Abstract
Rensselaer Polytechnic Institute has instituted the most ambitious graduate Program in Architectural Acoustics in the United States. It covers comprehensively most relevant aspects of architectural acoustics, including room acoustics, computational modeling, noise control and sound isolation, signal processing, and psychoacoustics. The program’s ambition is to give the students a well-rounded education and the necessary skills for successful careers as acoustical consultants, while at the same time providing in-depth knowledge required for continued doctoral studies. The contents and approach of the program will be discussed in the presentation.

1. Introduction
The field of architectural acoustics is in rapid development. New technologies such as novel microphone array techniques, computer-aided measurement and modeling, auralization—as well as personal computers and digital signal processing in general—will continue to change the way that practicing acousticians work, both as consultants and as researchers. The new tools will be brought into practice by students graduating from universities. The students will be the carriers and catalysts that will change what is expected from acoustic consultants. Charging a client for simply using Sabine’s formula will become a thing of the past. Fitting all the new knowledge into a reasonable curriculum, which in addition must also cover selected traditional material, is thus an important task for educators.

2. Expectations of Future Employers
For students to be successful in finding their first job they should have significant experience to a number of fields: Acoustics, Architecture, Audio, Electrical and Mechanical Engineering, Music, Physics, and Theatre, just to mention some of the items on a consultant’s wish list when hiring new help. On top of this, students must have exceptional written and verbal communication skills. The need for these interdisciplinary skills means that students from both technical and non-technical backgrounds must work hard to reach a useful level in areas where they have limited previous knowledge. Furthermore, the students at some time perhaps will work in large offices where there are staff knowledgeable not only in the fields mentioned but also in materials science, psychology, recording, theater arts and technology.

In order to assess how to shape the Program, some consulting firms (either specializing in room acoustics or building acoustics in general) were asked to list specific qualities that graduates should have. Some of these qualities dealt with educational depth: fundamental understanding of room and building acoustics, signal processing, psychoacoustics, basic statistics, hands-on familiarity with measurement techniques and transducers, computer simulations and their assumptions/limitations, basic architectural drawing (CAD) software. Employers also valued highly professional aspects: excellent written and communication skills (writing concisely without too much technical jargon), project management, “professionalism, marketing and networking skills” (interacting with a project team, “selling” your idea, and reinforcing client satisfaction), leadership and diversity of experience (e.g., travel abroad, athletics, other extracurricular activity, etc.). As one consultant wrote: “Above all, we are looking for dynamic people that are open-minded, can learn, and can communicate with a broad spectrum of individuals.”

3. The Program in Architectural Acoustics
Responding to these needs, Rensselaer Polytechnic Institute has instituted what we believe to be the most ambitious graduate Program in Architectural Acoustics in the United States [1]. Founded by the internationally known acoustician Dr. Christopher Jaffe, the Program in Architectural Acoustics has grown rapidly with faculty and students. The program comprehensively covers most relevant aspects of architectural acoustics, including room acoustics, computational room modeling, noise control and sound isolation, signal processing, and
psychoacoustics. The Program's ambition is to give the students a well-rounded, excellent education with the necessary skills for successful careers as acoustical consultants, while at the same time providing in-depth knowledge required for continued doctoral studies. The M.S. program is an intense year, during which the students not only must take various courses but also find time to write a Master’s thesis of an expected level of quality.

The Program is geared toward college graduates who have interests in acoustics, music, architecture, and/or engineering. One important aspect of this interdisciplinary program at Rensselaer is its absence of a requirement that the students must have an engineering, physics, mathematics or similar background. Rensselaer’s Program in Architectural Acoustics is open to all students who are talented and motivated enough to spend a year of intensive study in Architectural Acoustics. A general requirement is that the student must have some background or interest in music so that the student can speak the language of some consultants’ clients. We value musical ability in addition to other academic skills, since in our experience musical ability and familiarity with musical jargon is nearly essential to a successful career in consulting in architectural acoustics.

Students in the Program have had backgrounds in physics, music, acoustics, architecture, mathematics, electrical engineering, mechanical engineering, civil engineering, architectural engineering, philosophy, recording engineering, among other fields. Since its inception in 1999, the program has had a gender balance of 41% women, 59% men (in total 22 graduate students as of Fall 2003). Students have come from the USA, Korea, Greece, China, Mexico, and Romania. Although it is challenging and sometimes difficult to provide a unified curriculum to such a diverse group, we believe that the diversity is ultimately a preparation for their professional lives and compels the students to have new and broader perspectives than they would otherwise.

The faculty includes former consultants and acoustical researchers from Yamaha Acoustics Lab (Yasushi Shimizu, Hamamatsu, Japan), and Carrier Corporation (Charles Ebbing), as well as internationally known academic faculty such as Dr. Mendel Kleiner (former head of Chalmers Room Acoustics Group, Sweden), Dr. Rendell Torres, and Dr. Ning Xiang (formerly of National Center for Physical Acoustics, Fraunhofer Institute, and Head Acoustics). The Program also brings international guest lecturers from industry and academia.

4. Curriculum

The intense one-year M.S. curriculum balances theoretical understanding with practical application to real-world design issues. It includes fundamentals in architectural acoustics, experience in measurements of real spaces (from classrooms to concert halls) and data analysis using Matlab and other software, auralization and binaural hearing demonstrations, concepts in theater and stagecraft, applied psychoacoustics, and courses emphasizing verbal and written communication skills. It contains the following courses (1 credit = 1 lecture hour/week, plus homework, laboratory, and project assignments):

**Fall**
- Architectural Acoustics 1 (4 credits)
- Sonics Research Laboratory 1 (4 credits)
- Advanced Projects in Acoustics (3 credits)
- Stagecraft and Theatre Design (2 credits)
- Research Design Seminar (2 credits)

**Spring**
- Architectural Acoustics 2 (4 credits)
- Sonics Research Laboratory 2 (2 credits)
- Applied Psychoacoustics (2 credits)
- Graduate Thesis Seminar (2 credits)
- Master’s Thesis (5 credits + summer)

Students may sometimes choose other concentration electives with significant relevance to their thesis research.

5. Course Descriptions

**Architectural Acoustics 1 & 2**

These courses teach the essentials for architectural acoustics design of performance and public spaces, including concert halls, theaters, museums, classrooms, sports arenas, courtrooms, and religious buildings. The course covers basic principles of sound, room acoustics, sound absorption in rooms, sound isolation and privacy, acoustics of mechanical systems, and sound quality. In the spring semester, students design their own performance hall, including continued studies of acoustics measurements, simulated sound fields, community noise issues, and professional practice in acoustics consulting. The course also covers sound quality and auralization. In these courses, auralization is a key component. Since room acoustics deals with the audible but invisible, conventional book- and lecture-based education is often less satisfactory for enhancing students’ learning. Although specific terms as direct sound, reverberant sound, flutter echo, early/late ratios...
can be abstractly understood by intuitive and simple reasoning, their aural meaning is less easy to understand. It is essential that the students after finishing a course on room acoustics are able to have an impression of the meaning and validity of various room acoustics concepts and metrics. Auralization – the aural equivalent of visualization – can help in this learning and is a natural complement in multimedia learning.

**Sonics Research Laboratory 1 & 2**

Sonics Research Lab is based on hands-on work and applied research methods. Students develop an in-depth understanding of the measurement equipment and analysis to quantify qualitative aspects of various sonic environments, including classrooms, concert halls, and other spaces. They learn how to understand how to interpret measurement results intelligently and how they assist the acoustical design of rooms. The second semester of the Sonics Research Lab focuses on predictability models and virtual acoustics “auralization.” State-of-the-art software is used for simulation of room acoustics in order to demonstrate how such programs assist in refining the design of performance and public spaces. The objectives are to understand the capabilities and limitations of current acoustical modeling methods, to understand the concepts of auralization and its current limitations in accuracy, to understand how to use modeling programs to analyze acoustical design issues, and to understand how to input the best data possible into the programs and how to interpret results intelligently. Students work on projects modeling spaces with different uses (e.g., lecture hall, concert hall) and submit a reports describing their approach, results, and auralizations.

**Applied Psychoacoustics**

From this course students should understand fundamentals and current models of human hearing, including binaural hearing. Students should also be knowledgeable in psychometrics and be able to design and analyze some common types of tests (ROC curves, Thurstone scaling, MDS). This will help the students to understand the limitations of psychoacoustic data available in current texts. This will be further achieved by having the students repeat some tests already reported in journals and other texts. The course achieves these goals by introducing students to the concepts and methods of applied psychoacoustics as used for architectural acoustics and for audio engineering. These concepts include fundamental hearing phenomena, basic hearing models, spatial hearing, experimental techniques used in psychoacoustics, and of course fundamental statistical description of data and inference. Experimental techniques include pair comparisons, ABX-testing, multidimensional scaling, parametric and non-parametric statistics, among others. The graduate-level course requires an extensive individual project and advanced data analysis.

**Stagecraft and Theatre Design**

This course introduces students to the elements of theater design and construction. The course discusses the physical structures in which live performances occur, as well as the economic and social forces (e.g., trade unions, production, financing, and organizational structures of play production). Particular emphasis is given to understanding historical methods of stagecraft and their relation to modern construction techniques and use of materials. Also, the course discusses acoustical considerations for theater and stage shell design.

**Advanced Projects in Acoustics**

This course utilizes advanced projects to give a deeper understanding of measurement techniques, signal processing and signal analysis, and psycho-acoustical listening tests. It also prepares each student for specific research work with individualized projects in acoustics. Project presentations evaluated on both quality of presentation and of content.

**Research Design & Graduate Thesis Seminars**

These seminar courses help students to structure their thesis research. Research Design includes (1) identifying and selecting focused research problems/opportunities/ideas; (2) documenting the state-of-the-art in the selected research area; (3) identifying the critical resources and settings to carry out the research; (4) designing the research program including strategies and tactics for carrying out the research. They also form an interdisciplinary forum where acoustics students interact with students from other graduate programs in architecture (e.g., informatics, computing, building technology, workplace design, etc.) so that they see a broader picture of architectural research. Finally, they require the students to practice and polish their written and oral communication skills.
6. Graduate Student Research Topics

Graduate students have concentrated on various research topics, in some of the research work in some of the following areas:

Concert Halls and Room Acoustics

- Models and Measurements of Non-Exponential Reverberation in Coupled Rooms (Jason Summers, Ph.D.);
- Audibility of Non-Exponential Reverberation Decays (Delphine Picard, visiting researcher, Ecole Polytechnique);
- Audibility of Non-Exponential Decays in Running Reverberation (Derrick Knight, M.S.);
- Stage Acoustics for the Solo Violinist (William Chu, M.S.);
- Reverberation in Popular Recorded Music—Motivations and Metrics (Alex Case, M.S.);
- Youngmin Kwon (M.S.): Under-Balcony Acoustics in Concert Halls;
- Acoustics for Gospel Music Worship Spaces (Richard Lee, M.S.);
- Aurally Adequate Time-Frequency Analysis of Room Impulse Responses (Molly Norris, M.S.);
- Auralization of Room Impulse Responses with Varying Scattering Coefficient (Jake Mueller, M.S.);
- Perceived Directivity of Reverberation (Jonah Sacks, M.S.);
- Transition Times in Reverberation (Julie Byrne, M.S.);

Auralization and Telepresence

- Fast and Novel Computation of Sound Fields using Cellular Automata and Multi-Dimensional Scaling (Dr. Sung Yoon, post-doctoral researcher);
- Immersive Telepresence Systems (Paul Henderson, M.S., Ph.D. student);
- Perception and Visualization of Surface Scattering (Weifang Wang, M.S., Ph.D. student);
- Parametric Modeling of Edge Diffraction for Auralization (Nicolas de Rycker, visiting researcher, Ecole Polytechnique);
- Rendering Techniques for Acoustic Telepresence Systems (Ioana Pieleanu, M.S.);
- Visual Effects on Auditory Localization and Perception (Evelyn Way, M.S.);

Human Performance and Acoustics:

- Effects of Acoustical Environment on Memory (Dana Smith, M.S.);
- Ease of Hearing in Classrooms (Abigail Stefaniw, M.S.);
- Ease of Speaking in Classrooms (Jessica Shearer M.S.);
- Listening Training Stations for Room Acousticians (Martha Schad, M.S.);
- Audio-Visual Interaction in Listener Training (Sebastian Otero, M.S.);

Electroacoustic Enhancement Systems in Performance Spaces

- “Virtual Microphone Technique,” utilizing Active Sound Field Control for low-frequency reverberation enhancement (Iraklis Lampropoulos M.S.);

7. Summary

The Program in Architectural Acoustics at Rensselaer continues to shape itself to address the growing interdisciplinary nature of Architectural Acoustics, the needs of contemporary acoustical employers, and the new simulation and measurement technologies that can redefine acoustics practice. The Program pursues excellence in its theoretical and hands-on curriculum, its research areas, and its student recruits. Auralization, psychoacoustics, and listening experience are deemed as essential as theoretical understanding of architectural acoustics fundamentals and form an important part of the curriculum and research. In order to teach effectively to students with widely different academic backgrounds, the Program looks for excellent, open-minded, and dedicated students. It offers an intense one-year M.S. curriculum integrating fundamentals of architectural acoustics, auralization, and professional fluency necessary for successful careers. The Program faculty also mentors doctoral students toward Ph.D. degrees in new areas in architectural acoustics. In these ways, the Programs endeavors to prepare students for state-of-the-art, cutting-edge professions in acoustics.

8. Acknowledgement

The authors thank Scott Pfeiffer of Kirkegaard Associates and Emily Heinze of Cerami Associates and other consultants for their input. The authors are also grateful for feedback from past and present students and faculty in the Program in Architectural Acoustics.

9. References