly to their liking, and there is no mercy for the fool who touches the instrument without close supervision. Were WPI to install a new organ, this would be a primary reason to go the acoustic route. Were the school to have a first-rate pipe organ, the possibility of holding recitals and organ concerts would be a draw for the Worcester and WPI community. The installation of an acoustic instrument allows the possibility of expanding WPI's musical visibility, whereas no visiting musician would come to WPI to play an electronic instrument. The digital organ would better serve the current use of accompanying the choirs, playing during church services, and playing at the baccalaureate ceremony. The acoustic instrument would open the door for the expansion of WPI's musical uses.

The primary point in the favour of the digital organ is price. A general rule of thumb for the cost of an acoustical instrument is fifteen to twenty thousand dollars per rank of pipes. The current organ contains 34 stops. The digital instrument is far cheaper, with a large instrument costing in the $250,000 range. The digital organ can replicate the sound of the acoustic instrument very well, and the technology is constantly improving. Additionally, WPI is a school of technology. I must admit that while a digital organ may not be as musically authentic as an acoustic instrument, it does fit with the character of this school as a high-technology school.

Reaching the decision that a digital organ was the optimal solution for the organ, I contacted Greg Martiros, of Gpaul Music. Greg is the representative for the Allen Organ company, one of the premier electronic organ manufacturers in the united states. I met with Greg in Alden Memorial to discuss the space and options for a new organ. After walking around the great hall, he agreed that the space had the capability to support a new allen organ, without major construction.

his ballpark guess on cost was in the neighborhood of $250,000, including all costs of construction for resonance chests and installation.

In addition to feasibility and cost, we also discussed location. My research had indicated that the best location for an organ is on the main axis of the room, either at the front or rear. The stage precludes installation at the front, leaving the rear, probably in the balcony and perhaps into the stairwells leading to the balcony. Greg agreed, adding that antiphonal ranks could be installed in the location of the existing organ, but oriented to speak into the room. The façade of the new organ chambers would be constructed to match the existing organ façade in order to maintain the décor of the hall.

The Original Organ

Now that the decision has been made to replace the organ, the question arises of what to do about the old organ. It is in a state of disrepair, especially with regards to the console. I disassembled the pedalboard at one point, and removed literally 1/8" – 3/16" thick layer of dust from beneath it. Because of this disrepair, as well as the fact that the Aeolian-Skinner company is now defunct, spare parts are in demand. The most money could probably be raised by placing the organ for sale as parts with the Organ Clearinghouse, an organisation dedicated to finding new homes for pipe organs. The sale of the organ could help defray the costs of a new organ. The additional benefit in selling the organ for parts is that WPI could keep the pipes of several ranks, and sell most of the organ. These ranks could be used to construct a small continuo organ or some similar portable organ type. This would be useful to WPI, as well as financially prudent. All schools own pianos, and the Worcester Consortium owns a harpsichord it rents to the consortium schools when it is needed. However, no one in the area has a portative organ, meaning opportunity for use by travelling WPI groups, as well as renting the organ to other schools.

Summary

In summary, the great hall and its organ do not meet the needs of the student groups that perform there. To address this problem, a new pipe organ should be installed. A contractor has already been contacted, and is aware of our interest. Also, before the organ can be installed, all acoustical modifications must be complete. This is because the real-time signal generation of a digital organ uses fixed data about the acoustics of the room as input. The Great Hall has enormous potential as a performance space. That potential is not currently being used, but it could be with a few critical changes.

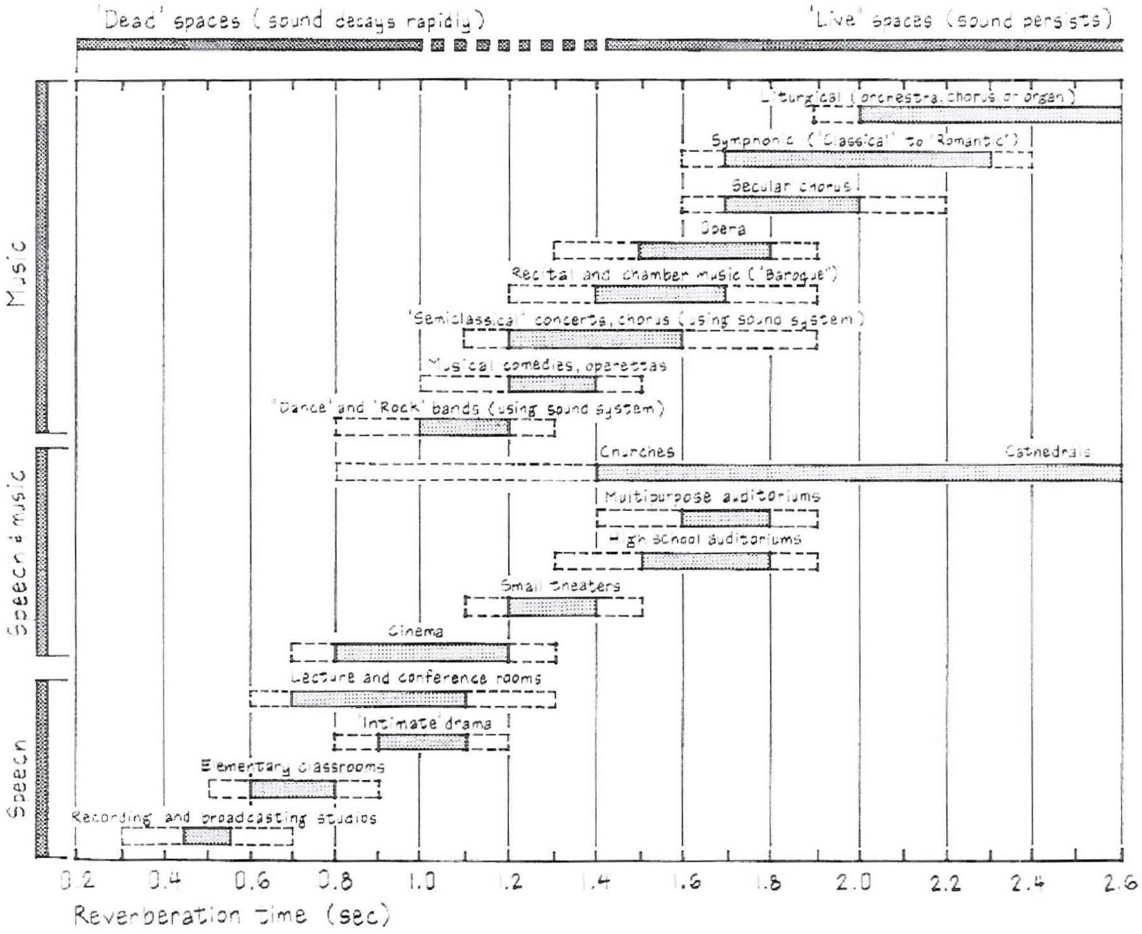


Figure II: optimal reverberation time based on intended usage of space

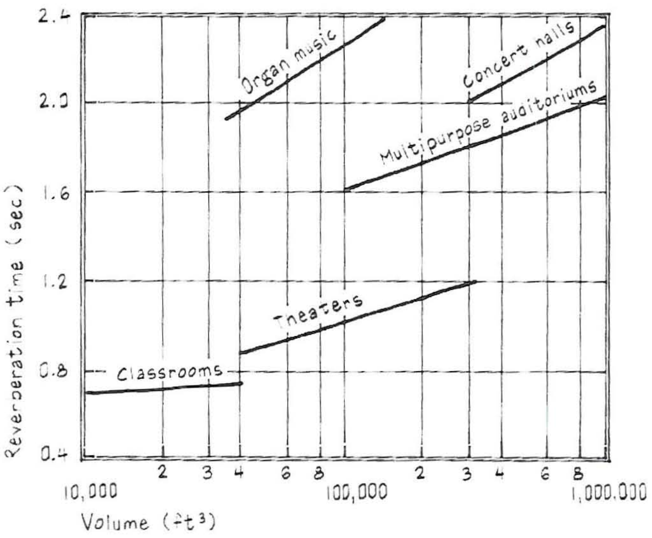
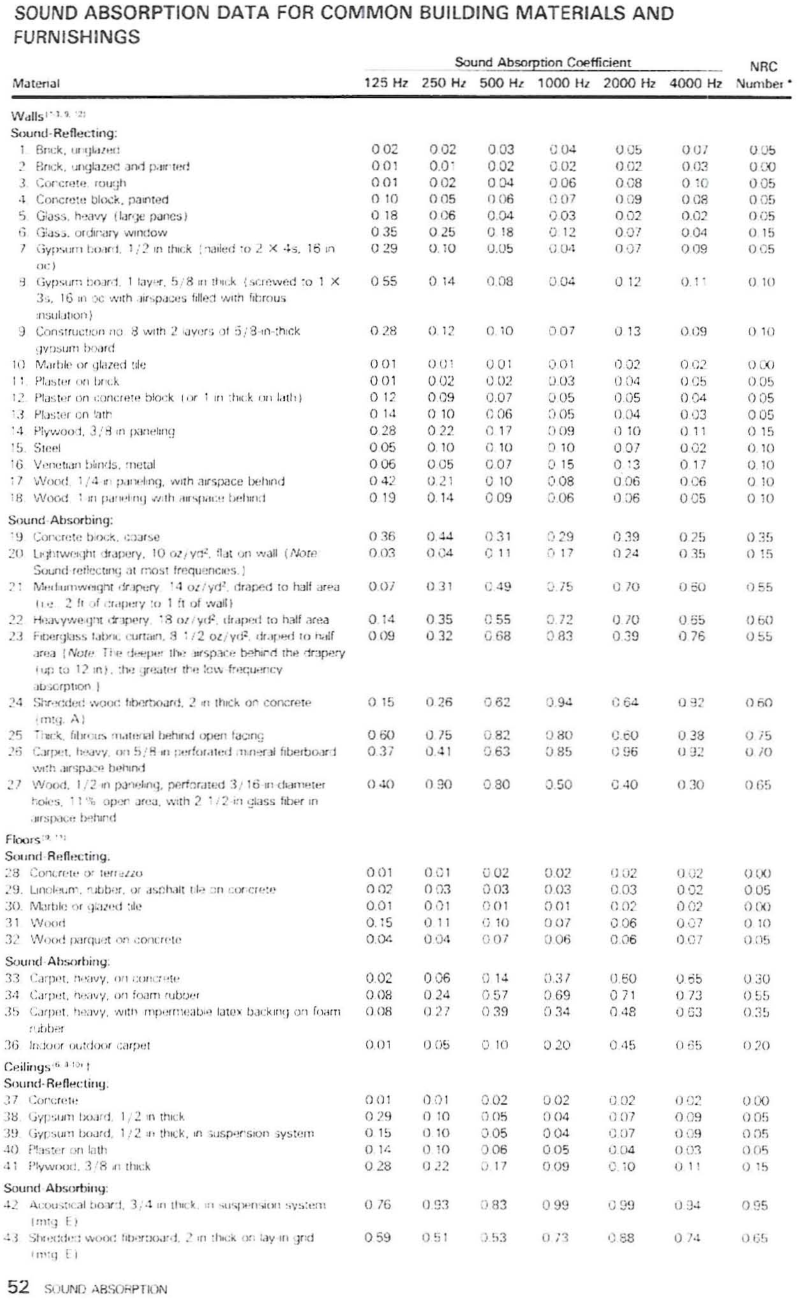


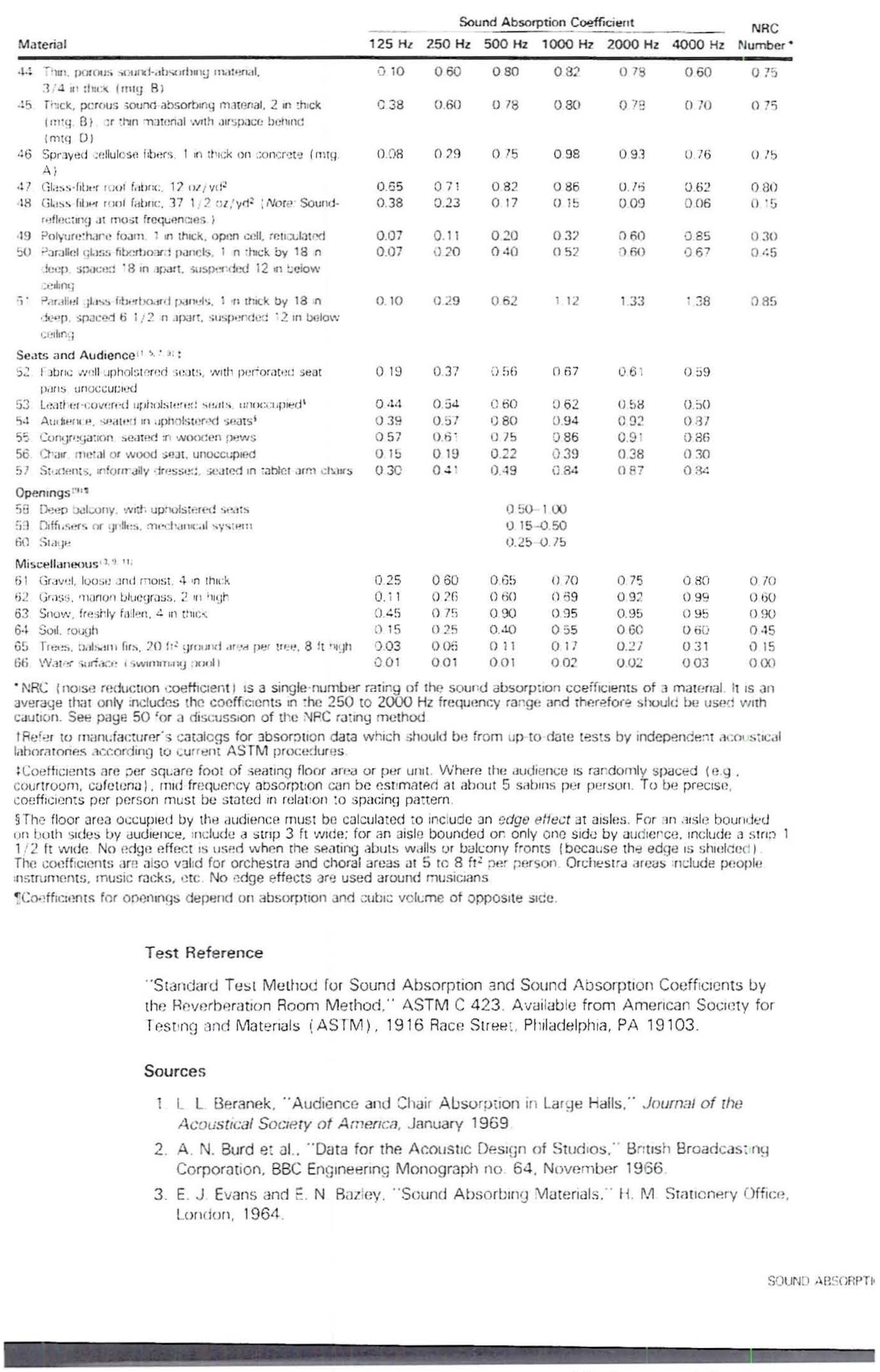
Figure III: reverberation time based on volume of the space



SOUND ABSORPTION DATA FOR COMMON BUILDING MATERIALS AND FURNISHINGS

Material	Sound Absorption Coefficient						NRC
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Number *
Walls(1-3, 9, 12)							
Sound-Reflecting:							
1. Brick, unglazed	0.02	0.02	0.03	0.04	0.05	0.07	0.05
2. Brick, unglazed and painted	0.01	0.01	0.02	0.02	0.02	0.03	0.00
3. Concrete, rough	0.01	0.02	0.04	0.06	0.08	0.10	0.05
4. Concrete block, painted	0.10	0.05	0.06	0.07	0.09	0.08	0.05
5. Glass, heavy (large panes)	0.18	0.06	0.04	0.03	0.02	0.02	0.05
6. Glass, ordinary window	0.35	0.25	0.18	0.12	0.07	0.04	0.15
7. Gypsum board, 1/2 in thick (nailed to 2 × 4s, 16 in oc)	0.29	0.10	0.05	0.04	0.07	0.09	0.05
8. Gypsum board, 1 layer, 5/8 in thick (screwed to 1 × 3s, 16 in oc with airspaces filled with fibrous insulation)	0.55	0.14	0.08	0.04	0.12	0.11	0.10
9. Construction no. 8 with 2 layers of 5/8-in-thick gypsum board	0.28	0.12	0.10	0.07	0.13	0.09	0.10
10. Marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02	0.00
11. Plaster on brick	0.01	0.02	0.02	0.03	0.04	0.05	0.05
12. Plaster on concrete block (or 1 in thick on lath)	0.12	0.09	0.07	0.05	0.05	0.04	0.05
13. Plaster on lath	0.14	0.10	0.06	0.05	0.04	0.03	0.05
14. Plywood, 3/8 in paneling	0.28	0.22	0.17	0.09	0.10	0.11	0.15
15. Steel	0.05	0.10	0.10	0.10	0.07	0.02	0.10
16. Venetian blinds, metal	0.06	0.05	0.07	0.15	0.13	0.17	0.10
17. Wood, 1/4 in paneling, with airspace behind	0.42	0.21	0.10	0.08	0.06	0.06	0.10
18. Wood, 1 in paneling with airspace behind	0.19	0.14	0.09	0.06	0.06	0.05	0.10
Sound-Absorbing:							
19. Concrete block, coarse	0.36	0.44	0.31	0.29	0.39	0.25	0.35
20. Lightweight drapery, 10 oz/yd², flat on wall (*Note:* Sound-reflecting at most frequencies.)	0.03	0.04	0.11	0.17	0.24	0.35	0.15
21. Mediumweight drapery, 14 oz/yd², draped to half area (i.e., 2 ft of drapery to 1 ft of wall)	0.07	0.31	0.49	0.75	0.70	0.60	0.55
22. Heavyweight drapery, 18 oz/yd², draped to half area	0.14	0.35	0.55	0.72	0.70	0.65	0.60
23. Fiberglass fabric curtain, 8 1/2 oz/yd², draped to half area (*Note:* The deeper the airspace behind the drapery (up to 12 in), the greater the low-frequency absorption.)	0.09	0.32	0.68	0.83	0.39	0.76	0.55
24. Shredded wood fiberboard, 2 in thick on concrete (mtg. A)	0.15	0.26	0.62	0.94	0.64	0.92	0.60
25. Thick, fibrous material behind open facing	0.60	0.75	0.82	0.80	0.60	0.38	0.75
26. Carpet, heavy, on 5/8 in perforated mineral fiberboard with airspace behind	0.37	0.41	0.63	0.85	0.96	0.92	0.70
27. Wood, 1/2 in paneling, perforated 3/16-in-diameter holes, 11% open area, with 2 1/2-in glass fiber in airspace behind	0.40	0.90	0.80	0.50	0.40	0.30	0.65
Floors(9, 11)							
Sound-Reflecting:							
28. Concrete or terrazzo	0.01	0.01	0.02	0.02	0.02	0.02	0.00
29. Linoleum, rubber, or asphalt tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02	0.05
30. Marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02	0.00
31. Wood	0.15	0.11	0.10	0.07	0.06	0.07	0.10
32. Wood parquet on concrete	0.04	0.04	0.07	0.06	0.06	0.07	0.05
Sound-Absorbing:							
33. Carpet, heavy, on concrete	0.02	0.06	0.14	0.37	0.60	0.65	0.30
34. Carpet, heavy, on foam rubber	0.08	0.24	0.57	0.69	0.71	0.73	0.55
35. Carpet, heavy, with impermeable latex backing on foam rubber	0.08	0.27	0.39	0.34	0.48	0.63	0.35
36. Indoor outdoor carpet	0.01	0.05	0.10	0.20	0.45	0.65	0.20
Ceilings(6, 8-10) †							
Sound-Reflecting:							
37. Concrete	0.01	0.01	0.02	0.02	0.02	0.02	0.00
38. Gypsum board, 1/2 in thick	0.29	0.10	0.05	0.04	0.07	0.09	0.05
39. Gypsum board, 1/2 in thick, in suspension system	0.15	0.10	0.05	0.04	0.07	0.09	0.05
40. Plaster on lath	0.14	0.10	0.06	0.05	0.04	0.03	0.05
41. Plywood, 3/8 in thick	0.28	0.22	0.17	0.09	0.10	0.11	0.15
Sound-Absorbing:							
42. Acoustical board, 3/4 in thick, in suspension system (mtg. E)	0.76	0.93	0.83	0.99	0.99	0.94	0.95
43. Shredded wood fiberboard, 2 in thick on lay-in grid (mtg. E)	0.59	0.51	0.53	0.73	0.88	0.74	0.65

Figure IV: Sound-absorption coefficients for various materials



Material	Sound Absorption Coefficient						NRC Number*
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
44. Thin, porous sound-absorbing material, 3/4 in thick (mtg. B)	0.10	0.60	0.80	0.82	0.78	0.60	0.75
45. Thick, porous sound-absorbing material, 2 in thick (mtg. B), or thin material with airspace behind (mtg. D)	0.38	0.60	0.78	0.80	0.78	0.70	0.75
46. Sprayed cellulose fibers, 1 in thick on concrete (mtg. A)	0.08	0.29	0.75	0.98	0.93	0.76	0.75
47. Glass-fiber roof fabric, 12 oz/yd²	0.65	0.71	0.82	0.86	0.76	0.62	0.80
48. Glass-fiber roof fabric, 37 1/2 oz/yd² (*Note:* Sound-reflecting at most frequencies.)	0.38	0.23	0.17	0.15	0.09	0.06	0.15
49. Polyurethane foam, 1 in thick, open cell, reticulated	0.07	0.11	0.20	0.32	0.60	0.85	0.30
50. Parallel glass-fiberboard panels, 1 in thick by 18 in deep, spaced 18 in apart, suspended 12 in below ceiling	0.07	0.20	0.40	0.52	0.60	0.67	0.45
51. Parallel glass-fiberboard panels, 1 in thick by 18 in deep, spaced 6 1/2 in apart, suspended 12 in below ceiling	0.10	0.29	0.62	1.12	1.33	1.38	0.85
Seats and Audience(1, 5, 7, 9)‡							
52. Fabric well-upholstered seats, with perforated seat pans, unoccupied	0.19	0.37	0.56	0.67	0.61	0.59	
53. Leather-covered upholstered seats, unoccupied§	0.44	0.54	0.60	0.62	0.58	0.50	
54. Audience, seated in upholstered seats§	0.39	0.57	0.80	0.94	0.92	0.87	
55. Congregation, seated in wooden pews	0.57	0.61	0.75	0.86	0.91	0.86	
56. Chair, metal or wood seat, unoccupied	0.15	0.19	0.22	0.39	0.38	0.30	
57. Students, informally dressed, seated in tablet-arm chairs	0.30	0.41	0.49	0.84	0.87	0.84	
Openings(9)¶							
58. Deep balcony, with upholstered seats			0.50–1.00				
59. Diffusers or grilles, mechanical system			0.15–0.50				
60. Stage			0.25–0.75				
Miscellaneous(3, 9, 11)							
61. Gravel, loose and moist, 4 in thick	0.25	0.60	0.65	0.70	0.75	0.80	0.70
62. Grass, marion bluegrass, 2 in high	0.11	0.26	0.60	0.69	0.92	0.99	0.60
63. Snow, freshly fallen, 4 in thick	0.45	0.75	0.90	0.95	0.95	0.95	0.90
64. Soil, rough	0.15	0.25	0.40	0.55	0.60	0.60	0.45
65. Trees, balsam firs, 20 ft² ground area per tree, 8 ft high	0.03	0.06	0.11	0.17	0.27	0.31	0.15
66. Water surface (swimming pool)	0.01	0.01	0.01	0.02	0.02	0.03	0.00

*NRC (noise reduction coefficient) is a single-number rating of the sound absorption coefficients of a material. It is an average that only includes the coefficients in the 250 to 2000 Hz frequency range and therefore should be used with caution. See page 50 for a discussion of the NRC rating method.

†Refer to manufacturer's catalogs for absorption data which should be from up-to-date tests by independent acoustical laboratories according to current ASTM procedures.

‡Coefficients are per square foot of seating floor area or per unit. Where the audience is randomly spaced (e.g., courtroom, cafeteria), mid frequency absorption can be estimated at about 5 sabins per person. To be precise, coefficients per person must be stated in relation to spacing pattern.

§The floor area occupied by the audience must be calculated to include an *edge effect* at aisles. For an aisle bounded on both sides by audience, include a strip 3 ft wide; for an aisle bounded on only one side by audience, include a strip 1 1/2 ft wide. No edge effect is used when the seating abuts walls or balcony fronts (because the edge is shielded). The coefficients are also valid for orchestra and choral areas at 5 to 8 ft² per person. Orchestra areas include people, instruments, music racks, etc. No edge effects are used around musicians.

¶Coefficients for openings depend on absorption and cubic volume of opposite side.

Test Reference

"Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method," ASTM C 423. Available from American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, PA 19103.

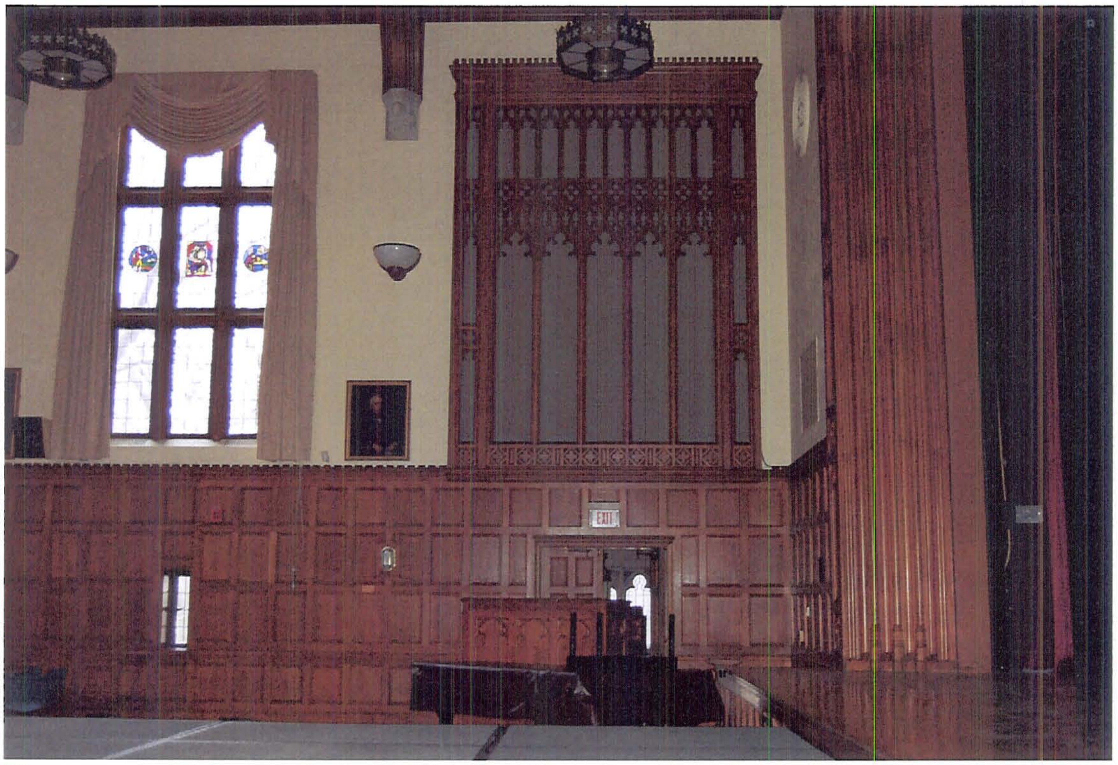
Sources

1. L. L. Beranek, "Audience and Chair Absorption in Large Halls," *Journal of the Acoustical Society of America*, January 1969.
2. A. N. Burd et al., "Data for the Acoustic Design of Studios," British Broadcasting Corporation, BBC Engineering Monograph no. 64, November 1966.
3. E. J. Evans and E. N. Bazley, "Sound Absorbing Materials," H. M. Stationery Office, London, 1964.

Figure V: Sound absorption coefficients ctd.

Appendix: Photos of the Great Hall, Surrounding Spaces, Organ Chambers, and Plans

The stage thrust and round tables are not a normal configuration for the hall. Most often, there are no thrust, no tables, and no chairs. During a performance, the chairs would be arranged auditorium style.



The organ console and pipework façade

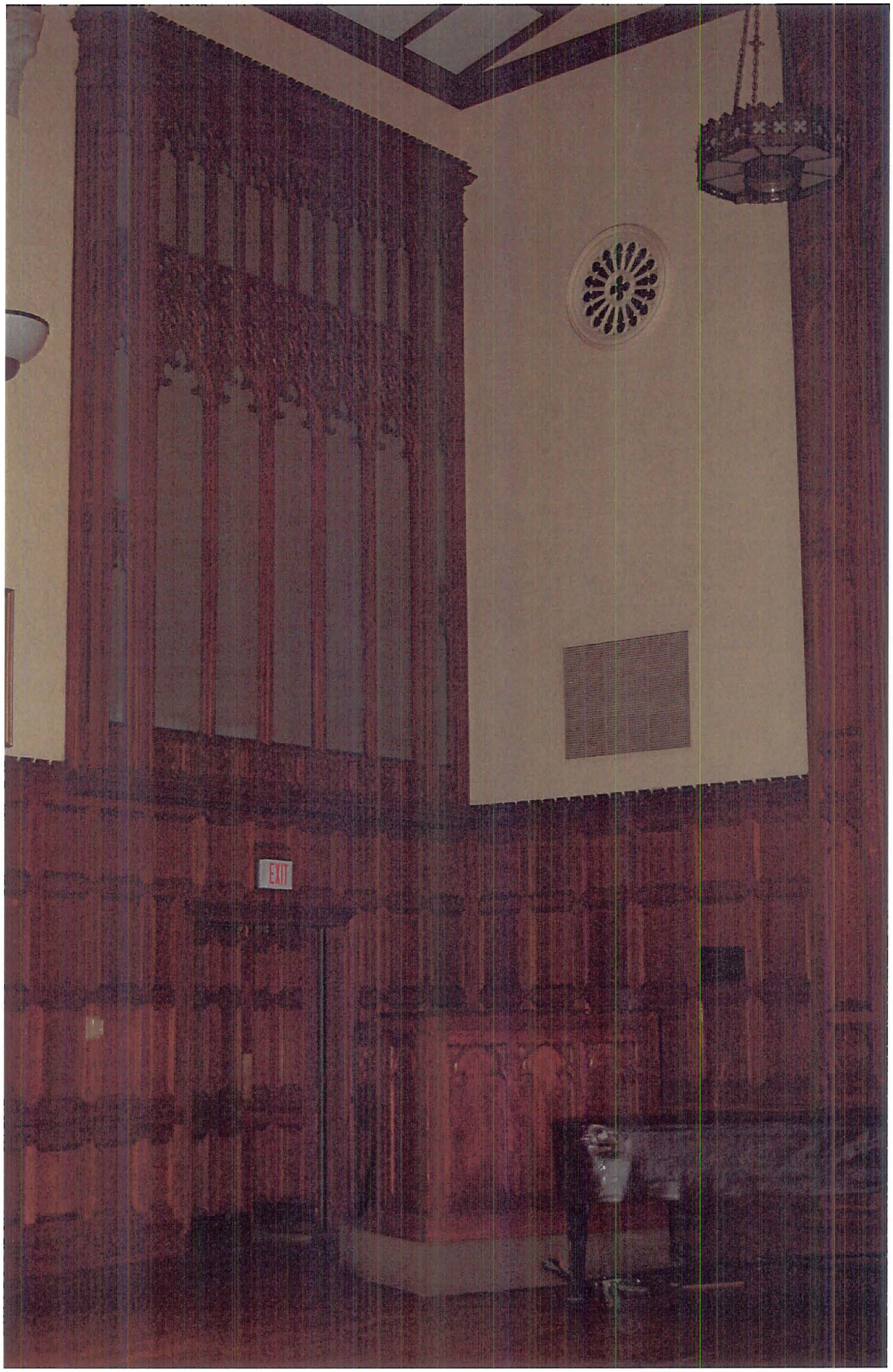
The main foyer. The great hall is through the two sets of double doors in these photos. Curved stairs lead to the balcony.


Restrooms

When discussing installing the speaker chambers in the rear of the hall, expanding through the wall to add a resonating chamber in this space should be considered.

View from the balcony

Archway at the top of the front of the balcony, and the ceiling of the Great Hall.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