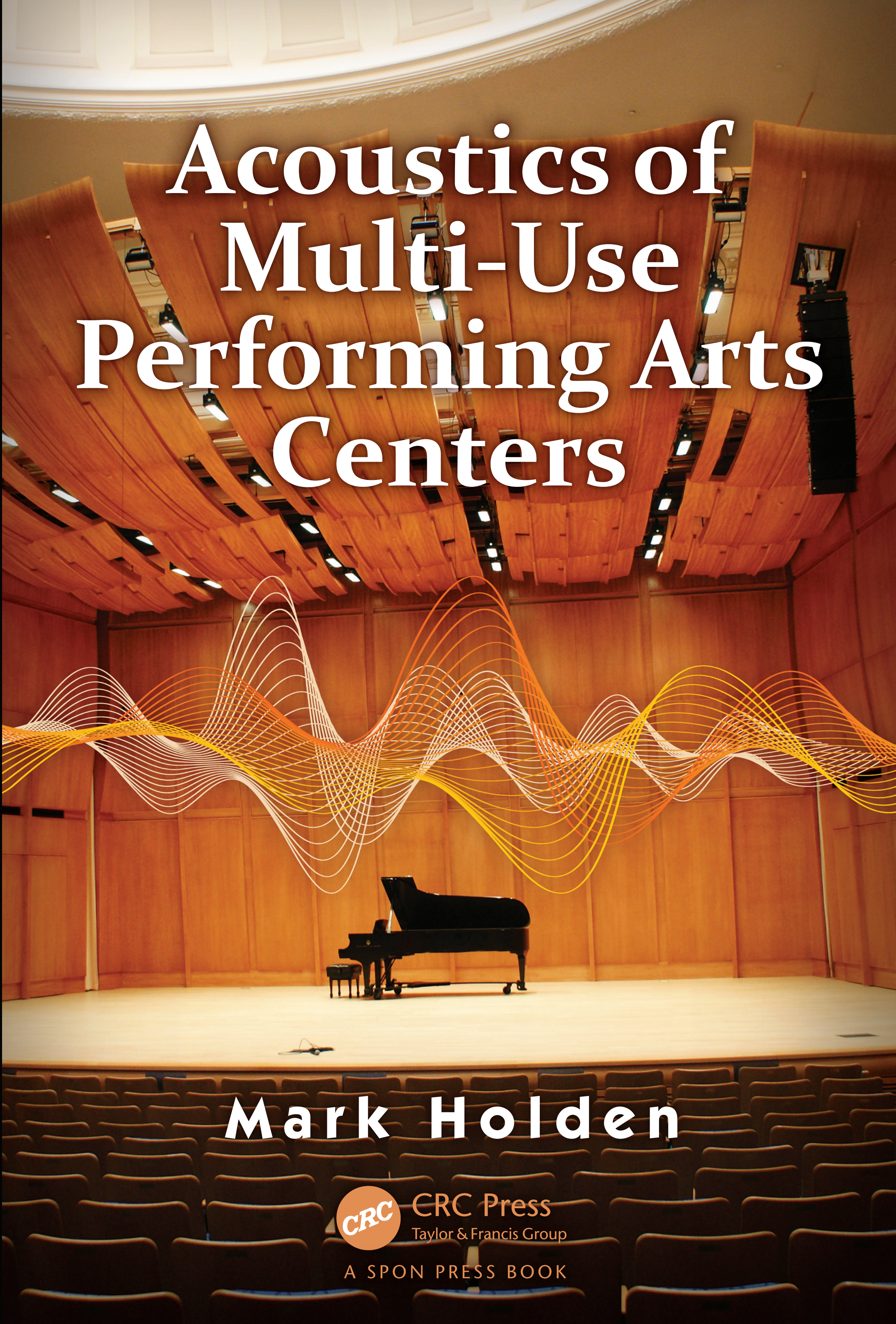

Acoustics of Multi-Use Performing Arts Centers

Mark Holden

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Acknowledgments

This book would not have been possible without the generous and dedicated assistance of many. I fear that I might leave someone out but thank everyone who contributed to getting this modest work completed. When Taylor & Francis approached me with the idea to write a text on acoustics within multi-use halls, I agreed because I believed that I had something unique to contribute.

I began this book with the naïve idea that it could be completed in a couple of years, in the kitchen, on Saturday and Sunday mornings. My optimism stretched for another year and a half, and then I compelled the team at Jaffe Holden and staff at Malcolm Holzman's office to help me complete the editing and illustrations. For their assistance, I am eternally grateful.

Much of what I have expressed here was learned from many expert acousticians and scientists who paved the way with their research, testing, calculations, and measurements. I have acknowledged specific instances where I have used others' work, but much of it was learned in technical meetings of the Acoustical Society of America and Audio Engineering Society (AES) and in conversations with great acousticians such as my mentor, the late J. Christopher Jaffe, and with Leo Beranek, the father of everything known about acoustics.

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Finally, I want to thank my family—my sons John and Luke and, especially, my dear wife Becky—for their patience, tolerance, and understanding of my obsession with writing this book and why it was important for me to share some of what I have learned over the last 35 years.

Mark Holden

Author

Mark Holden has explored acoustics within orchestra shells, orchestra pits, attics, and audience chambers in multi-use performing arts centers around the globe. Many of Mark's passions are complemented by his work as an acoustician, including classical and jazz music, the physics of wave energy, mathematics, and the design of highly complex buildings. His mission is to create aural environments that transport audiences and performers to new aesthetic and spiritual levels.

Mark was born into a family of musicians and scientists. His great grandfather Hubert Holden participated in the creation of the first direct drive motorcycle in 1914, the development of the Brooklands motor racing track with banked curves, and the development of an improved World War II anti-aircraft gun. Mark's mother, Jean Fisher, is an accomplished soprano who auditioned for the West End premiere of *My Fair Lady* but lost the part to the venerable Julie Andrews. Jean sang for years with the Cleveland Orchestra Chorus at Blossom Music Center, a Chris Jaffe–designed outdoor pavilion.

Born in Toronto, Canada, and educated at Western Reserve Academy prep school in Hudson, Ohio, Mark attended Duke University and earned a bachelor of science degree in 1978 in electrical engineering. He participated in the jazz ensemble and performed in Baldwin Hall in 1977. During his time at Duke, Mark became enamored with acoustics while participating in an acoustic study of Duke's student union as part of a physics course. This experience came full circle when Mark worked on the renovation of Duke's Baldwin Hall (explored as a case study within this book) and further services on a new student union building at Duke.

Mark has authored columns for major trade publications and lectured at Harvard's School of Design and at Duke's Pratt School of Engineering. Mark is a member of the National Council of Acoustical Consultants, a member of the United States Institute of Theater Technology (USITT), and an elected fellow of the Acoustical Society of America. He regularly presents at conferences for USITT and the American Institute of Architects.

Mark lives in Connecticut with his wife, Becky, an accomplished visual artist and educator, and two adult sons, John and Luke. When not traveling, he enjoys jogging, creating dishes in his carefully designed kitchen, and tending to his extensive collection of perennial flower gardens.

Introduction

Acoustics of Multi-Use Performing Arts Centers

Multi-use performing arts centers were once considered pariahs of the arts community. Through the use of adjustable acoustics systems, these types of halls can now adapt to different types of performance without degradation in sound quality and are comparable to many concert halls and single-purpose halls. My passion for the complexity and artistry required in the acoustic design of these spaces is revealed within this book. I hope that it serves to enrich the reader.

This book is a step-by-step manual on how to achieve outstanding acoustics in multi-use performance spaces. I will guide the reader from planning of the initial concept to the final tuning. This book is a tool for architects, acousticians, musicians, and students in addition to the general public. It is important to note that this book is informed by evidence-based design gleaned from real-world experience and not just theory. Only necessary mathematics and terminology explanations are included within this book. A glossary includes more in-depth definitions and derivations.

This book is structured into the following sections:

- Building Blocks: Chapters 1–4
  - This section covers the fundamentals of acoustics as it relates to initial stages of multi-use hall design in order to provide a solid foundation for the reader.
- Creating the Building: Chapters 5–8
  - In this section, concepts of acoustics are explored in terms of new and renovated spaces, and the basic components of the building structure are defined.
- Architectural Details: Chapters 9–14
  - This section examines floors, walls, ceilings, shells, and finishes and how they can be designed to achieve acoustic excellence.
- Measuring Results: Chapters 15–17
  - This section discusses how to use and tune adjustable acoustic systems in a multi-use hall in order to achieve acoustic excellence.
- Case Studies: Appendix
  - A collection of case studies on both new and renovated facilities is included in this section to demonstrate successful acoustic attributes and design.

It has been an honor and a privilege to work with talented architects, project managers owners, engineers, contractors and artists on multi-use performing arts centers around the world. I have collaborated with and learned from nine Pritzker Architecture Prize winners and am truly grateful for the many teachers I have had over the past 38 years. There is still much to learn about the science of acoustics and how the ear and brain interact. I look forward to continuing this journey and sharing it with my readers.

Mark Holden

BUILDING BLOCKS

I

Chapter 1

Making the Case for a Multi-Use Hall

Introduction

Purpose-built halls that serve solely as concert halls or opera houses are increasingly rare today because of high construction and operational costs. Only a few major international cities and high-profile institutions with deep pockets can afford them. Single-purpose halls have the advantage of being able to provide an ideal acoustic, theatrical, and artistic environment for each art form in individual facilities. The symphony can rehearse on the stage unencumbered by other performers needing the facility. The opera only needs to share its home for occasional outside performances. The theater can arrange sets that remain in place for extended periods of time (see Figure 1.1).

This exclusivity comes at significant capital and operational cost. In the United States, there is pressure by civic and business leaders for halls to consistently attract large audiences who pay to park, dine, and shop.

Capital costs for single-purpose facilities are substantial. For example, Kansas City, Missouri, privately raised more than $400 million for separate ballet/opera and symphony halls, and over a quarter of that sum was donated by a single foundation. The Kauffman Center for the Performing Arts opened in 2011 and features an 1800-seat ballet/opera house and a 1600-seat pure concert hall (see Figure 1.2).

The New World Center, designed by Frank Gehry, is a pure concert hall in Miami Beach that opened in 2011. This building cost $160 million and features innovative video display systems, excellent acoustics, and high-tech communication systems. The stage is nearly as large as the hall's seating area and is a viable financial model only because unique teaching and presenting opportunities exist for the space. Academic institutions with endowments, tuition, and donors can indeed build and operate intimate purpose-built halls for use by students and faculty. Jaffe Holden has collaborated on dozens of successful models like the New World Symphony Hall. However, it would be a mistake to assume that this hall design is the rule when, in fact, it is the exception.

Figure 1.1 Carnegie Hall, New York, NY, 1891. This iconic, purpose-built concert hall is known for excellent symphonic acoustics but is not well suited for opera, dance, or theatrical productions.

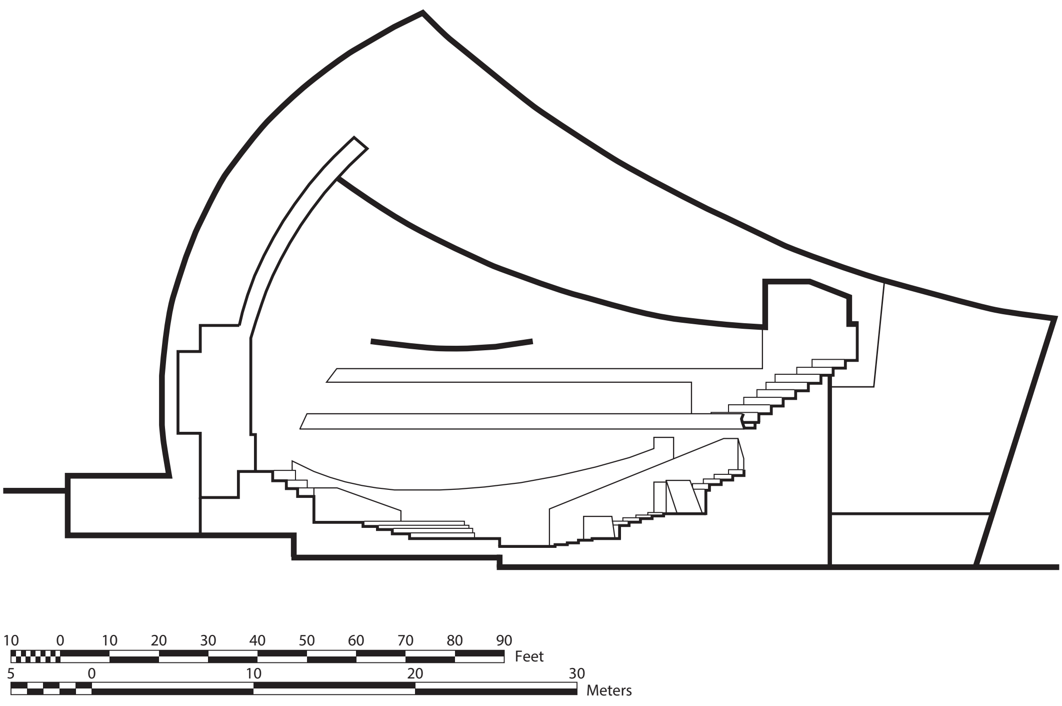

Figure 1.2 Helzberg Hall in the Kauffman Center, Kansas City, MO, 2011. With a cost of more than $400 million, this 1600-seat hall is an excellent concert hall but is less suited for dance, theater, and opera productions.

Short History

Despite the recent increase in popularity, the multi-use hall is not a new invention. The use of this type of building dates back to the 1920s. Although many aspects have changed over the years, the reasoning behind implementing this design has remained largely the same.

The 1920s and 1930s

Grand but technically unsuccessful municipal auditoriums in American cities during the 1920s and 1930s paved the way for the emergence of the multi-use hall. The municipal auditorium was the result of pressure from the artistic community for a large performance facility that would further the artistic development of local symphony, opera, and theater companies, as well as serve as a convention hall, grand ballroom, and ceremonial space (see Figure 1.3).

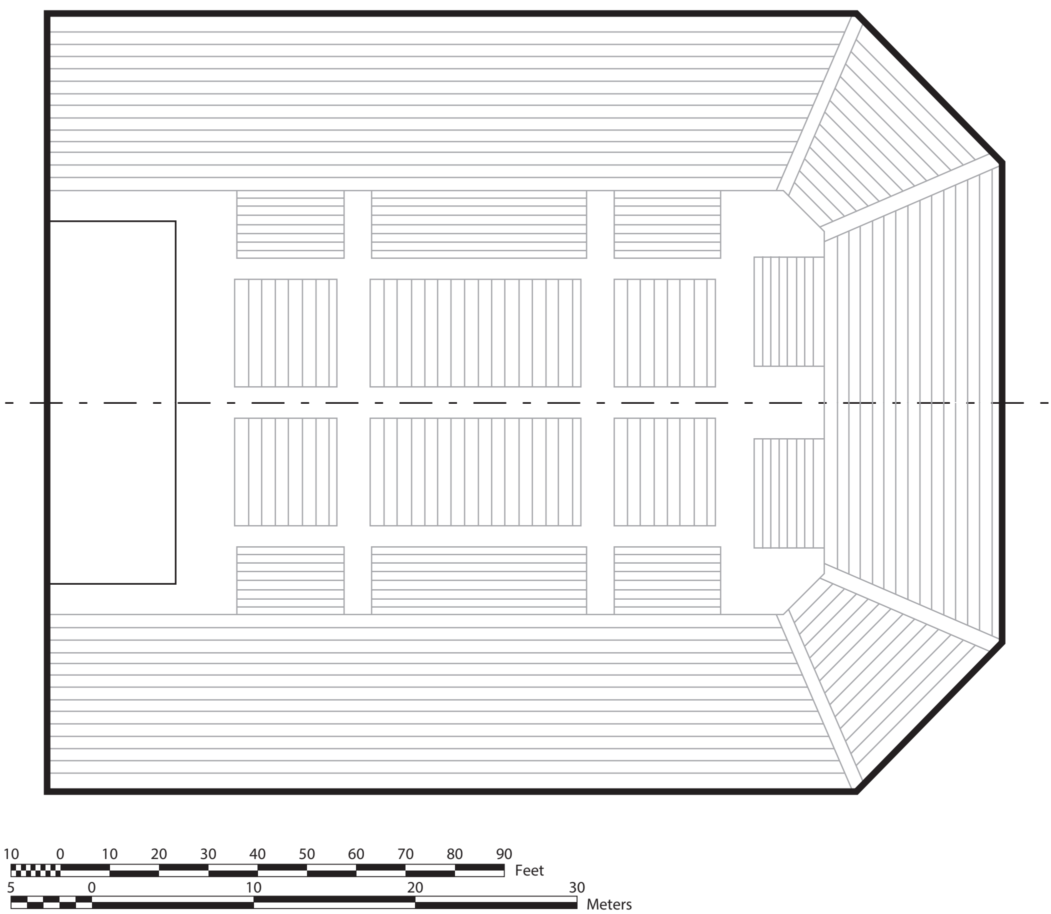

Figure 1.3 Columbus Civic Center, Columbus, GA, 1926. An early multi-use auditorium built to house performing arts, sports, exhibits, conferences, and political conventions. Acoustics are poor for all functions.

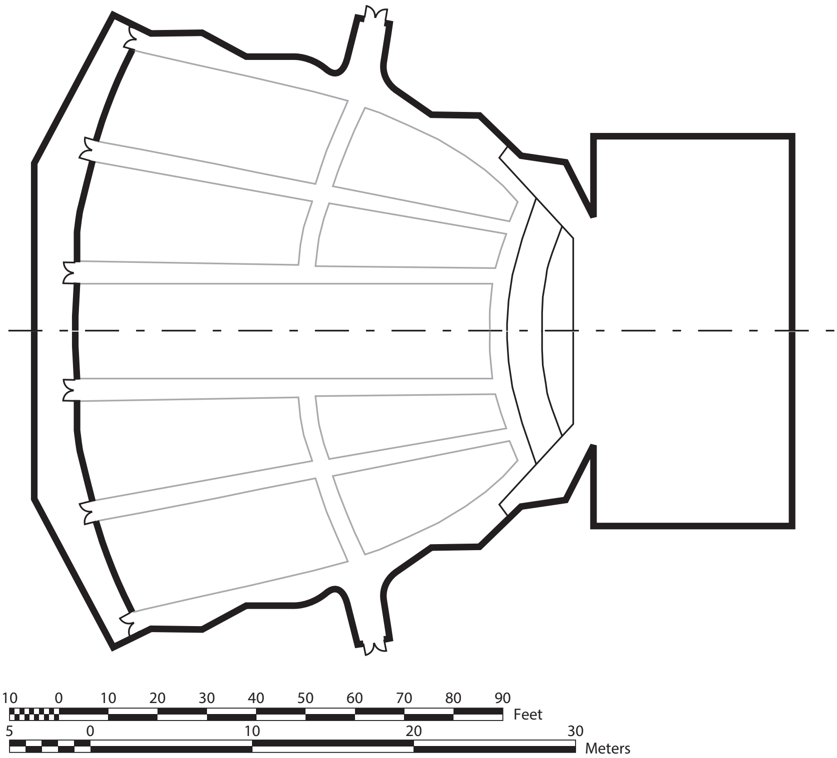

Figure 1.4 Jacksonville Civic Auditorium, Jacksonville, FL, 1962. This wide, 2000-seat fan-shaped multi-use hall was an improvement over earlier civic centers but had poor acoustics and was gutted in 1990.

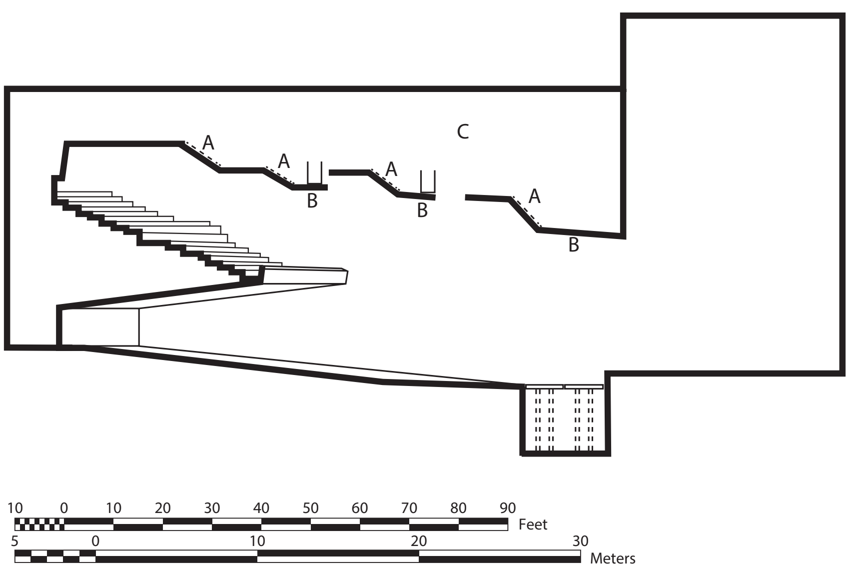

Figure 1.5 Jacksonville Civic Auditorium, Jacksonville, FL, 1962. This is a large, single balcony space. (A) Coffin-shaped ceiling openings. (B) Ceiling reflectors. (C) Upper acoustic volume.

The 1940s

During this decade, manufacturing and building construction industries focused on war efforts. As a result, very few halls were built during the 1940s (see Figure 1.3).

The 1950s and 1960s

After World War II, there was a growing desire from the public for modern halls to take on a more egalitarian form and thus eliminate exclusive boxes and grand tiers that created barriers between audiences. As part of this postwar civic expansionism and pride, democratic civic buildings were designed as homes for symphonies, theater troupes, and community concerts. Some also served as a war memorial or provided office space. In the 1950s and 1960s, cities such as Austin, Charleston, and Memphis built what was then considered to be fantastic new facilities. At the time they were created, these single-balcony, wide fan-shaped halls were considered to be state of the art technically, acoustically, and artistically.

It is now known that these halls lacked sonic impact and intimacy for theater, provided limited presence and clarity for opera, and were devoid of warm, rich reverberation for symphony. Still, they were a huge improvement over the barn-like convention centers that had served the communities for prior decades (see Figures 1.4 and 1.5).

The 1970s and 1980s

A new breed of multi-use halls came about in the 1970s and 1980s that were a vast improvement visually and theatrically but not much better acoustically. These buildings were technologically quite sophisticated and often employed moving ceilings to close off hall volume and create adjustable acoustic environments that met reverberation requirements and reduced seat capacity. Counterweighted, multiton steel contrivances supported the ceilings, catwalks, and lights but provided only a gross level of acoustic tunability and variability. Similar multi-use halls with subpar acoustics can be found in Northern Alberta, Canada, and Tokyo, Japan. In all fairness, these halls utilized the best available acoustic knowledge and consultants, but the tools available at the time were crude and unwieldy (see Figures 1.6 through 1.9).

Tools of the Trade

Manufacturers had few tools other than winches, cables, and counterweights to offer acousticians throughout the 1980s. Frankly, adjustable acoustic devices were more closely related to rigging ship anchors than to the needs of orchestras and opera companies. It is not a surprise that the multi-use halls got a bad reputation within the musical community. They were no match for the well-known pure concert halls such as Symphony Hall in Boston and Carnegie Hall in New York.

The 1990s

In the 1990s, Jaffe Holden set about to solve the conundrum of providing acoustic excellence for symphonic performances while at the same time meeting the theatrical and acoustic needs of other types of performance. Three new design directions were developed based on a facility's needs, end users, and budget. The first involved a sophisticated orchestra shell called the concert hall shaper. The second employed a system of double pit lifts to bring the orchestra past the proscenium and

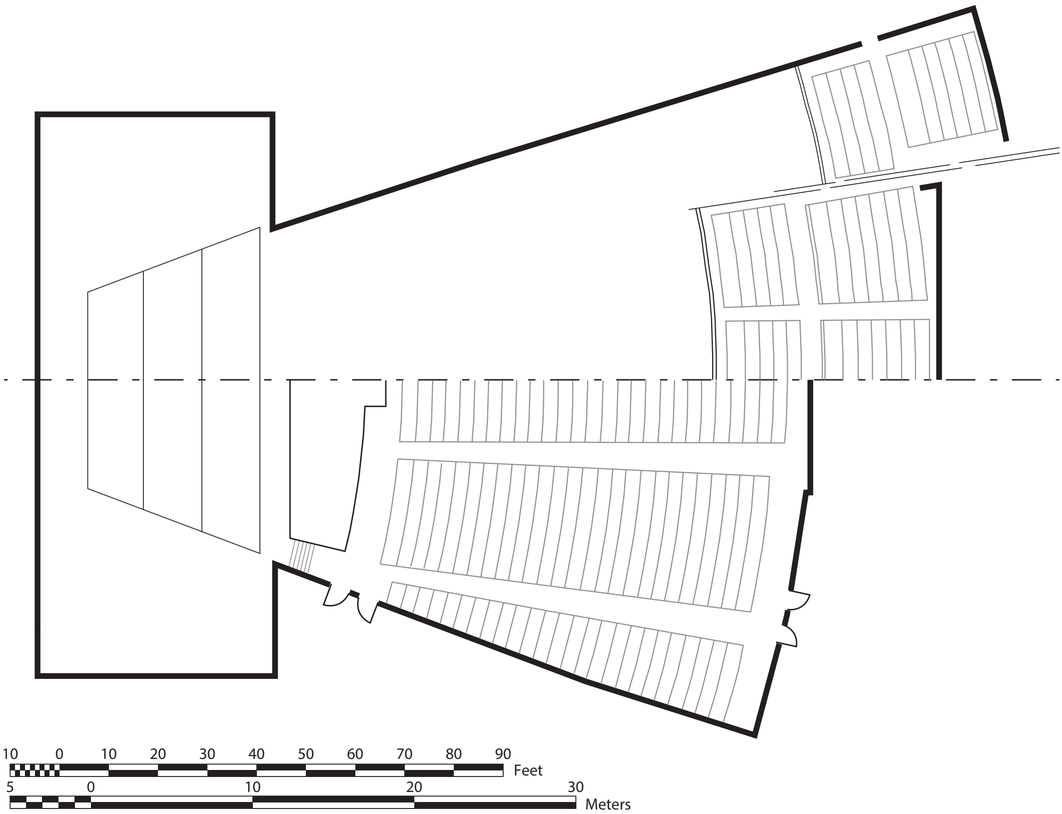

Figure 1.6 Northern Alberta Jubilee Auditorium, Edmonton, AB, Canada, 1957. A 2500-seat fan-shaped hall with shallow balconies and low acoustic volume. Remodeled in 2004.

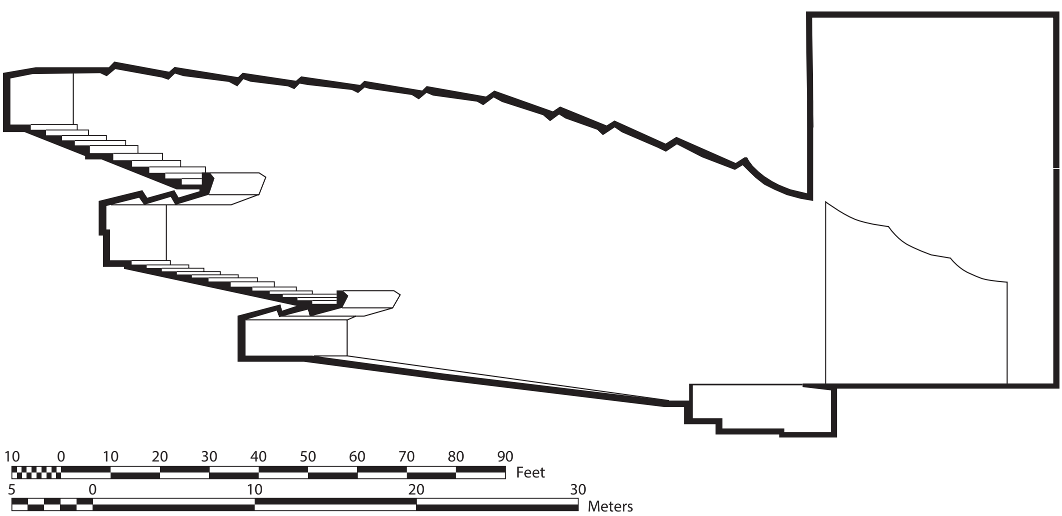

Figure 1.7 Northern Alberta Jubilee Auditorium, Edmonton, AB, Canada, 1957. An example of an acoustically poor multi-use halls from the 1950s built in North America that tarnished the reputation of multi-use halls. Remodeled in 2004.

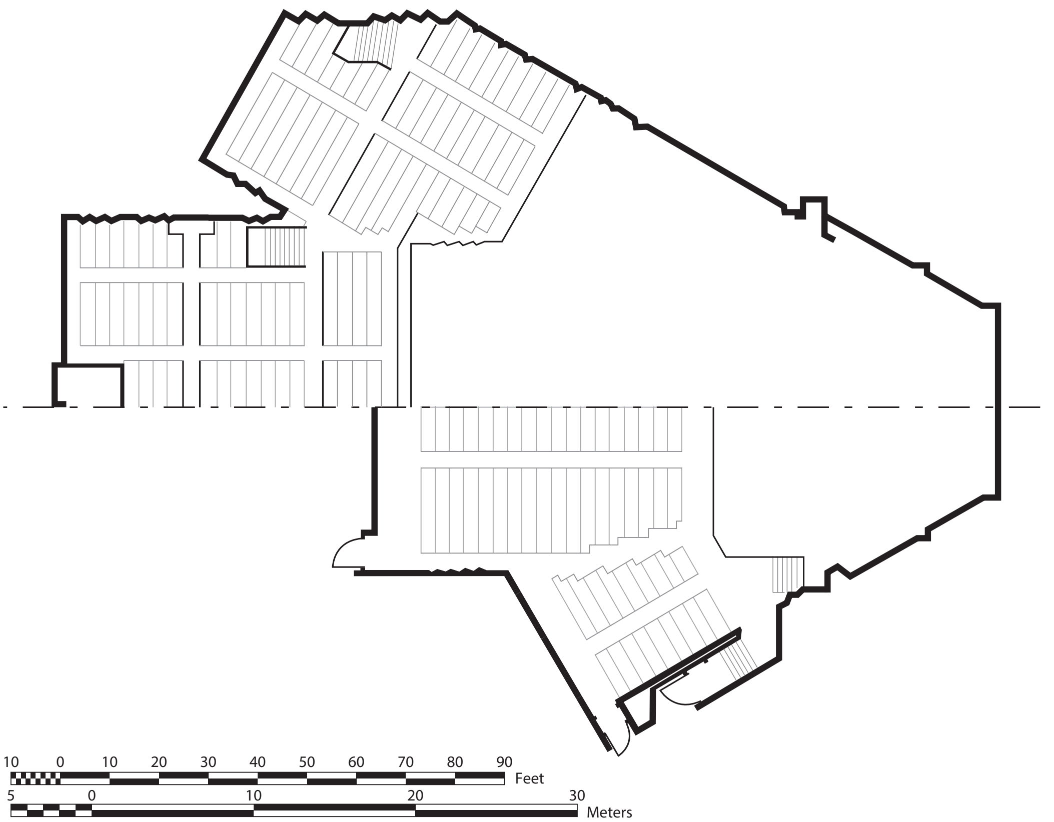

Figure 1.8 The NHK Hall, Tokyo, Japan, 1955. A fan-shaped multi-use hall with seating sections in terraces and low ceiling height.

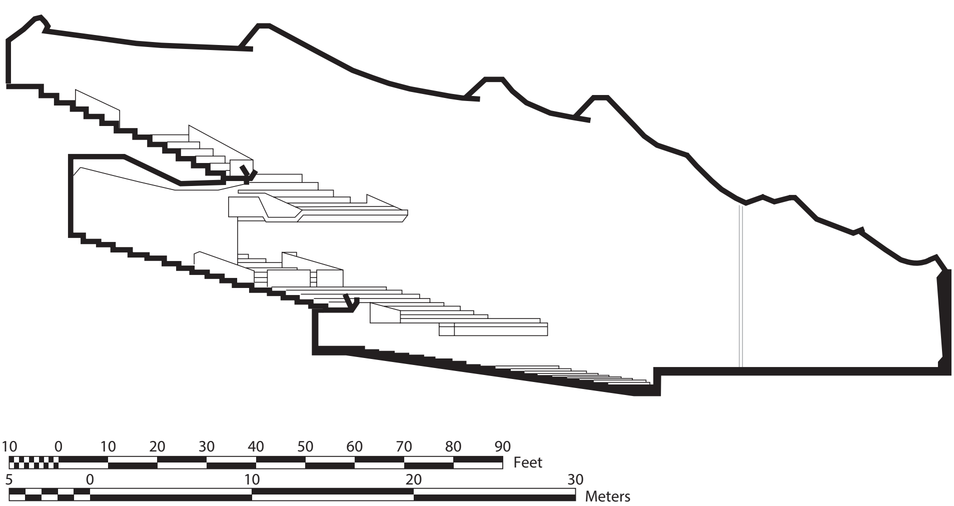

Figure 1.9 The NHK Hall, Tokyo, Japan, 1955. NHK Hall is a more successful example of a 1950's multi-use hall. Note that the wide fan shape is divided into smaller seating zones.

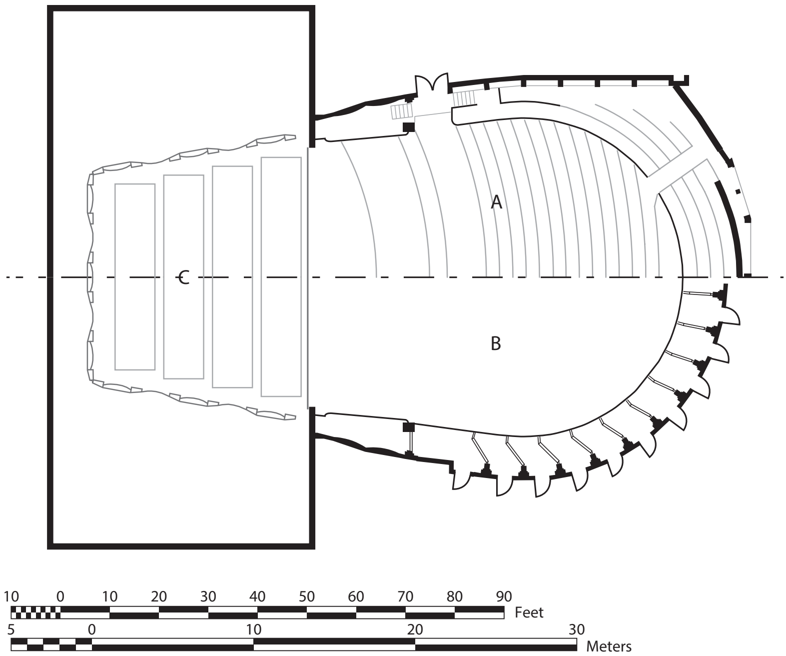

Figure 1.10 Bass Performance Hall, Fort Worth, TX, 1998. A 2000-seat multi-use hall with excellent acoustics, detailed in the Case Studies. (A) Orchestra level plan. (B) Box tier plan. (C) Concert Hall Shaper orchestra shell.

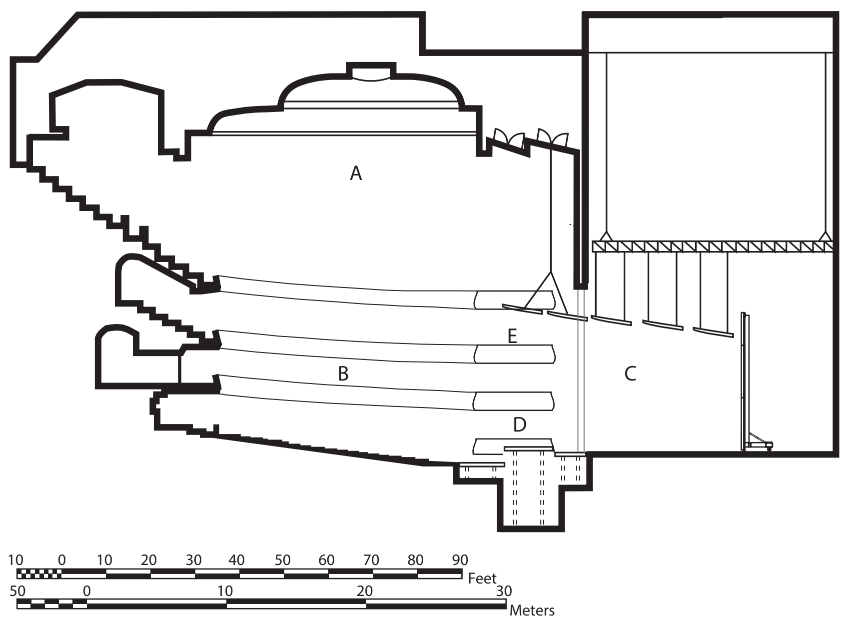

Figure 1.11 Bass Performance Hall, Fort Worth, TX, 1998. (A) High ceiling for proper acoustic volume with adjustable acoustic drapes. (B) Shallow balconies and side boxes for acoustic reflections and adjustable acoustic banners. (C) Tunable Concert Hall Shaper orchestra shell. (D) Orchestra pit/stage extension. (E) Forestage reflector.

out into the hall so that the auditorium could function as a one-room concert hall. The third approach placed a modified orchestra shell behind the proscenium and around the ensemble to project, blend, and aid onstage hearing.

Creating a flexible hall with excellent acoustics for classical music was but one piece of the acoustic conundrum. The acoustic challenges involving opera, amplified music, amplified musicals, and film or video presentations still needed to be addressed (see Figures 1.10 through 1.13).

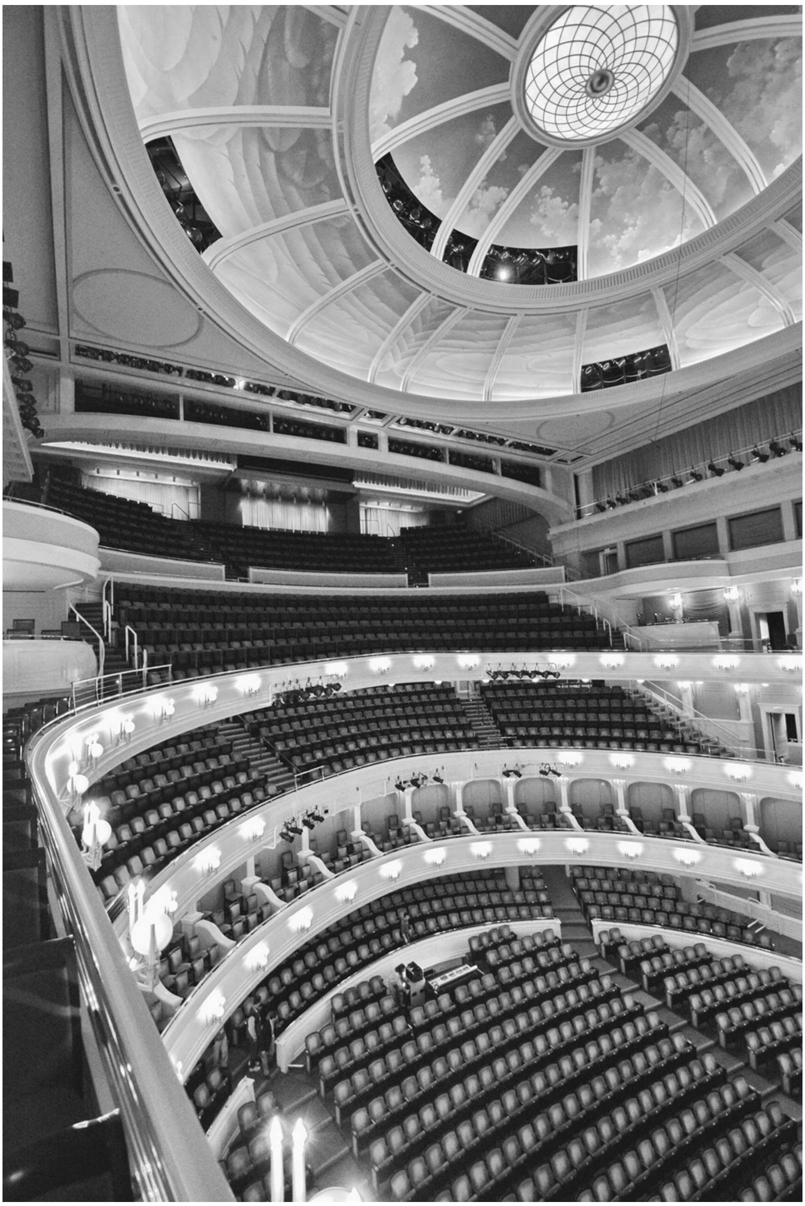

Figure 1.12 Bass Performance Hall, Fort Worth, TX, 1998. Features complete adjustable acoustics technology within a classically designed hall. Featured as a case study.

Figure 1.13 Dell Hall at Long CPA, Austin, TX, 2008. A 2400-seat multi-use hall built within the shell of a 1950s civic auditorium. The green renovation showcases many of the adjustable acoustic systems described in this book at a modest budget. This hall is featured as a case study.

The Need for Multi-Use Halls

Communities that have a need for multi-use performance halls often hesitate to embrace them because of the misconception that they are not acoustically successful. Those quoting acoustic disasters in flexible halls have plenty of ammunition to draw from, as there have been more than a few spectacular failures. Acoustics as a “black art” is a common explanation for these failures. A careful study will reveal that poor acoustic results are often rooted in uninformed clients, bad design, team chemistry, inadequate funding, or inexperienced acoustic designers.

Shortfalls

Why is it that the acoustics of some halls have failed to meet expectations?

Lackluster Partnership

Acousticians have advanced computer modeling systems and years of field experience. Yet, there are halls that do not meet acoustic expectations. My theory is that, while the science of sound is quite well understood, the successful design of these halls requires more than raw scientific facts and years of theoretical experience. It requires a design team that works in total collaboration and partnership. Relationships must be carefully nurtured. I believe that relationships have a direct correlation to the outcome of the design and the acoustics of a space. A team that does not work well together and cannot communicate is likely to create a substandard project.

Pressure from Donors

While well intentioned, those that fund the construction costs of a new hall often have high goals and expectations well beyond acoustics. Donors know that sound is significant but place a great deal of importance on the ability of the new hall to stand as an icon especially since their name may be on the building. When the idea of the hall becomes more important to the donor than its actual functionality, decisions can often made that compromise acoustics.

Compromised Upgrades

Compromises to acoustic quality can sneak up on the design team. For example, well-intentioned designers or contractors could swap out materials without consulting the acousticians. Less-expensive wall materials often have a lower acoustic mass, seat upholstery perceived to be upgraded often absorbs more sound, and greener air systems are often noisier than the specs reviewed by the acoustician.

Communicating Ideas

The decisions and design solutions that make the difference between a successful hall and a mediocre one occur when the design and construction team work in total collaboration. When the team communicates and trusts each other, the hall is much more likely to succeed. Since every little detail can affect the acoustics of a hall, it is necessary for the acoustician to be involved in every design decision.

Multi-use hall design is often considered to be the most complex design. Contractors who have built nuclear power plants and military research labs agree that concert halls, theaters, and flexible performance halls are by far the most complex projects. Any slight change can affect the acoustic, structural, mechanical, theatrical, and code compliance in unintended ways. This domino effect is what renders multi-use hall design both complex and exciting.

Everyone in the business of hall design must have strong self-confidence in order to make their case during design meetings. However, an exaggerated ego can shut down the collaboration that is necessary for great buildings and great acoustics. It is important to be a good listener and a clear communicator.

Fear of losing control can also halt the open communication of ideas. The mentality of "my way or the highway" does not make for great collaboration. The stakes are very high. Reputations and prestige are on the line, as are millions of dollars. Holding on too tightly and micromanaging details can quickly throw a project off track just as trusting in the team's abilities encourages respect. In my experience, I have learned that respect and trust come more quickly when the team has a successful history of working on projects together. Good relationships strongly affect the outcome of any project. A team that does not work well together is doomed to create a substandard facility.

Success Stories

Engaging the acoustician very early in the design process results in successful halls. Ideally, acousticians begin the collaboration with donors, owners, and performing arts stakeholders when the initial design concepts are first put forth by the architects. In the best-case scenario, the acoustician is engaged before the rest of the design team and has a hand in influencing the selection of the design architect. In this scenario, it is assured that the lead designer will engage the acoustician in a meaningful way.

Individual groups acting independently, or within silos, often exist on a multidisciplinary design team. The success of the hall depends upon close collaboration and the removal of these silos. Acousticians; theater consultants; architects; interior designers; contractors; and structural, electrical, and mechanical engineers must form one cohesive and respectful team in order to achieve success.

There are a number of examples of multi-use halls that have excellent acoustics for various performance types, are affordable to build and operate, and revitalize communities. The Long Center for the Performing Arts in Austin, Texas, was a well-loved municipal auditorium built in the 1950s that has since been successfully transformed into two very flexible halls: the Michael & Susan Dell Hall and the Debra and Kevin Rollins Studio Theatre. These two spaces meet the needs of the Austin Symphony Orchestra, Austin Lyric Opera, and Ballet Austin in addition to touring Broadway productions, headliner acts, and local productions.

The case studies in the appendix of this book showcase successful halls, including Dell Hall, to more fully illustrate how a flexible-use hall can blossom into a magnificent facility for the community.

Chapter 2

The Building Block of Reverberation

Introduction

What makes for excellent acoustics in some halls and what defines poor acoustics in others can be confusing to both the average listener and the sophisticated performer. Oftentimes, poor acoustics are blamed on the lack of wood materials in the walls or floor or on the excessive number of seats in a hall. Some myths for ensuring excellent acoustics are that concrete makes for bad acoustics, or placing broken wine bottles under the stage improves sound, as discussed by Goldsmith (2014)in *Discord: The Story of Noise*. These are both untrue and are proven as such by a number of reputable halls.

Both the Wiener Musikverein in Vienna, Austria, and the Concertgebouw in Amsterdam, Netherlands, are considered the gold standard for symphonic acoustics and have limited wood surface areas. The wood floor under the audience in the Concertgebouw is directly attached to a substantial concrete floor slab. The halls that achieve the highest acoustic ranking are built primarily of heavy plaster, which is more closely related to concrete in weight and chemical composition than wood. Some of these buildings have heavy wood timber under the plaster, but there also are examples of buildings structured with steel and concrete that have excellent symphonic acoustics, such as the Nancy Lee and Perry R. Bass Performance Hall in Fort Worth, Texas, or the Morton H. Myerson Symphony Center in Dallas, Texas.

Defining the Programming

The acoustics of a space must be determined by the particular type of performance that utilizes the space. Halls that are excellent for one performance type, amplified music for example, are often terrible for other types like classical symphonic performances. Radio City Music Hall in New York City demonstrates this point. The 6000-seat theater excels at presenting loud amplified popular music but fails at presenting operatic or unamplified symphonic music (see Figure 2.1).

Figure 2.1 Radio City Music Hall, New York, NY, 1932, 6000 seats, renovated by Jaffe Holden in 1999. (A) Sound absorptive rear wall. (B) Ceiling sound absorptive cast plaster now painted and sound reflective. Reverberation time 1.5 s, mid freq.

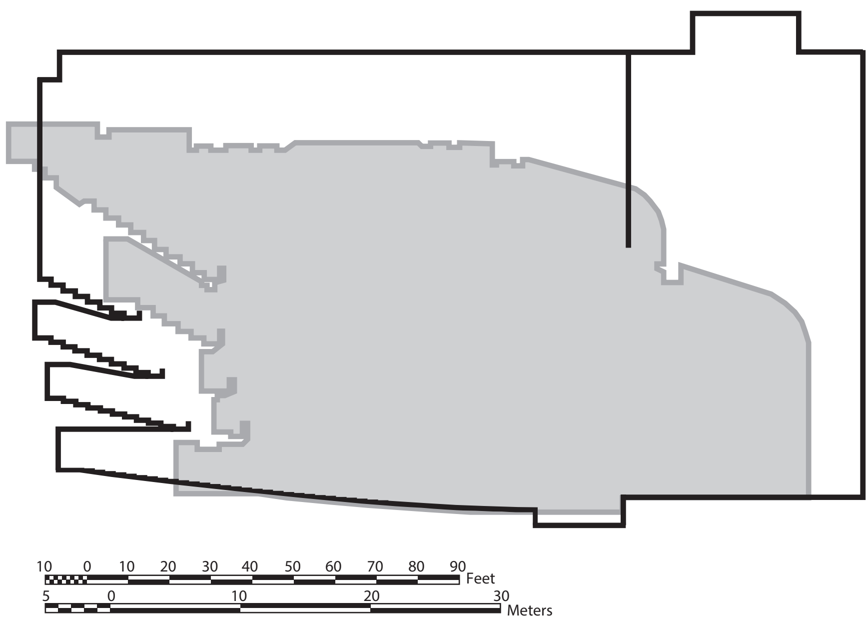

Figure 2.2 Overlay of Carnegie Hall section (in gray) with Radio City Music Hall section. Carnegie Hall is acoustically excellent for symphony concerts but not for highly amplified shows. Radio City Music Hall is acoustically excellent for amplified productions but not for the symphony.

Radio City Music Hall has a very large air volume, a concave ceiling, concave wall shapes, carpet covering all floor surfaces, and heavily upholstered seats. Comparing this hall to Carnegie Hall is useful in illustrating the point. Intuitively, the air volume of Radio City Music Hall is twice that of a concert hall, meaning that the fixed maximum sound energy of a symphonic or operatic ensemble is dissipated in the large space and leads to results of low loudness and weak sound impact. The walls and the ceiling surfaces are at vast distances from the listener, shaped in such a way that the sound is directed to the back of the hall. The rear walls of Radio City Music Hall kill any reverberation with their silk-screened fabric over thick fiberglass absorption materials.

The hall has excellent acoustics for amplified programs but has poor acoustics for unamplified performances. The reason lies in the specific and quantifiable acoustic qualities required for classical events. The acoustic qualities must be appropriate for the performance type. This will be proven and discussed in greater detail later, but for now, the point to be made is that excellent acoustics are defined only when the type of performance is fully defined (see Figure 2.2).

Reverberation Time

Opera houses and ballet halls share many of the same acoustic criteria for excellent sound but differ from concert halls or amplified music halls. The Seattle Opera House in Seattle, Washington, has a lower air volume than both Radio City Music Hall and Carnegie Hall and a lower ceiling. Excellent acoustics for opera and ballet are defined by different criteria from that of amplified music halls or concert halls. The acoustics of the Seattle Opera House would be considered only fair for symphonic performances. Compared to Carnegie Hall or Boston Symphony Hall, it has a lower reverberation time (RT) and shapes that optimize the balance of stage singing to orchestra pit musical instruments.

Consider the following optimal mid-frequency RT ranges for excellent acoustics in different spaces:

- Classical music (unamplified): 1.7–2.0 seconds
- Opera/ballet music (unamplified): 1.3–1.7 seconds
- Amplified music or speech: 1.0–1.4 seconds

All performance types will fall into these three main categories. Other RT criteria exist for liturgical music and film theaters, but these facilities are not classified as multi-use halls.

Sabine and Eyring

The acoustician regularly uses two RT formulas in the design of multi-use halls: the Sabine equation and the Eyring equation.

The Sabine equation relates RT, the time required for the level of reverberant sound to decay by 60 decibels (dB), to the volume (V) and total sound absorption (A), assuming that the shape of the room allows reverberant sound to be evenly distributed throughout. The even distribution of sound is critical for RT to be defined. This is why large stadiums, outdoor theaters, and small rooms will not have a defined RT per Sabine's formula.

Eyring is most useful when room shape or absorption materials will not allow even distribution of reverberant sound. Cinemas, drama theaters, and media studios have wall and ceiling sound absorption treatments covering much of the walls and ceiling therefore canceling even sound distribution. The RT in a multi-use hall that is set for amplified events will more closely follow Eyring than Sabine.