

**International Symposium on Room
Acoustics - 2013**
Toronto, June 9-11, 2013



Conference Program



ISRA 2013

International Symposium on Room Acoustics

9-11 June 2013

**Royal Conservatory of Music
Toronto**

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INTRODUCTION

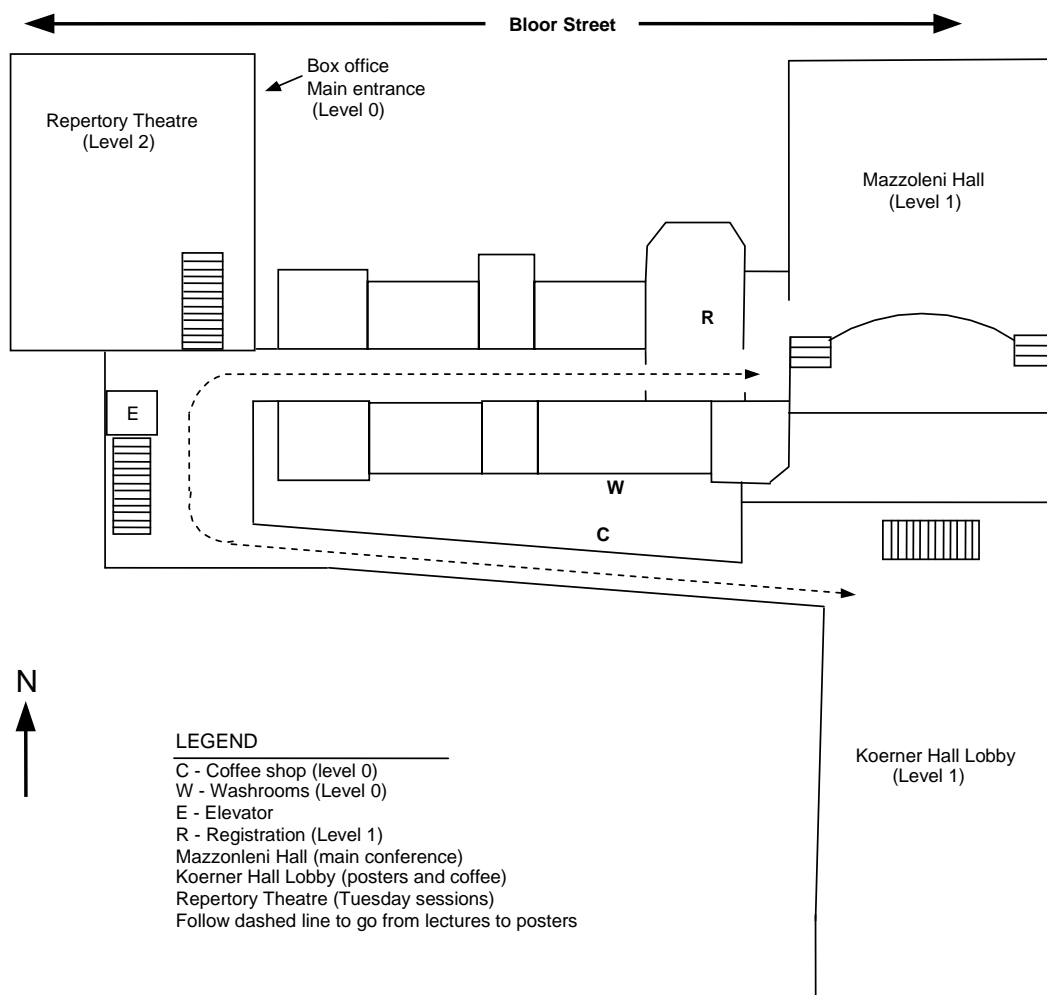
The organisers of ISRA 2013 and the Canadian Acoustical Association welcome researchers and practitioners from around the world to ISRA 2013, the latest International Symposium on Room Acoustics. There has been a long history of conferences on room acoustics being held as satellite conferences to the triennial International Congress on Acoustics meetings. These date from the International Symposium on Architectural Acoustics held in Edinburgh in 1974. The Vancouver Symposium on Acoustics and Theatre Planning for the Performing Arts was another earlier symposium of this series and was the first held in Canada in Vancouver in 1986. This was a great success and we hope it set the pattern for ISRA 2013 to follow. More recent ISRA conferences have been in: Hyogo Japan 2004, Seville Spain 2007 and Melbourne Australia 2010.

ISRA conferences have a tradition of being more intimate and bringing together a broad range of consultants and practitioners to exchange ideas and new experiences. It is this bringing together of such a wide range of experiences from so many different parts of the world that has made them so successful in the past. Being relatively small, even the least experienced newest student can talk to the leading experts from all parts of the world. ISRA 2013 has made particular efforts to make it possible for students to attend, including 9 travel support awards and especially low student fees to attend ISRA 2013.

ISRA conferences have usually focussed on the acoustical issues related to performing arts spaces such as theatres and concert halls. These problems can be very multi-disciplinary, including the need for expertise in perception, psychology, room acoustics and music just to name a few areas. ISRA 2013 includes a special session that explores some of these issues. There is also a special session on mathematical techniques for optimising reflector designs; a topic that is now practical to do with modern computer power. There are as well special sessions on room acoustic measurements to assess designs and another on ambient noise issues in performing arts spaces. Finally there is a quite extended session on objective and subjective aspects of scattering surfaces, a complex topic that is becoming better understood.

We hope you find the symposium a rewarding experience and that you are able to sample a little of what Toronto has to offer.

Conference Venue



ISRA 2013 is to be held at the Royal Conservatory of Music (RCM) at 273 Bloor St. West, in downtown Toronto. The closest subway station is St. George station which is at the junction of the Bloor-Danforth and the Yonge-University-Spadina lines. See map of main local streets on following page.

You should enter RCM via the street level entrance in the new part of the building facing Bloor Street and where the box office is located. After entering past the box office walk up the stairs to Level 1. (There is also an elevator).

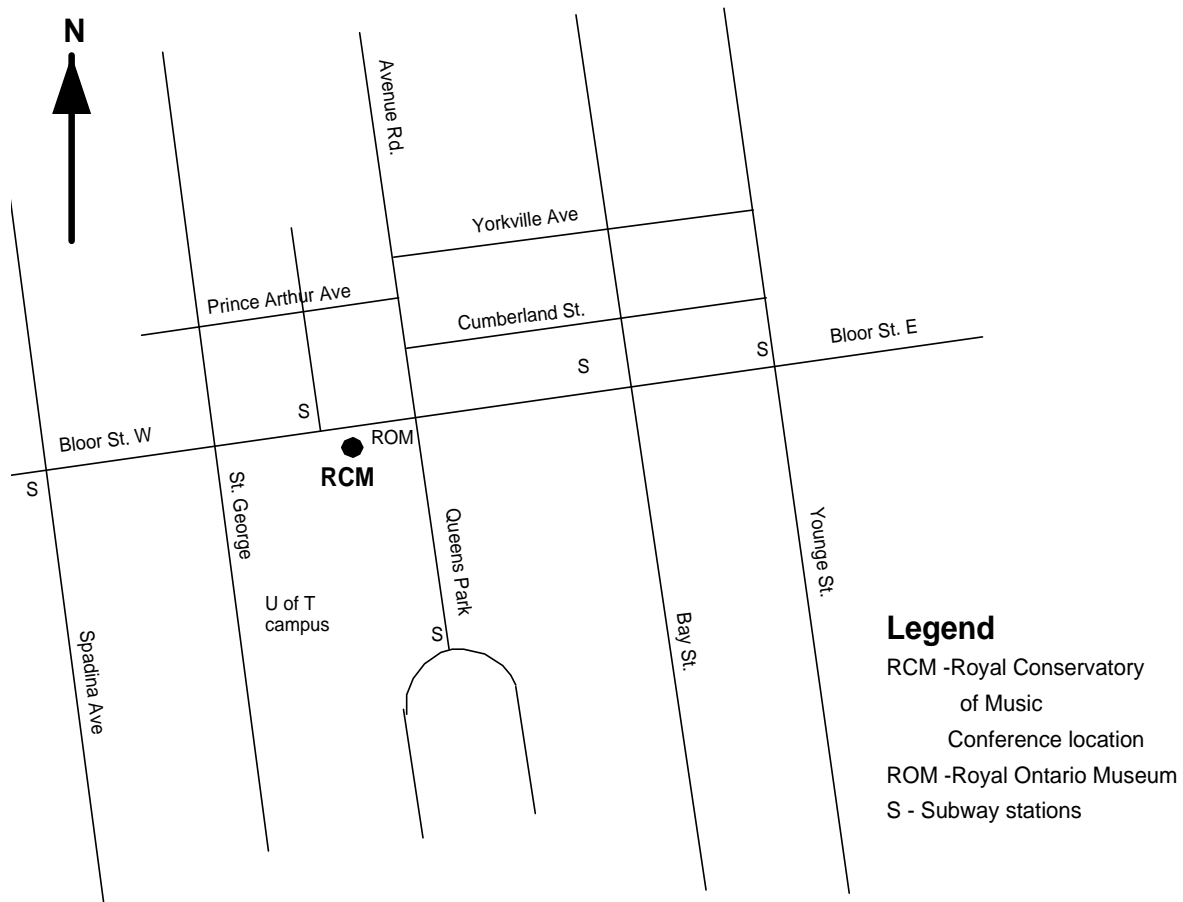
Mazzoleni hall is the location of the lecture presentations on Sunday and Monday June 9 and 10. Mazzoleni Hall is on Level 1 which is one floor above ground level. Please see the floor plan sketch above for the location of the various rooms. Registration is in the area just outside the entrance to Mazzoleni Hall.

Poster presentations, as well as coffee breaks and lunches, will be in the Koerner Hall lobby which is also on Level 1. Follow the dashed line on the floor plan to get there. On Tuesday June 11, the lecture presentations and the special lecture-demonstration Tuesday afternoon will be in the Repertory Theatre on Level 2.

Local Area Map

The map below is a simple sketch showing only main local streets close to the conference location. The Royal Conservatory of Music (RCM), the location of ISRA 2013, is shown by a large black filled circle. The Royal Ontario Museum (ROM) is on the east side of RCM. The University of Toronto campus (U of T) is adjacent on the west and south sides of the conference location.

Bloor St. is a major east-west artery in Toronto with the Bloor Street subway line running below it. There are many stores on Bloor St. in the Bay St. to Younge St. area. There are a number of restaurants on the parts of Cumberland St and Yorkville Ave shown on the map. More modest restaurants can be found to the west of RCM on Bloor St.



Acknowledgements

Symposium Organisers

Co-Chairs:	John Bradley John O'Keefe
Treasurer:	Brad Gover
Website:	Payam Ashtiani
Proceedings:	Tim Estabrooks

International Advisory Committee

Michael Barron
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Session Organisers

Stefan Weinzierl, Tapio Lokki, Lilly Wang,
Michael Barron, Eckhard Kahle, John O'Keefe, Jin Yong Jeong,
Roberto Pompoli, Michelle Vigeant

Conference Volunteers

Seanna Guilleman, Frances King, Ramani Ramakrishnan

Sponsors

ISRA 2013 was carried out with the sponsorship and financial support of the Canadian Acoustical Association.



The Acoustical Society of America and the International Commission for Acoustics were Co-Sponsors of ISRA 2013. Both provided funds to be directed to the support of student participants and travel expenses of eminent invited speakers.



A number of corporate sponsorships were also received to help with the cost of the conference. All sponsorship help was greatly appreciated and helped keep conference fees to an acceptable level and to make ISRA as rich an experience as possible.



Corporate sponsors included the following:

Arup



Aercoustics Engineering Ltd.



Swallow Acoustics, Noise & Vibration Control



Wenger Corp.



Jade Acoustics



ODEON Room Acoustics Software



HGC Engineering



Scantek Inc.



ECKEL Industries Canada and
ECKEL INC USA



STUDENT AWARDS

Nine awards of \$500 each will be made to students who are the first author of a presentation to help with the cost of travel to the conference. The winning students were selected based on ratings of their submitted paper to ISRA 2013 and the awards will be presented at the Conference banquet. The funds to make possible these awards were obtained by combining the contributions of Arup, the Acoustical Society of America (ASA) and the International Commission for Acoustics (ICA).

Keynote Speakers

Sir Harold Marshall KNZM FRSNZ

A. Harold Marshall is an architect, engineer and physicist who is recognised internationally for his contribution to concert hall design. Formerly Professor of Architecture at the University of Auckland and Head of the Acoustics Research Centre, Dr Marshall has over 45 years experience in the acoustical design of auditoria and concert halls. His work is widely cited in technical literature. Over the years his interest in these fields has been sharpened by his active involvement in musical performance as a bass-baritone.



Harold's present task in *Marshall Day Acoustics* is Group Consultant, leading the conceptual design of concert halls and similar commissions as required by any of the practice offices. This is a role for which his architectural and musical skills have uniquely equipped him to communicate with architects and their clients.

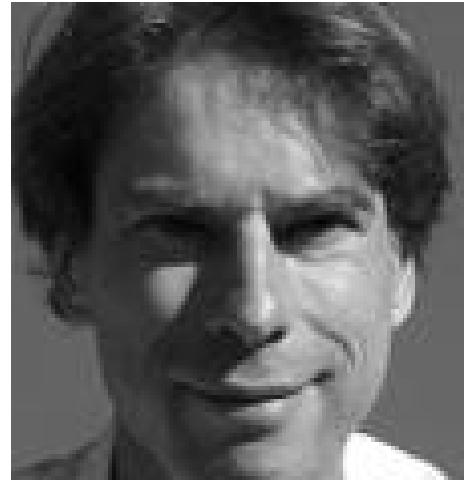
In 1994 Harold was elected a *Fellow of the Royal Society of New Zealand*. He also holds Fellowships in the *Acoustical Society of America*, the *New Zealand Institute of Architects* and the *Royal Australian Institute of Architects*.

In 1995 Dr. Marshall was awarded the *Wallace Clement Sabine Medal* by the *Acoustical Society of America* for his contributions to the field of architectural acoustics, particularly for the understanding and design of concert halls, and in 2006 he received the Gold Medal of the *Acoustical Foundation of India*.

In 2008, Emeritus Professor Marshall was made a *Distinguished Companion of the New Zealand Order of Merit* for services to acoustical science and in 2009 he accepted the title *Knight Companion of the Order*, KNZM.

Eckhard Kahle

Eckhard Kahle was born in Karlsruhe. After receiving a Vordiplom at the University of Bonn, an M Phil in physics at Clare College, Cambridge, and a physics degree, with a major in acoustics, at the University RWTH Aachen, he joined the room acoustics group at IRCAM in Paris. His work on a model of acoustical quality in concert halls, opera houses, and recital halls, was tested in several European facilities.



In addition to his extensive research in acoustics, Eckhard Kahle pursued a parallel career as a professional viola player in the European Community Youth Orchestra, holding the position of principal viola at the time of his departure. He performed with such outstanding musicians as Claudio Abbado, Zubin Mehta, Radu Lupu, and Leonard Bernstein, and also played in the Chamber Orchestra of Europe and the Ensemble Baroque de Limoges.

In 1995, Dr. Kahle joined Artec Consultants Inc, making important contributions to a number of projects, including: Culture and Congress Center (KKL), Lucerne; Salle du Métropole, Lausanne; Auditorium de Dijon; SangNam Hall, LG Arts Center, Seoul; Flemish Theatre (KVS), Maison de la Radio, and Théâtre Royal de la Monnaie, Brussels.

In 2001, he founded, Kahle Acoustics in Brussels. Clients of the firm have included: Guthrie Theatre, Minneapolis (Jean Nouvel, architect); Pierpont Morgan Library, New York (Renzo Piano, architect), The Curve Theatre and Performing Arts Centre, Leicester, (Rafael Viñoly, architect); Victoria Hall, Geneva; Singapore Conservatory of Music; the City of Perpignan, new theatre (Jean Nouvel, architect); the city of Stavanger, a new concert hall, and the city of Jinan, China, a new Performing Arts Center with an opera and a concert hall (Paul Andreu, architect). He is also client acoustician for the future Philharmonie de Paris concert hall.

Since 1988, Eckhard Kahle has published a large number of scientific articles in journals and congress proceedings. He is regularly invited to give lectures and Masterclasses, and is Professor at the National Music Conservatory in Karlsruhe.

Michael Vorländer

Michael Vorländer is Professor at RWTH Aachen University, Germany. After university education in physics and a doctoral degree (Aachen 1989), with a thesis on room acoustics computer simulation, he worked in various fields of acoustics at the PTB, the National Laboratory for Physics and Technology, in Braunschweig. His initial research activities were focused on psychoacoustics, electroacoustics and room and building acoustics. In 1995 he finished the qualification as university lecturer (habilitation, Technical University of Dresden) with a thesis on reciprocity calibration of microphones. Since 1996 he is Professor and Director of the Institute of Technical Acoustics at RWTH Aachen University. Michael Vorländer is active in several organizations

such as DEGA (*German Acoustical Society*), EAA (*European Acoustics Association*) and ASA (*Acoustical Society of America*). He was President of the EAA for the term 2004 – 2007 and now serves as President of the *International Commission for Acoustics*, ICA, for the term 2011-2013. He was awarded the Stephens Medal of the *Institute of Acoustics*, IOA, United Kingdom in 2005, Fellow of the Acoustical Society of America in 2006, and the Caracola of the *Acoustical Society of Spain* in 2009. His current research interest is auralization and acoustic virtual reality in various applications in architectural acoustics and environmental noise.



Tapio Lokki

Born in Helsinki, Finland in 1971, Dr. Tapio Lokki has studied acoustics, audio signal processing, and computer science at the Helsinki University of Technology (TKK) and received an M.Sc. degree in electrical engineering in 1997 and a D.Sc. (Tech.) degree in computer science and engineering in 2002.

At present Dr. Lokki is an Associate Professor (tenured) with the Department of Media Technology at Aalto University. Dr. Lokki leads the virtual acoustics team jointly with Prof. Lauri Savioja. The team currently consists of 6 post-docs, 5 PhD students, and 2 MSc students, and their research aims to create novel objective and subjective ways to evaluate concert hall acoustics. In addition, the team develops physically-based room acoustics modeling methods to obtain authentic auralizations of performance spaces. The team also studies augmented reality audio and eyes-free user interfaces. They are funded by the Academy of Finland and by Dr. Lokki's Starting Grant from the European Research Council (ERC).

Dr. Lokki has published over 30 journal articles and almost 100 conference papers. He is a member of the editorial board of Acta Acustica united with Acustica. Dr. Lokki is a member of the Audio Engineering Society, the IEEE Computer Society, and Siggraph, Helsinki, Finland. In addition, he is currently the President of the Acoustical Society of Finland.



Summary of Conference Schedule

Time	Sunday	Monday	Tuesday	Time
7:30	Registration		Technical tours	8:30
8:30	Keynote	Keynote	P1	9:00
9:20	P1	P1	P2 SCAT	9:20
9:40	P2 DEH	P2 DEF	P3	9:40
10:00	P3	P3	P4	10:00
10:20	P4	P4	P5	10:20
10:40	coffee & posters	coffee & posters	coffee	10:40
11:20	P5	P5	P6	11:20
11:40	P6 Noise	P6 ISO3382-1	P7 SCAT	11:40
12:00	P7	P7	P8	12:00
12:20	P8	P8	P9	12:20
12:40	lunch	lunch	lunch	12:40
13:40	Keynote	Keynote	Tutorial	13:40
14:30	P9	P9 ISO3382-1		
14:50	P10 RAQ	P10		
15:10	P11	P11 NURBS		
15:30	P12	P12		
15:50	coffee & posters	coffee & posters	coffee	15:40
16:30	P13	P13		16:15
16:50	P14 RAQ	P14 NURBS		
17:10	P15	P15		
17:30	Tech tour Koerner Hall			
	Reception	Banquet		

Full Names of Sessions

Sunday June 9

- DEH** Design and existing halls
- NOISE** Rating ambient noise in performing arts spaces
- RAQ** Room acoustic quality: A multidimensional concept

Monday June 10

- DEF** Design fundamentals
- ISO3382-1** ISO3382-1 and auditorium design
- NURBS** Geometrical acoustics revisited - Traditional and NURB Based reflector optimisation

Tuesday June 11

- SCAT** Objective and Subjective Aspects of Scattering Surfaces in Performance Spaces
- Tutorial** Using the loudspeaker orchestra to better understand concert halls
 - design, implementation, recordings in concert halls, and playback and analysis in the laboratory

Complete ISRA 2013 Schedule

(To find the corresponding abstract look for the paper number in the abstracts section, e.g. the abstract of the first paper below is #P070 is on page 41)

Sunday, June 9, 2013 (Mazzoleni Hall)

7:45 Registration (Entrance to Mazzoleni Hall)

Keynote 1

Chair: *Anders C. Gade*

8:30 - P070. *Harold Marshall*, The acoustical design of the Christchurch Town Hall

Design and Existing Halls

Chair: *John Bradley*

9:20 - P002. *Leo Beranek*, Concert hall design: some considerations

9:40 - P122. *Andreas Wagner, Juergen Reinhold*, Bolshoi Theatre, Moscow, Russian Federation: The secrets of the acoustical reconstruction

10:00 - P028. *Magne Skålevik*, Certainties and uncertainties from using a selection of data to predict concert hall preference

10:20 - P045. *Takayuki Hidaka*, An earthquake and a concert hall

10:40 Coffee and Posters (Koerner Hall Lobby)

Rating Ambient Noise in Performing Arts Spaces

Chair: *Lily Wang*

11:20 - P119. *Robert Essert*, Why silence?

11:40 - P115. *Scott Pfeiffer*, Anticipating the challenges of modern mechanical system approaches in low-noise design

12:00 - P068. *Lily Wang, Brent Kraay*, Rating low levels of ambient noise in performing arts facilities

12:20 - P061. *Jonah Sacks, Robert William Wolff, Ana Maria Jaramillo*, Investigation of background noise conditions during music performance

12:40 – Lunch and Posters (Koerner Hall Lobby)

Keynote 2

Chair: *John Bradley*

13:40 - P074. *Eckhard Kahle*, Room acoustical quality of concert halls: perceptual factors and acoustic criteria - return from experience

Room Acoustic Quality: A Multidimensional Concept (Part 1)

Chairs: *Stefan Weinzierl and Tapio Lokki*

14:30 - P073. *Pamela Clements*, Orchestral performance practice and the perception of acoustic quality in concert halls

14:50 - P019. *Antti Kuusinen, Tapio Lokki*, Individual differences in quality judgments and preferences of concert hall acoustics

15:10 - P124. *Hans-Joachim Maempel, Jentsch Matthias*, Audio-visual interaction of size and distance perception in concert halls: a preliminary study

15:30 - P127. *Shin-ichi Sato, Alejandro Bidondo, Yuezhe Zhao, Suoxian Wu, Nicoli Prodi*, Effect of Acoustic and Visual Stimuli on Preference for Different Seating Positions in a Concert Hall and an Opera Theater

15:40 Coffee and Posters (Koerner Hall Lobby)

Room Acoustic Quality: A Multidimensional Concept (Part 2)

16:30 - P103. *Anders Christian Gade*, Subjective and objective measures of relevance for the description of acoustics conditions on orchestra stages

16:50 - P086. *Zora Schärer Kalkandjiev, Stefan Weinzierl*, Room acoustics viewed from the stage: Solo performers' adjustments to the acoustical environment

17: 10 - P030. *Densil Cabrera, Manuj Yadav, Luis Jofre Miranda, Ralph Collins, William L. Martens*, The sound of one's own voice in auditoria and other rooms

Tour of Koerner Hall 17:30 (meet in Koerner Hall Lobby)

Reception 18:15 (Koerner Hall Lobby)

Monday, June 10, 2013 (Mazzoleni Hall)

Keynote 3

Chair: *Trevor Cox*

8:30 - P110. *Michael Vorländer*, Simulation and evaluation of acoustic environments

Design Fundamentals

Chair: *John O'Keefe*

9:20 - P012. *David Griesinger*, Optimizing loudness, clarity, and engagement in large and small spaces

9:40 - P047. *Umberto Berardi, Higin Arau-Puchades*, Increasing Reverberation Time with Diffusers: a new acoustic design for more sustainable halls

10:00 - P046. *Jukka Pätynen, Sakari Tervo, Tapio Lokki*, Binaural dynamic responsiveness in concert halls

10:20 - P067. *Matthew G. Blevins, Adam T. Buck, Zhao Peng, Lily M. Wang*, Quantifying the just noticeable difference of reverberation time with band-limited noise centered around 1000 Hz using a transformed up-down adaptive method

10:40 Coffee and Posters (Koerner Hall Lobby)

ISO3382-1 and Auditorium Design (Part 1)

Chair: *Michael Barron*

11:20 - P056. *Mike Barron*, Assessment of numerical data from ISO3382

11:40 - P089. *Oskar Lindfors, Jukka Ahonen, Henrik Möller*, Strength measurements with in-situ reference

12:00 - P016. *Wolfgang Ahnert, Tobias Behrens*, Acoustic measurements in a theatre during the performance

12:20 - P078. *Hyung Suk Jang, Jin Yong Jeon*, Evaluation of the absorption by the orchestra in concert halls using scale models and computer simulations

12:40 Lunch and Posters (Koerner Hall Lobby)

Keynote 4

Chair: *John O'Keefe*

13:40 - P040. *Tapio Lokki*, Throw away that standard and listen: your two ears work better

ISO3382-1 and Auditorium Design (Part 2)

Chair: *Michael Barron*

14:30 - P010. *Claus Lynge Christensen, Georgios Koutsouris, Jens Holger Rindel*, The ISO 3382 parameters: Can we simulate them? Can we measure them?

14:50 - P096. *Margriet Lautenbach, Martijn Vercammen*, Stage Acoustics, ISO 3382 and beyond

Geometrical Acoustics Revisited - Traditional and NURB based Reflector Optimisation Design (Part 1)

Chairs: *Eckhard Kahle and John O'Keefe*

15:10 - P108. *Alban Bassuet, David Rife, Lucas Dellatorre*, Acoustical design through optimization

15:30 - P095. *John O'Keefe, Payam Ashtiani, David Grant*, A new software tool to facilitate NURB based geometries in acoustic design

15:50 Coffee and Posters (Koerner Hall Lobby)

Geometrical Acoustics Revisited - Traditional and NURB based Reflector Optimisation Design (Part 2)

16:30 - P042. *Tomas Mendez Echenagucia, Arianna Astolfi, Mario Sassone, Louena Shtrepi, Arthur Van Der Harten*, Interactive design methods for complex curved reflectors in concert halls

16:50 - P064. *Yann Jurkiewicz, Thomas Wulfrank, Eckhard Kahle*, How far should the geometry of a concert hall be optimized?

17:10 - P112. *Thomas Scelo, Simon Yu*, Integration of acoustics in parametric architectural design

Banquet (Koerner Hall Lobby)

18:00 Drinks (cash bar)

19:00 Meal

Tuesday, June 10, 2013

Technical tours (in parallel with lecture session)

8:00 Roy Thomson Hall

9:30 Four Seasons Centre for the Performing Arts

Objective and Subjective Aspects of Scattering Surfaces in Performance Spaces (Repertory Theatre – Level 2)

Chairs: *Jin Yong Jeon, Roberto Pompoli and Michelle Vigeant*

9:00 - P063. *Toshiki Hanyu*, Method for estimating diffuseness of sound fields by using decay-cancelled impulse responses

9:20 - P035. *Louena Shtrepi, Sönke Pelzer, Renzo Vitale, Arianna Astolfi, Monika Rychtáriková*, Subjective assessment of scattered sound in a virtual acoustical environment simulated with three different algorithms

9:40 - P039. *Aki Haapaniemi, Alex Southern, Tapio Lokki*, A finite-difference time-domain investigation of reflections from layered wall structures

10:00 - P014. *Markus Müller-Trapet, Michael Vorländer*, In-situ measurements of surface reflection properties

10:20 - P077. *Jin Yong Jeon, Hyung Suk Jang, Yong Hee Kim, Michael Vorländer*, Subjective and objective evaluations of scattered sounds in concert halls

10:40 Coffee break

11:20 - P009. *David T. Bradley, Markus Müller-Trapet, Jacob Adelgren, Michael Vorländer*, Comparison of hanging panels and boundary diffusers in a reverberation chamber

11:40 - P033. *Tetsuya Sakuma, Hyojin Lee*, Recent topics in acoustic scattering coefficient determination for wall surfaces

12:00 - P013. *Evan Green*, Systematic spatial variations of objective measures in a 1:25 scale model rectangular concert Hall with variable scattering

12:20 - *Akira Omoto, Kohta Sugiura*, Visualization and evaluation of reflections inside an enclosed space using sound intensity measurement

12:40 Lunch

13:40 Special Lecture-Demonstration Session

Jukka Pätynen, Sakari Tervo, and Tapio Lokki, Using the loudspeaker orchestra to better understand concert halls - design, implementation, recordings in concert halls, and playback and analysis in the laboratory

This extended tutorial session will bring together the results of the Virtual Acoustics team at Aalto University, Finland, who over the past 4 years have used their loudspeaker orchestra to capture the acoustics of concert halls for objective analysis and subjective listening tests. The loudspeaker orchestra consists of 34 calibrated loudspeakers on stage to simulate an orchestra,

the most common and important sound source in concert halls. For objective analysis and spatial sound reproduction, the spatial impulse responses from each loudspeaker are measured at accurately defined receiver positions. So far over 16 concert European halls have been measured and this tutorial will include numerous spatial sound examples from different halls reproduced using an eight-channel playback system.

This tutorial will explain in detail the design and implementation of the loudspeaker orchestra. It will discuss the spatial room impulse response measurement techniques that are being used and discuss how spatial impulse responses can be analyzed accurately for efficient comparisons of the acoustical properties of halls. Furthermore, the methods used to convolve enhanced anechoic symphony orchestra recordings with the measured spatial impulse responses for multichannel loudspeaker listening (or binaural headphone listening) are described.

15:40 Conference closing

Posters - Sunday (Koerner Hall Lobby)

- P071. *Niels Adelman-Larsen*, New On/Off absorption technology that includes low frequencies
- P121. *Juergen Reinhold, Andreas Wagner*, Nuovo Teatro dell'Opera, Florence, Italy: Innovative solutions for a seemingly traditional auditorium
- P104. *Iara Cunha, Roberta Smiderle, Stelamaris Bertoli*, Influence of sound reinforcement system on acoustical performance in a Catholic Church
- P107. *Hoshi Kazuma, Hiroyuki Okubo, Jun Kanda, Takumi Asakura, Atsushi Marui*, A study to establish benchmarks for acoustical parameters derived from impulse responses
- P048. *Young-Ji Choi, Dae-Up Jeong, John Bradley*, The effects of occupancy on theatre chair absorption characteristics
- P062. *Roger Schwenke, Steve Ellison, Pierre Germain*, Active acoustics in physically variable spaces
- P114. *David Kahn*, Acoustical design of concert halls with small seating capacities
- P076. *Suyatno Suyatno, Harijono A. Tjokronegoro, IGN Merthayasa*, The effects of stage layout in 'Pendopo Isi Solo' hall on acoustics parameters of Javanese Gamelan instruments
- P087. *Ingo Witew, Dietrich Pascal, Sönke Pelzer, Michael Vorländer*, Comparison of strategies to model spatial fluctuations of room acoustic single number quantities
- P113. *Bård Støfringsdal*, Desired room acoustical response for amplified music
- P051. *Ayumi Ishikawa, Takane Terashima, Yasunobu Tokunaga*, A basic study on possibility to improve stage acoustics by active method
- P075. *Joko Sarwono, Wimanda Moestopo, Soelami FX Nugroho*, Acoustic measurements and simulations for the Gki Maulana Yusuf church in Bandung, Indonesia
- P082. *Lamberto Tronchin, Andrea Venturi, Angelo Farina, Amendola Alberto*, Implementing a spherical microphone array to determine 3-D sound propagation in the 'Teatro 1763' in Bologna, Italy
- P057. *Jeremy Rouch, Isabelle Schmich-Yamane, Marie-Annick Galland*, Under-balcony acoustics improvement with simple electro-acoustic means: A Theoretical development and numerical simulations
- P050. *Martin Guski, Michael Vorländer*, Noise compensation methods for room acoustical parameter evaluation
- P049. *Sakari Tervo, Jukka Pätynen, Philip W. Robinson, Lokki Tapio*, Spatial analysis of concert hall impulse responses
- P088. *Remy Wenmaekers, Constant Hak*, Early and Late Support measured over various distances: the covered versus open part of the orchestra pit
- P005. *Carlos Jiménez Dianderas*, Comparison of the acoustical behaviour of colonial churches of three architectural styles in Peru

- P080. *Hansol Lim, Hyung Suk Jang, Yong Hee Kim, Jin Yong Jeon*, Effects of stage volume on concert hall acoustics as a design element
- P032. *Luis Jofre Miranda, Densil Cabrera, Ken Stewart, Nicolas Epain, Craig Jin*, A concentric source-receiver transducer and its applications in stage measurements
- P043. *Tomas Mendez Echenagucia, Arianna Astolfi, Mario Sassone, Louena Shtrepi, Arthur Van Der Harten*, EDT,C80 and G driven auditorium design
- P020. *Massimo Garai, Simona De Cesaris, Dario D. Orazio*, Spatial distribution of monaural acoustical descriptors in historical Italian theatres
- P022. *Salvador Cerdá, Segura Jaume, Giménez Alicia, Cibrián Rosa, Montell Radha*, Sound quality maps of halls for classical music
- P017. *Daniel Protheroe, Bernard Guillemin*, 3-D impulse response measurements of spaces using an inexpensive tetrahedral microphone array
- P128. *Tor Halmrast*, When source is also receiver

Posters - Monday (Koerner Hall Lobby)

- P125. *Keiji Kawai, Kosuke Kato, Ueno Kanako, Tetsuya Sakuma*, Experiment on adjustment of piano performance to room acoustics: Analysis of performance coded into MIDI data
- P116. *Kazuma Hoshi, Toshiki Hanyu*, Theoretical modeling of room shape for ray tracing simulation
- P123. *Matthew Lella, Andrea Tocchini*, Refinements in raytracing technique for room shaping
- P111. *Yong Hee Kim, Yoshiharu Soeta*, Design of diffusive surfaces for improving the sound quality of underground stations
- P100. *Thomas Wulfrank, Yann Jurkiewicz, Eckhard Kahle*, Design-focused acoustic analysis of curved geometries using a differential raytracing technique
- P120. *Paul Luizard, Catherine Guastavino, Brian F.G. Katz*, Perception of reverberation in coupled volumes: discrimination and suitability
- P099. *Thibaut Carpentier, Markus Noisternig, Olivier Warusfel*, Parametric control of convolution based room simulators
- P097. *Thineshan Kathirchelvan, Prasanth Nair*, Shape Optimization using NURBS Definition of Acoustic Reflectors
- P117. *Anne Guthrie, Terence Caulkins, Sam Clapp, Jonas Braasch, Ning Xiang*, Using Ambisonics for stage acoustics research
- P083. *Sönke Pelzer, Dirk Schröder, Lukas Aspöck, Michael Vorländer*, Interactive real-time simulation and auralization for modifiable rooms
- P044. *Milos Markovic, Søren Krarup Olesen, Dorte Hammershøi*, Room acoustics modelling using a point-cloud representation of the room geometry
- P092. *Constant Hak, Remy Wenmaekers*, Room in room acoustics: Using convolutions to find the impact of a listening room on recording acoustics
- P065. *Shin-ichiro Koyanagi, Takayuki Hidaka, Toshiyuki Okano*, The error analysis and correction of the reflection calculation for the FDTD method
- P038. *Philip W. Robinson, Samuel Siltanen, Tapio Lokki, Lauri Savioja*, Concert hall geometry optimization with parametric modeling tools and wave-based acoustic simulations
- P090. *Remy Wenmaekers, Rick de Vos, Constant Hak*, Binaural sound exposure to the direct sound of one's own musical instrument
- P079. *Ho Cheul Park, Young Sun Kim, Yong Hee Kim, Jin Yong Jeon*, Preferred Acoustical Conditions for Musicians on Stage with Orchestra shell in multi-purpose halls
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Abstracts in Order of Paper Number (Pnnn)

Concert hall design: some considerations

Leo Beranek (Consultant)

Paper #: P002

Before 1960 the audiences in concert halls generally faced the conductor's podium. In 1963 the Berlin Philharmonie XYZ Hall opened with nearly half of the audience seated behind and to the sides of the stage. This hall has been a success even though the orchestral balance differs considerably from one seat location to another due to the fact that the sounds of the various instruments are radiated in different directions. This paper presents several matters that should be considered when planning the design of a new hall: (a) choosing between a shoebox, surround or fan shaped hall; (b) suggested minimum and maximum number of seats in each shape; (c) the effect of the audience-seat upholstery on the acoustics and on the cost of the building; and (d) the effect on bass perception due to the weight of the wall and the mid-frequency sound absorption.

Comparison of the acoustical behaviour of colonial churches of three architectural styles in Peru

Carlos Jiménez Dianderas (Pontificia Universidad Católica del Perú, Departamento de Arquitectura)

Paper #: P005

The paper presents a comparison of the acoustic behavior of churches built under three architectural styles during the Spanish colonial domination in representative cities of Peru. European architectural styles of the Renaissance, Baroque and Neoclassical were adapted to the geography, geology and construction process of the current Peruvian territory. Using five typical acoustical objective parameters, the acoustic behavior of each church was analyzed. Then, a comparative analysis of these acoustic conditions was performed by grouping the churches according to architectural style.

Neuroacoustics: Study on the perception of stereo reverberant sound field at the cortical level

Alejandro Bidondo (Departamento de Ciencia y Tecnología, Universidad Nacional de Tres de Febrero)

Paper #: P006

On the basis of the Ando's brain hemispheric specialization auditory model, spatial information is processed in the right hemisphere. When hearing a complex sound stimuli, like a monaural sound source reproduced in a reverberant sound field, several independent acoustic cues are processed in both hemispheres simultaneously. To study the brain specialization while perceiving these types of sounds, the Auditory Evoked Potentials analysis for 2000ms after the first 80ms from the sound onset was developed, even though the first 300ms is normally analyzed. Cortical Activity descriptors were applied to Mismatch Negativity electro-physiological signals taken from Left and Right hemispheres. It was possible to measure the specialization of hemispheres by using two different monaural and anechoic sound sources, one with a minimum effective duration of its autocorrelation function $\tau(e)$ as low as 0.2ms and another with minimum $\tau(e)$ of 190ms, both embedded into the same reverberant sound field and reproduced thru headphones. This study opens the possibility to measure the perception of listener envelopment to further develop a subjective descriptor.

Comparison of hanging panels and boundary diffusers in a reverberation chamber

David T. Bradley (Vassar College)

Markus Müller-Trapet (RWTH Aachen University)

Jacob Adelgren (Vassar College)

Michael Vorländer (RWTH Aachen University)

Paper #: P009

Achieving a diffuse sound field in a reverberation chamber is crucial for measurements of acoustic quantities such as sound absorption coefficient, scattering coefficient, and sound power level. Toward this aim, diffusing elements such as hanging panels or rotating vanes are typically installed in the chamber. However, previous research has suggested that hanging panels violate certain theoretical assumptions regarding diffusivity. Also, rotating vanes cause the chamber to be a time-variant system, precluding the use of some measurement approaches such as sine-sweep integrated impulse response techniques. Boundary diffusers are offered as an alternative in the current study. The effects of both hanging panels and boundary diffusers on sound field diffusivity in a 1:5 scale reverberation chamber are systematically and comparatively analyzed. The field diffusivity is characterized based on the guidelines set forth in American and international standards, including ASTM C423, ASTM E90, and ISO 354. Resulting data suggests that these standardized methods do not adequately or rigorously quantify diffusivity. Several non-standardized diffusivity quantifiers are also presented along with their associated data. The relative effectiveness of hanging diffusers vs. boundary diffusers based on both the standardized and non-standardized quantifiers will be discussed.

The ISO 3382 parameters: Can we simulate them? Can we measure them?

Claus Lynge Christensen (Odeon A/S)

Georgios Koutsouris (Odeon A/S)

Jens Holger Rindel (Odeon A/S)

Paper #: P010

The measured impulse response is often used as a true reference of a real room impulse response and geometrical acoustic simulations are considered to be only a crude representation of it. However, both approaches have their own limitations. Geometrical acoustic models do not include wave phenomena, such as interferences and diffraction, as they simplify sound propagation by rays. The advantages of acoustic simulations with such models, besides being able to predict room acoustics, include a perfectly omnidirectional and impulsive sound source, no distortion problems, full control of the background noise, and a well-defined onset time of the impulse response. On the other hand, impulse response measurements include wave phenomena, but they do have their own weaknesses, which may cause significant errors in the derivation of the ISO-3382 room acoustic parameters. Due to the presence of background noise in the measured impulse response it is difficult to evaluate which part is valid. In addition, the sound source used for measurements often has strong lobes at high frequencies and cannot produce an ideal Dirac impulse. For this reason and due to distortion products by the octave-band filtering process detection of the arrival time of the direct sound from a measured impulse response is always of questionable accuracy. In this paper measured and simulated parameters are compared in a number of well documented cases and the various sources of errors are discussed. It is concluded that doing room acoustic measurements correctly may be more difficult than it appears at first glance.

Physiologically based measures of clarity and engagement

David Griesinger (David Griesinger Acoustics)

Paper #: P011

Humans evolved to detect the direction and the information content of sounds that travel directly from a source to the ear of a listener, and evolution has provided us with sophisticated neurology that separates direct sound from noise with remarkable acuity. When separation is possible signals become clearer, more attention-grabbing, more reverberant, and easier to remember. Reflections and reverberation garble the sonic information that makes separation possible; knowing when and how this happens is vital to room and hall acoustics. But the measures in ISO3382 are nearly blind to the direct component of a sound field, and the continuing legacy of these standards is a diminishing number of audience members willing to sit in expensive, mediocre seats. This talk will demonstrate the vital importance of clarity through examples of 'clear' and 'muddy' speech and music. We will discuss the physics which makes direct sound separation possible, and propose measurement methods based on the physiology of this process, using data from impulse responses and live speech. Techniques for maximizing both clarity and reverberance will be suggested.

Optimizing loudness, clarity, and engagement in large and small spaces

David Griesinger (David Griesinger Acoustics)

Paper #: P012

It is vital in building both large and small spaces to understand that the (unfortunately rare) designs which are successful for large spaces are not successful when scaled to smaller sizes. But a few fine recital halls, practice rooms, rehearsal spaces, and halls of all sizes exist. We can learn a lot from them, particularly in the light of recent work on the neurology of hearing. This talk will demonstrate and present some hard-earned lessons leading to solutions for common problems. Successful solutions include careful attention to shape and size, absorption in critical areas, electronic acoustics, and the Arrau diffuser.

Systematic spatial variations of objective measures in a 1:25 scale model rectangular concert Hall with variable scattering

Evan Green (Sound Space Design)

Paper #: P013

The revised theory of sound level developed by Barron and Lee [Energy relations in concert halls I, 1986] indicates that systematic variations in sound level with source-receiver distance are to be expected in a concert hall environment. Here we use a 1:25 scale rectangular concert hall with variable scattering surfaces to investigate the behaviour of sound level with source-receiver distance. In some cases significant deviations from revised theory are found whilst in others sound level behaviour closely matches revised theory even for room configurations with double-slope decays. For the scattering configurations demonstrating double-slope decays, systematic variations of T20 with source-receiver distance have been found. The variation has been associated with the position of the 'bending point' between the two slopes. The expanded revised theory proposed by Luizard and Katz [Coupled volume multi-slope room impulse responses: a quantitative analysis method, 2011] for multi-slope decays has been used to gain insight into the acoustical coupling in a single-volume room exhibiting double-slope decays.

In-situ measurements of surface reflection properties

Markus Müller-Trapet (Institute of Technical Acoustics, RWTH Aachen University)

Michael Vorländer (Institute of Technical Acoustics, RWTH Aachen University)

Paper #: P014

In order to characterize surfaces with respect to their sound reflecting properties, the absorption and the scattering or diffusion coefficient can currently be measured under standardized laboratory conditions. However it is questionable whether the data from measurements performed under such laboratory conditions can be used to accurately model the actual sound field in rooms. Additionally, it is not always possible to obtain a transportable sample of a material. In-situ measurement methods can overcome these shortcomings, as they measure the desired quantities at the location where the material is installed. For this purpose, a portable setup was built that allows for a complete hemispherical measurement of the sound pressure distribution using less than 30 sensors. This contribution will present the setup together with the challenges for post-processing the acquired data. First measurement results will be presented and discussed.

Acoustic measurements in a theatre during the performance

Wolfgang Ahnert (ADA Acoustics & Media Consultants GmbH)

Tobias Behrens (ADA Acoustics & Media Consultants GmbH)

Paper #: P016

To measure impulse responses in rooms and free fields is a daily job for acousticians but mainly this is done in the empty venues. Results for the occupied case are derived by use of simulation software or by estimations based on experience. Using a newly developed multithread algorithm speech, music or any other signals from a microphone input and from a mixing console can be utilized to obtain impulse response data for further evaluation. During the performance in a theatre measurements have been done by using the speech and the singing of male and female actors as sound sources. The method will be explained in detail and the needed conditions are described. All factors of influence are discussed to derive impulse responses and to calculate in post processing all interesting parameters according ISO 3382. The influence of the noise floor and the absolute signal level at the receiver point is discussed. All recordings are done with a dummy head, an omni-directional and a figure eight microphone.

3-D impulse response measurements of spaces using an inexpensive tetrahedral microphone array

Daniel Protheroe (Marshall Day Acoustics)

Bernard Guillemin (The University of Auckland)

Paper #: P017

The acoustical characteristics of a room are traditionally determined using omnidirectional impulse response measurements, yielding information about sound reflections in terms of magnitude and time, but not direction. However, the direction of reflections is important in this application, and thus the need for a practical, low cost measurement system for determining this. Such a system might be used for verifying the design of a newly completed hall, fault finding in a problematic space, or analysis of an existing facility already exhibiting desirable sound properties. In this paper we present the performance of a low cost measurement system, utilising an inexpensive microphone array, namely the Core Sound TetraMic, for the determination and display of 3D room impulse responses. From acoustic measurements, sound intensity can be derived, which then permits an analysis of sound arrivals in terms of magnitude, direction and time. These arrivals are then visualised as a hedgehog pattern. Experiments undertaken in an anechoic chamber using single and multiple reflectors indicate that the accuracy of

directional estimation of this system is generally within $\pm 5^\circ$. By way of example in a more real-world environment, the use of the system in the Music Theatre at The University of Auckland, is presented. It is shown that there is close correspondence between the acoustic reflections estimated by the measurement system, and the architectural features of the room.

An optimum combination of absorptive and diffusing treatments for classroom acoustic design

Young-Ji Choi (Faculty of Architectural Engineering, Chonbuk National University)

Paper #: P018

The present study investigates an optimum combination of absorptive and diffusing treatments for achieving preferred acoustics in classrooms. The measurements were carried out in a 1/10 scale model classroom, adding different amounts of absorptive and diffusing materials to one or more of five surfaces of the room. Adding diffusers on 25% of the ceiling area with the other 75% absorptive was more beneficial for achieving higher G50 and G values than adding absorptive materials on the entire ceiling. Adding absorptive materials on the entire ceiling area and diffusers on the front or side wall was beneficial for achieving shorter T30, EDT values and higher C50 values. Adding diffusers on the front or side wall slightly increased G50 and G values by more than 1 JND. Adding diffusers on the ceiling and lower front wall or side wall and adding diffusers on the ceiling and absorptive materials on the lower front wall were selected for consideration as the more successful treatments for classroom acoustic design.

Individual differences in quality judgments and preferences of concert hall acoustics

Antti Kuusinen (Aalto University)

Tapio Lokki (Aalto University)

Paper #: P019

The acoustic quality of concert halls can be studied in many different ways. While usually the focus is on revealing the average or common perceptual space, the individual differences in perception can also provide important insight and substance to the interpretation of the results. Here we discuss the individual differences that have been observed in the sensory evaluation experiments of concert hall acoustics. We propose that the dimensionality or complexity of the sensory data provides one practical viewpoint to the sensory skill of the test subject. In addition, we connect the analytical sensory data and the affective preference ratings by preference mapping. This techniques allows the evaluation of not only the determinants of the preference but also how the individual preferences can be modeled. The ideal point models refers to 'eclectic listeners', whereas 'the more-the better', type of listeners are modeled with vector models. Moreover, the results depend not only on the individual, but also on the properties of the sample space, for instance, the range of acoustical conditions and the music used in the evaluations. These aspects are illustrated with examples from our previous studies employing the individual vocabulary profiling method. Finally, implications for future research are discussed.

Spatial distribution of monaural acoustical descriptors in historical Italian theatres

Massimo Garai (University of Bologna)

Simona De Cesaris (University of Bologna)

Dario D. Orazio (University of Bologna)

Paper #: P020

In order to qualify a performance space, ISO 3382 recommends a minimum number of receiver positions as a function of hall size, to be selected according to given rules. Different acoustic criteria and different

degrees of accuracy may require a different set of measurement points. The Charta of Ferrara extends these method to historical Italian theatres, characterized by a horseshoe shaped audience, a series of tiers and a gallery. In order to verify the representativity of the number and disposition of the measurements points proposed in the Charta, a measurement campaign has been conducted in eight historical Italian theatres. These have been chosen with different volumes, seating capacity and surface materials. Impulse responses have been measured at each listener position. Monaural descriptors of ISO 3382 have been extracted from the impulse responses and analyzed. The statistical frequency distribution of each parameter has been calculated, according to similar literature for different shaped theatres. Then various reduced sets of impulse responses, selected from the total ensemble according to the procedure of ISO 3382, Charta of Ferrara, etc., have been compared. Differences between different receiver sets have been found, and dissimilarity between adjacent seats have been related to different acoustical zones of the hall.

Recording and analysis of head movements, interaural level and time differences in rooms and real-world listening scenarios

Alan Boyd (University of Strathclyde)

William Whitmer (MRC Institute of Hearing Research)

Michael Akeroyd (MRC Institute of Hearing Research)

Paper #: P021

The science of how we use interaural differences to localise sounds has been studied for over a century and in many ways is well understood. But in many of these psychophysical experiments listeners are required to keep their head still, as head movements cause changes in interaural level and time differences (ILD and ITD respectively). But a fixed head is unrealistic. Here we report an analysis of the actual ILDs and ITDs that occur as people naturally move and relate them to gyroscope measurements of the actual motion. We used recordings of binaural signals in a number of rooms and listening scenarios (home, office, busy street etc). The listener's head movements were also recorded in synchrony with the audio, using a micro-electromechanical gyroscope. We calculated the instantaneous ILD and ITDs and analysed them over time and frequency, comparing them with measurements of head movements. The results showed that instantaneous ILDs were widely distributed across time and frequency in some multi-source environments, while ITDs were less widely distributed. The type of listening environment affected head motion. These findings suggest a complex interaction between interaural cues, egocentric head movement and the identification of sound sources in real-world listening situations.

Sound quality maps of halls for classical music

Salvador Cerdá (Universitat Politècnica de València)

Segura Jaume (Universitat de València Estudi General)

Giménez Alicia (Universitat Politècnica de València)

Cibrián Rosa (Universitat de València, Estudi General)

Montell Radha ()

Paper #: P022

For several years we have done an extensive measurement campaign in halls of diverse typology and use. Together with these measurements, we have also done assessment surveys of general public and experts who served as control group. The analysis of the results has permitted to establish a model to classify a hall according to the classical music performance which depends on the reverberation time (T30), the lateral factor coefficient (LFC) and the listener envelopment (LEV). In addition, an optimum interval of the model was established for classical music. From the measurements of these three quality

parameters, we can determine quality maps for halls for classical music. In this paper these maps are shown for 6 halls. These maps are a useful tool allowing a quick and clear visualization of locations in the hall which meets the quality criteria as concert halls for classical music.

Certainties and uncertainties from using a selection of data to predict concert hall preference

Magne Skålevik (www.akutek.info and Brekke & Strand)

Paper #: P028

Ever since Sabine and the definition of the Reverberation Time, many researchers have explored the possible correlation between physical properties of the concert halls and listeners assessment of the acoustics of the same halls. Rather soon it became evident that two halls with the same RT could differ significantly as to listeners' preference. The pursuit after the perfect set of parameters began. And we are still searching. This author has previously shown that some sets of room acoustical parameters can, with their appropriate qualifying criteria, be used to explain the subjective ranking of a selection of halls from Beranek's rank ordering of 58 halls. A set of five listening aspects in ISO-3382 seems to be important, but trials with even more physical quantities has provided more explanation potential. In this context, explanation does not necessarily include full insight in underlying processes. A critical limitation in the research has turned out to be the difficulty in finding a large enough selection of halls with sufficient amount of subjective AND objective data. An online concert hall acoustics rating survey is launched in order to collect more data, and anyone interested are invited to participate in the survey on <https://www.surveymonkey.com/s/MMFMZ5W> In this paper, the latest results of results from this author's work is presented, together with a demonstration of how the size of selected data affects uncertainties and statistical significance in the results.

The sound of one's own voice in auditoria and other rooms

Densil Cabrera (Faculty of Architecture, Design and Planning, The University of Sydney)

Manuj Yadav (Faculty of Architecture, Design and Planning, The University of Sydney)

Luis Jofre Miranda (Faculty of Architecture, Design and Planning, The University of Sydney)

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Paper #: P030

When speaking or singing, one's voice returns to one's ears with information about the room, and the interaction between voice and room may yield satisfaction or frustration in speech and song. This paper summarises recent work in measuring, simulating and auralizing rooms for one's own voice. The room acoustical contribution to the sound of one's voice is represented by the oral-binaural room impulse response (OBRIR) that follows the direct sound from mouth to ear. Combined with computational auditory modelling, OBRIRs can be used to estimate the loudness of a singing voice to the singer. They can also be used for low-latency auralization or simulation of rooms, including auditorium stage environments. Such experiments show that the spatial and temporal distribution of room-reflected energy can have a substantial effect on the qualities and quality of a space for singing, even if established acoustical parameters are held constant.

The subjective effect of random-incidence scattering coefficients

Dae-Up Jeong (Chonbuk National University)

JeongSu Kim (Chonbuk National University)

Young-Ji Choi (Chonbuk National University)

Paper #: P031

Diffusion has been regarded as one of the most important room acoustic components for the good acoustics of a room. Recently, ISO 17497-1 standard proposed the technique for measuring random-incidence scattering coefficients (RISC) in a reverberation room, which will provoke a broad application in the acoustic design process of a room. However, it has not been examined thoroughly how the change in RISC influences the room acoustic quality. The present work investigated the subjective effect of RISC on the audience using a scale model of a small performance hall. Simple one-dimensional periodic type diffusers were considered, since they were easy to define and comparable with many other works. The effect of changes in RISC was measured and analysed through a listening experiments. Subjective attributes in question were reverberance, clarity, loudness, and spaciousness in the present work, since any proper subjective attribute which enables direct appraisal of surface diffusions is not available yet.

Recent topics in acoustic scattering coefficient determination for wall surfaces

Tetsuya Sakuma (University of Tokyo)

Hyojin Lee (University of Tokyo)

Paper #: P033

Three recent topics in acoustic scattering coefficient determination for wall surfaces are briefly presented: 1) validation of the reverberation room method of ISO 17497-1, 2) a new method of measuring normal-incidence coefficients, and 3) alternative determination by numerical analysis. First, it is pointed out that the current ISO 17497-1 has a critical problem on measurement accuracy due to unclear requirements of two alternative approaches with stepwise and continuous rotation. Theoretically and experimentally, it is verified that: the stepwise approach has a minimum number of angular steps; the continuous approach has a minimum revolution period if using MLS signals, however if using swept sine signals, the same as for the stepwise approach. Furthermore, it is found that both minimum requirements increase as the sample scattering coefficient is higher, and unexpectedly, as the room absorption area is smaller. Second, a new laboratory method is introduced for measuring normal-incidence scattering coefficients, which can be useful to predict the suppression of flutter echoes. The measurement is done in a rectangular room where installing highly absorbent materials on all side walls, and a test sample on the floor. In the one-dimensional sound field, normal-incidence scattering coefficients of the sample can be determined by measuring the change in reverberation time with and without it. Third, as the alternative to measurement, numerical determination of scattering coefficients is demonstrated, and its practical use and further applications are discussed.

Subjective assessment of scattered sound in a virtual acoustical environment simulated with three different algorithms

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Renzo Vitale (Institute of Technical Acoustics, RWTH Aachen University, D-52056 Aachen, Germany)

Arianna Astolfi (Energy Department, Politecnico di Torino, Corso Duca degli Abruzzi, 24-10129 Torino, Italy)

Monika Rychtáriková ()

Paper #: P035

A mystery around perception of music in concert halls concerns the subjective perception of diffusing surfaces situated on walls and/or ceiling. Former studies have shown that listeners prefer diffuse conditions. Hence, further investigation on the audibility of diffusion in auralized concert halls has been necessary. The following research aimed to determine the threshold of hearable differences of the scattering changes in a virtual concert hall in two different positions of the audience area: one position next to the side wall and the other one close to the rear wall. Six different scattering coefficient values $s = 10, 30, 50, 60, 70$ and 90% were assigned to the interior surfaces of the ceiling, side and rear walls in simulations carried out with three different software: Odeon® 10.1, Catt-Acoustic v8.0 and Raven. The analysis has been performed by investigation of subjective perception of scattered sound in three sessions of listening tests by applying the 3AFC (three Alternative Forced Choice) method where stimuli were presented to subjects via headphones using signals auralized in the three software.

Influence of a volume scale factor on the scattering coefficient effects for the prediction of room acoustic parameters

Louena Shtrepi (Energy Department, Politecnico di Torino, Corso Duca degli Abruzzi, 24-10129 Torino, Italy)

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Monika Rychtáriková (K.U. Leuven, Laboratory of Acoustics and Thermal Physics, Celestijnenlaan 200D, 3001 Heverlee, Belgium)

Paper #: P036

Surface scattering has become an important input parameter in work on geometric models and in the research concerning the enhancement of auralized sound. This contribution deals with the comparison of four virtual scale models of the same concert hall and studies the importance of the scattering coefficient in simulations while the size of a concert hall was increased. The influence of a volume scale factor on the scattered sound effects the prediction of the objective room acoustic parameters such as T30, EDT, C80, D50, LF and G, is investigated. Five different alternatives were simulated. Scattering coefficient values $s = 10, 30, 50, 70$ and 90% respectively, were applied separately and in combination to the interior surfaces of the ceiling, side and rear walls. Analyses were performed by studying the results of the objective room acoustical parameters predicted by simulations carried out using the Odeon 11.00 and Catt-Acoustic v 8.0 software.

Subjective evaluation of reverberation with a non-exponential sound decay

Hyun-Kyung Joo (Ph. D student , Department of architectural engineering, Jeonbuk national university)

Dae-up Jeong (Professor , Department of architectural engineering, Jeonbuk national university)

Paper #: P037

It has been known that the application of diffuse field theory to the sound field with a non-exponential sound decay. Recent researches have concentrated on quantifying and controlling the non- exponential decay processes in rooms. However, the effect of non-exponential sound decay on listener perception of reverberation is not been clearly known. The present work tried to explore the relationship between the non-exponential decay of sound in rooms and the perceived reverberance, and further to develop a simple way of predicting subjective reverberance in such spaces. A series of listening experiments were performed with various non-exponential sound decay patterns using a 2AFC paired comparison method. A new way of predicting listener perceived reverberation for non-exponential sound decays was proposed based on the relationship between the results of subjective tests and the analysis of

Schroeder decay curves. The correlation analyses suggest that the proposed method can predict perceived reverberation caused by non-exponential sound decays quite well.

Concert hall geometry optimization with parametric modeling tools and wave-based acoustic simulations

Philip W. Robinson (Aalto University, School of Science, Department of Media Technology)

Samuel Siltanen (Aalto University, School of Science, Department of Media Technology)

Tapio Lokki (Aalto University, School of Science, Department of Media Technology)

Lauri Savioja (Aalto University, School of Science, Department of Media Technology)

Paper #: P038

Advances in computational capacity made available through graphics processing unit (GPU) processing and developments in parametrically driven design tools are creating new possibilities for acoustic design and analysis. In particular, wave-based numerical simulations are becoming more tractable, and geometry manipulations, which were once cumbersome manual work, can now be automated. A case study of concert hall section profile optimization is presented. Using RHINOCEROS software with the GRASSHOPPER parametric modeling plugin, geometries were automatically generated based on a few parameters, then evaluated using Finite Difference Time Domain (FDTD) numerical simulations using GPU processing in MATLAB. The results from each iteration are used to inform a global optimization algorithm that conducts an intelligent search of the parameter space to find a solution in as few iterations as possible. The optimization is based on a stochastic model of the multidimensional objective function. The objective function is iteratively sampled and a simplified Bayesian approach is used for finding the set of parameters which is most likely to improve the current estimate of the global minimum at each iteration. With this method, curved and linear iterations of the sidewalls and under-balcony surfaces of a concert hall section were investigated. The objective was to deliver the most early energy, in the most uniform distribution, from multiple sources to multiple receiver positions.

A finite-difference time-domain investigation of reflections from layered wall structures

Aki Haapaniemi (Aalto University, Department of Media Technology)

Alex Southern (Aalto University, Department of Media Technology)

Tapio Lokki (Aalto University, Department of Media Technology)

Paper #: P039

The acoustic reflection characteristics of layered wall structures were studied using the 2-D standard rectilinear (SRL) finite-difference time-domain (FDTD) method. The studied structures feature a slatted panel combined with a back wall, forming a cavity in between. The visual appearance of such structures resembles slatted resonant absorbers, but in this case the slat width is considerably wider and no absorptive material is present behind the panel. The types of structures studied here are found in use in some concert halls, e.g. in the Helsinki Music Centre concert hall in Finland. In the simulations, the structural features were varied in order to see how the reflection characteristics change with the features. The reflection responses are presented by normalizing the average frequency response of a line of multiple receiver points with respect to the corresponding average for a flat wall. Additional simulations were done to study the diffusive properties of such structures. Furthermore, 2-D FDTD visualizations of reflections from the structures are included to facilitate intuitive understanding. The structures were found to exhibit various degrees of comb filtering effects and frequency-dependent spatial and temporal spreading.

Throw away that standard and listen: your two ears work better

Tapio Lokki (Aalto University, Department of Media Technology)

Paper #: P040

The acoustics of a concert hall is often described with the help of ISO3382-1:2009 parameters. However, several recent studies suggest that ISO3382-1 cannot explain the details of subjective perception nor preferences of the listeners. The current parameters, averaged over listener positions, and the use of only mid frequencies are definitely inadequate. We have recently measured over 15 concert halls around Europe with a novel measurement system -- the loudspeaker orchestra. It consists of 34 calibrated loudspeakers on stage to simulate an orchestra, the most common sound source in concert halls. For objective analysis and spatial sound reproduction, we first measure spatial impulse responses from each loudspeaker at accurately defined receiver positions. This enables accurate comparison of the properties of spatial impulse responses between halls. Furthermore, we have developed methods to convolve anechoic symphony orchestra recordings with the measured spatial impulse responses for multichannel loudspeaker listening. Both subjective comparison of halls and objective analysis with time-frequency and spatio-temporal properties of impulse responses have helped us to link architectural features and subjective perceptions. This presentation will explain these links and their relationship to properties of binaural hearing. Several examples are given to highlight the differences between vineyard and shoe-box type concert halls. In particular, the extreme importance of early reflections for engaging sound is explained.

Interactive design methods for complex curved reflectors in concert halls

Tomas Mendez Echenagucia (Department of Architecture and Design - Politecnico di Torino)

Arianna Astolfi (Energy Department - Politecnico di Torino)

Mario Sassone (Department of Architecture and Design - Politecnico di Torino)

Louena Shtrepi (Energy Department - Politecnico di Torino)

Arthur Van Der Harten ()

Paper #: P042

Architects are used to having a high level of control in the early design phase. This phase is characterized by a large decision space and formal exploration. However, in this initial stage of design the most important formal and acoustic, decisions are made. The need for good communication between architect and acoustician is therefore highest in this stage of the process. Architectural need for exploration is often in contrast with acoustic standard solutions and recommendations. This is especially true in the case of freeform complex and double curvature surfaces now employed throughout the world. Often, the collaboration is reduced to the modification of the forms produced by the architect by the acoustician or vice versa. The overall process is comparable to an optimization process where form is improved, and where there is very little exploration of new solutions. These complex surfaces have great potential in directing energy where is needed, but they have a high risk of concentrating sound energy in some locations if they are not studied in depth. The advent of advanced computational geometry, in particular the use of Non-Uniform Rational Basis Splines or NURBS, give us the possibility to better represent 'free-form'? complex and curved geometry. This presents the opportunity to accurately to explore the acoustic potential of complex curved surfaces. In combination with NURBS geometrical tools, this paper presents the use of Multi Objective Genetic Algorithms (MOGAs) for acoustic design, as an interactive, communication and exploration tool, intended for the early design phase.

EDT, C80 and G driven auditorium design

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Arthur Van Der Harten ()

Paper #: P043

Acoustical Indexes as described in ISO3382-1, with their optimal values, are not necessarily positively correlated. Some of them are in fact negatively correlated (Barron, 2005). This means that when designers try to shape a room in such a way as to obtain optimal EDT and C80 values for a certain position in the room, they face contrasting objectives. This problem is further complicated by the fact that rooms are designed for multiple listening positions with different distances from the sound source and from reflecting surfaces. The distribution of energy in time and space that is required to obtain optimal acoustical values for all listening positions in a room is a complex problem. Multi-Objective Optimization algorithms can deal with contrasting design objectives and aid the designer by generating or suggesting a series of solutions that are said to be non-dominated from each other. This set of solutions is called the Pareto front, and can be of valuable information for acoustic consultants and architects early in the design process. This paper presents the use of Multi-Objective Genetic Algorithms (MOGAs) for the design of shoebox and hexagonal auditoriums using the EDT, C80 and G indexes as fitness functions to determine the room's main dimensions or angles between surfaces.

Room acoustics modelling using a point-cloud representation of the room geometry

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Paper #: P044

Room acoustics modelling is usually based on the room geometry that is parametrically described prior to a sound transmission calculation. This is a highly room-specific task and rather time consuming if a complex geometry is to be described. Here, a run time generic method for an arbitrary room geometry acquisition is presented. The method exploits a depth sensor of the Kinect device that provides a point based information of a scanned room interior. After post-processing of the Kinect output data, a 3-D point-cloud model of the room is obtained. Sound transmission between two selected points within the room is simulated using a 3-D point-cloud model to define a room geometry and a discrete ray-tracing method to calculate sound propagation paths within the enclosure. Based on a 3-D point-cloud room model a voxel grid is created and each voxel has been assigned certain properties. These properties define how a ray acts when it reaches the voxel, e.g. reflects specular and attenuates according to the surface absorption or runs straight through without any attenuation. Sound propagation is simulated by a ray traversal algorithm while two types of voxel grid representations are investigated - uniform and hierarchical (octree). Several simulations were done using room models with different voxel grid resolutions in order to represent the details of the surfaces more realistically and thus to provide an optimal geometrical input for the sound transmission module. The method proposed here can be used for telepresence applications to achieve a high level of user immersion by a real time acoustical simulation of a dynamic scenes.

An earthquake and a concert hall

Takayuki Hidaka (Takenaka R&D Institute)

Paper #: P045

A gigantic earthquake occurred in the northeastern part of Japan on March 11, 2011. Given the scale of disaster, the central area of the afflicted region certainly suffered serious damage. Unexpected damage, however, occurred in areas around Tokyo although the city is over a few 100 km away from the affected area. To be specific, the large ceiling of a concert hall fell because objective causes. This paper discusses causes of accidents related to the construction methodology unique to those halls and the recommended earthquake-proofing method of those ceilings based on the case example of the said hall in Tokyo.

Binaural dynamic responsiveness in concert halls

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Paper #: P046

The standard strength parameter (G) indicates the linear amplification by the concert hall between the sound source and the receiver. The parameter is commonly measured with an omnidirectional microphone. However, real music performance with musical instruments and human listeners involves factors far from linear. First, variation in musical dynamics is one of the basic means of expression in compositions and music performance. The effect of playing dynamics on the sound spectrum of the musical instruments is not linear. Instead, louder playing disproportionately excites higher harmonics more than harmonics near the fundamental frequency. Hence, the difference in high-frequency content between soft and loud playing is large, resulting in a different tone color. The degree of this effect depends on the instrument. Second, binaural directional hearing is also highly nonlinear; it emphasizes high frequencies more when the sound arrives from the sides of the head rather than from the median plane. The geometry of the concert hall has a direct connection to the amount and directions of reflected sound energy, and thus, to the binaural frequency response. These premises lead to a hypothesis that the binaural dynamic range of identical performances varies between different concert halls. It is possible that concert halls that better convey musical dynamic changes would be preferred. Studies of this paper aim to resolve how concert halls differ from each other with their binaural dynamic responsiveness. The analysis employs anechoic orchestra instrument recordings and recent acoustic measurements from renowned concert halls.

Increasing Reverberation Time with Diffusers: a new acoustic design for more sustainable halls

Umberto Berardi (Worcester Polytechnic Institute)

Higini Arau-Puchades (Arauacustica, Barcelona, Spain)

Paper #: P047

In recent years a volume diffuser, called grid diffuser or labyrinth diffuser, has been designed and introduced in musical halls. Two examples of this diffuser are described in the present paper: one is the orchestral rehearsal room at the Great Theatre of Liceu in Spain, and other is the Tonhalle St. Gallen hall in Switzerland. In both spaces, musicians and listeners have reported a substantial increase in subjective room volume after the introduction of the diffusers. The initial goal of this diffuser was to reduce the strength of ceiling reflections. However, an increase in the perceived volume occurred unexpectedly. Measurements show that both T and EDT have increased, and also G has been modified by the

introduction of the diffusers. Although the lack of a complete theory about labyrinth diffusers, these open new possibilities to obtain the effect of a large enclosure in rooms with relatively lower dimensions, and promise to be important to create smaller and more sustainable halls. Further research is needed to be able to control the mechanism by which the labyrinth diffuser achieves the increase of the reverberation time.

The effects of occupancy on theatre chair absorption characteristics

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Dae-Up Jeong (Faculty of Architectural Engineering, Chonbuk National University)

John Bradley (Institute for Research in Construction, National Research Council)

Paper #: P048

The successful prediction of audience absorption is particularly important because the audience is the largest single component of absorption in an auditorium. The present study investigates how the audience affects to the theatre chair absorption characteristics and varies with theatre chairs having different absorption coefficients using a scale model. A 1/10 scale model of theatre chairs and auditors was developed for simulating the absorption characteristics of full scale theatre chairs and audiences. The theatre chairs with various absorption coefficients were constructed and the absorption coefficients of the theatre chairs occupied with model auditors were measured in a model reverberation chamber.

Spatial analysis of concert hall impulse responses

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Jukka Pätynen (Aalto University School of Science, Department of Media Technology)

Philip W. Robinson (Aalto University School of Science, Department of Media Technology)

Lokki Tapio (Aalto University School of Science, Department of Media Technology)

Paper #: P049

Omni-directional measurements and parameters derived from them are not adequate for describing the details of concert hall acoustics. Inherently, spatial properties of the sound field are lost, and these spatial details are a major component of the musical presentation. Until relatively recently, spatial analysis of the sound field has been limited to simple microphone response patterns, such as omni, figure-of-eight, or cardioid. However, new microphone array analysis techniques allow high spatial resolution measurement and evaluation of concert hall sound fields. These measurements can be used for time-frequency and spatio-temporal analysis [Pätynen et al. 2013, JASA Vol.133, 1] to unravel the underlying physical phenomenon and perceptual consequences. This paper presents further results with the spatial analysis method. Detailed analysis results of 13 European concert halls are shown.

Noise compensation methods for room acoustical parameter evaluation

Martin Guski (Institute of Technical Acoustics - RWTH Aachen University)

Michael Vorländer (Institute of Technical Acoustics - RWTH Aachen University)

Paper #: P050

Room acoustical parameters are typically derived from measured room impulse responses. The unavoidable background noise which occurs during the measurements is inextricably contained within the impulse response and can distort the evaluated parameters. The magnitude of this error is a function of the signal to noise ratio and depends on the applied evaluation technique. ISO 3382 defines three different methods to compensate these noise effects for the calculation of the energy decay curve. In this contribution it will be shown theoretically that for moderate to high noise levels these

methods result in different systematic errors. Alternative noise compensation methods, which are not in accordance with ISO 3382 are more unsusceptible to noise. Several long-term measurements with various signal amplifications were conducted to obtain impulse responses with different peak signal to noise ratios (PSNR). The resulting dependency of the evaluated parameters on the PSNR confirms the theoretical findings. The advantages and limitations of the investigated methods will be shown in detail.

A basic study on possibility to improve stage acoustics by active method

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Takane Terashima (Division of Architecture, Graduate School of Engineering, Mie University)

Yasunobu Tokunaga (Department of Civil Engineering, Maizuru National College of Technology)

Paper #: P051

Even on limited stage area of a hall, sound field is not uniform and ST (Support) value varies from place to place. Then some of orchestra members are always unsatisfied with their environment for performance. The purpose of this study is to research on possibility to improve stage acoustics for orchestra musicians by active method. In this report, firstly, measurements of ST values distribution for several positions on the stage area of a hall were carried out. At positions on the stage area, impulse responses (IR) were measured under a few varieties of architectural conditions, the height of stage enclosure. Sound receiving points were located 1m front of sound source. Next, each sound field of positions on the stage was evaluated subjectively in terms of preference at playing musical instrument by simulation in anechoic chamber. Subjects play electronic musical instruments and their played signals are convoluted real-timely with impulse responses measured, then fed back to them. Subjects answered questions concerning impressions and preferences for each sound field while playing instruments. Additionally, sound fields, i.e. IR whose ST values are out of optimum range were modified computationally so as to have optimum ST values by superimposing IRs and then evaluated subjectively in the same way. The results of these subjective evaluations were compared with ST values and discussed the validity of improved sound field. In future, a concrete plan to improve sound field for musicians by sound feedback to local target area on the stage would be discussed.

The effects of scattering surfaces on the reverberation Time and Flutter Echoes in rectangular rooms

Uwe Stephenson (HafenCity University, Hamburg)

Paper #: P053

Different from the prediction by the Sabine formula, in non-diffuse sound fields reverberation times also depend on the room shape, the distribution of absorption coefficients and especially on the scattering coefficients. In long rectangular rooms with absorbing side walls they depend very sensitively (almost inversely proportionally) to the scattering coefficients of the front and the back wall. This was shown numerically in previous work in 2-D by considering absorption and scattering fractions in sound propagation. The aim has now been to extend this work to 3-D and to investigate also quantitatively, the qualitatively well-known-effect of scattering on the growth of flutter echoes. Therefore, the Dietsch echo criterion was utilized as an algorithm to compute the audibility of echoes from impulse responses. These semi-analytical approaches are compared with sound particle simulations.

Locally or non-locally reacting boundaries: Does it make a significant acoustic difference?

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Michael Vorländer (Institute of Technical Acoustics, RWTH Aachen University)

Paper #: P054

As an alternative for the common geometric room acoustical models, a wave theory-based model has been developed derived from the so-called WRW scheme, often used in seismic modelling. In this model, the wave properties of sound are appropriately taken into account. The proposed model is similar to the Boundary Element Method (BEM). Other than in BEM, in the WRW scheme non-locally reacting room boundaries can be included in the modelling process using only the fluid domain. The results of sound field modelling in rooms with locally as well as non-locally reacting boundaries are presented. The differences are analyzed and their relevance is discussed.

Re-creation of the acoustics of Hagia Sophia in Stanford's Bing Concert Hall for the concert performance of Cappella Romana

Wieslaw Woszczyk (McGill University)

Jonathan Abel (Stanford University)

Doyuen Ko (McGill University)

Travis Skare (Stanford University)

Jonathan Hong (McGill University)

Paper #: P055

The new Bing Concert Hall designed by Nagata Acoustics is to open in January 2013 at Stanford University. The hall's 842 seats are arranged in a vineyard format with the audience surrounding the stage. The February 1st concert performance of the renowned American vocal chamber ensemble Cappella Romana entitled 'From Constantinople to California' will be staged in the recreated acoustics of the magnificent Byzantine architecture of Hagia Sophia Museum in Istanbul. In the preparation for this event, detailed acoustical measurements of Hagia Sophia were made to provide useful building blocks for the low-latency recreation employing multichannel convolution, enabling a fully immersive interactive experience of the acoustics for the singers and their audience. The paper presentation will describe the preparations, testing, and the implementation of this active acoustic conversion of the concert hall acoustics needed to accommodate the musical performance. A number of challenges have been identified during the process leading to the application of novel solutions that will be presented during the conference.

Assessment of numerical data from ISO3382

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Paper #: P056

Expanding ISO3382 in 1997 to include measures beyond reverberation time was a significant milestone in the development of auditorium acoustics. The measures basically fall into two categories, those linked to rates of decay and energy measures. Several papers have been published providing advice on measurement and analysis to obtain reliable results. Several ways exist to analyse the results to understand better the behaviour of sound in a space. In spite of absorption being concentrated on only one of the six principal surfaces, the state of diffusion can be quite high in an auditorium, at least in an auditorium without a proscenium opening. The Normalised Standard Deviation of Reverberation Time (RT) looks like a useful measure of the state of diffusion. In a diffuse space, the Early decay time (EDT) equals the RT and energy measures follow prediction according to revised theory. But our hearing system appears not to be particularly sensitive to the state of diffusion. Ways to interpret EDT and deviations from revised theory will be discussed. Lateral Fraction on the other hand tends to be closely related to geometry. Currently ISO 3382 presumes using an omni-directional source. This is to ignore

instrument directivity, which is a major issue that distinguishes the subjective difference between a shoebox and terraced concert hall.

Under-balcony acoustics improvement with simple electro-acoustic means: A Theoretical development and numerical simulations

Jeremy Rouch (CSTB (French Scientific and Technical Centre for Building))

Isabelle Schmich-Yamane (CSTB (French Scientific and Technical Centre for Building))

Marie-Annick Galland (ECL (Ecole Centrale de Lyon))

Paper #: P057

In concert halls, the acoustical quality below a large balcony is often reduced compared to the rest of the concert hall. This is caused by significant differences in the behavior of the reverberated energy in these two volumes. The main difference is a global lack of reverberated energy under the balcony, which can be theoretically estimated by Sabine theory applied to coupled spaces. A solution for enhancing the reverberated energy below the balcony is to inject amplified sound picked up in the main volume. This can be performed with simple electro-acoustic channels such as those used in a feedback reverberation enhancement system. Thus, each channel is composed of a microphone in the main volume, an amplification processing unit and a loudspeaker under the balcony. In this paper, a theoretical development based on a Sabine approach is presented in order to explain and predict how the electro-acoustic channels increase the coupling coefficient between the main volume and the volume below the balcony. The theoretical limits of this coupling enhancement technique are also presented and discussed, especially with respect to feedback problems of electro-acoustic installations in a room. In order to prove the validity of these theoretical developments, numerical simulations based on ray-tracing methods are implemented. These numerical simulations also show that a properly calibrated electro-acoustic decoupling system can significantly decrease the acoustic shadow effect of the balcony with respect to the principal room acoustic criteria.

Investigation of background noise conditions during music performance

Jonah Sacks (Acentech)

Robert William Wolff (Acentech)

Ana Maria Jaramillo (Virginia Tech)

Paper #: P061

We recapitulate a series of studies of the perceptual role of low levels of background noise in quiet spaces for music listening. These include structured listening exercises in two quiet music rooms -Jordan Hall in Boston and the EMPAC Concert Hall in Troy, NY -wherein background noise levels were electronically manipulated while subjects listened critically to live and recorded music in these rooms. Our findings indicate meaningful preference for lower background noise levels, even at levels well below NC-15, while listening to music in unoccupied rooms. Also studied were sound levels during several concerts at another quiet music room -Distler Hall in Medford, MA to understand better the relationship between background sound levels in the occupied room and in the unoccupied room. Our findings agree with previous studies showing minimum audience noise levels during performances only slightly above unoccupied room background noise levels.

Active acoustics in physically variable spaces

Roger Schwenke (Meyer Sound Laboratories)

Steve Ellison (Meyer Sound Laboratories)

Pierre Germain (Meyer Sound Laboratories)

Paper #: P062

This paper presents an overview of venues with active acoustic systems where the venue itself can change size, arrangement, or be subdivided. Logomo Hall is a multi-purpose performing arts center in Turku Finland which hosts performances ranging from contemporary sound reinforced music to symphonic orchestra. It has a movable tribune with balcony seating. When it is closest to the stage the venue seats 1100, in its furthest position it accommodates 3500. Vendespace Grande Salle in the Vende region of France can seat up to 4900 in the round, with a stage that can be placed in two very different positions. Vendespace hosts sound reinforced music, opera, symphonic, and choral music as well as sports events. Valley Christian Schools' Conservatory of the Arts in San Jose has a rehearsal room which can be divided into two, and can accommodate groups ranging from a small string ensemble to a full marching band. The Asia-Pacific Center for Security Studies in Honolulu has a meeting room which be divided in two and hosts seminars, round-table meetings, and other educational events.

Method for estimating diffuseness of sound fields by using decay-cancelled impulse responses

Toshiki Hanyu (Nihon University)

Paper #: P063

An analysis method for estimating diffuseness of sound fields by measuring the time variation in reflected sound energy of impulse responses is proposed. In this method, first a decay-cancelled impulse response is obtained by removing the reverberation decay from the impulse response using a Schroeder decay curve. The degree of diffusion of the sound field is determined by evaluating the time variation in the reflected sound energy of the decay-cancelled impulse response. By using this method, the frequency characteristics of diffuseness in sound fields can be analyzed from the impulse response measured at a single point. The average degree of diffusion in a room can also be evaluated by averaging the analysis results at several points in the room, similar to the analysis of reverberation time. In order to verify the proposed method, the impulse responses in rooms having different types of diffusers were calculated by the wave acoustics computer simulation. The frequency characteristics of diffuseness were analyzed from the calculated impulse responses, by using the proposed method. The results showed that the frequency characteristics of diffuseness change depending on the size of the diffusers. Thus, the proposed method can be used for evaluating the effect of diffusers on the degree of diffusion in a sound field. Furthermore, diffuseness was also measured in actual sound fields. The proposed method could identify the occurrence of flutter echo. The results also showed that the degree of diffusion in the sound field was influenced by the room volume and the location of the installed diffusers.

How far should the geometry of a concert hall be optimized?

Yann Jurkiewicz (Kahle Acoustics)

Thomas Wulfrank (Kahle Acoustics)

Eckhard Kahle (Kahle Acoustics)

Paper #: P064

When designing concert halls, acoustic consultants tackle the challenge of providing an appropriate amount of early reflections to each audience member and to the musicians on stage. This critical issue in concert hall design implies the development of an appropriate architectural shape through a collaborative and creative process of geometrical optimization. But in the case of a large concert hall with a seat count of more than 2000 seats, how far can the geometry possibly be optimized? Is such an optimization process necessarily positive or can it be detrimental regarding the late diffused sound

field? In symphony halls of smaller seat count, is there a limit beyond which early reflections become excessive? A recently developed approach based on the acoustic solid angle criterion can shed some light on these key questions. In particular, the direction of arrival of early reflections is found to play an important role, which highlights interesting practical implications for acoustic design. The efficient solid angle can be used both as an architectural criterion and a prediction method relating the shape of a concert hall to its efficiency in providing early reflections. Implications of geometrical optimization for early reflections on the late diffused sound field can also be predicted and studied. This approach based on solid angles will be illustrated in the practical case of some existing or hypothetical concert hall geometries.

The error analysis and correction of the reflection calculation for the FDTD method

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Takayuki Hidaka (Takenaka R&D Institute, Inzai, Chiba, Japan)

Toshiyuki Okano (Takenaka R&D Institute, Inzai, Chiba, Japan)

Paper #: P065

The FDTD method has becoming an efficient tool as the numerical method for concert hall sound field. acoustic simulation technique. It may be because a wide frequency band analysis can be directly carried out in the time domain, while the computational cost and accuracy restrict range of application to large spaces. The space discretization procedures and the time evolution methods regarding to wave propagation with exception of the boundary are well improved on these issues. On the contrary, there are not many researches on a boundary reflection. So that accuracy of reflection calculation can be a bottleneck of the accuracy of the whole simulation. In most simulation research treating reflection phenomena, the boundary local reactive boundary condition is assumed. In this presentation, we show the result of investigating the computational error of the reflected wave in those methods and the method of error reduction is proposed.

Quantifying the just noticeable difference of reverberation time with band-limited noise centered around 1000 Hz using a transformed up-down adaptive method

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Adam T. Buck (Durham School of Architectural Engineering and Construction, University of Nebraska-Lincoln)

Zhao Peng (Durham School of Architectural Engineering and Construction, University of Nebraska-Lincoln)

Lily M. Wang (Durham School of Architectural Engineering and Construction, University of Nebraska-Lincoln)

Paper #: P067

This study seeks to quantify the just noticeable difference (JND) of reverberation time (RT) using band-limited noise. ISO 3382-1 lists the JND of reverberation metrics at 5% based on work by Seraphim (1958). However, others have found the JND of RT to be higher from 6% to 39%. Many of these studies utilized band-limited stimuli, e.g. speech, music motifs and band-limited noise. A previous study by the authors conducted on 30 subjects using white noise demonstrated a JND of RT at 22%. To further verify these results and investigate potential upward frequency masking, the present study was conducted following the same methodology but using octave-band limited noise centered at 1000 Hz instead of white noise. Binaural room impulse responses (BRIR) were created from the Elmia concert hall in ODEON by uniformly varying absorption coefficients across all surfaces and frequencies to achieve the

desired RTs. The desired RTs varied around three reference values (1, 2, and 3 seconds), with eight samples approaching the reference RT from below and another eight approaching from above, at 4% intervals of the reference RT. Auralizations of the BRIRs and 500 ms band-limited noise were randomly presented in a computer-based testing program using a three-interval one-up two-down forced choice method, while interleaving six staircase sequences (3 reference RT X 2 downward vs. upward approaching direction). Subjects were individually tested in a sound attenuated booth using headphones with flat frequency response. Results are presented and compared against those previously obtained using white noise.

Rating low levels of ambient noise in performing arts facilities

Lily Wang (University of Nebraska - Lincoln)

Brent Kraay (University of Nebraska - Lincoln)

Paper #: P068

Previous studies have indicated that common indoor noise rating metrics, such as Noise Criteria NC and Room Criteria RC, do not best correlate to human perceptions of annoyance and distraction in typical office environments. Based on investigations conducted at the University of Nebraska using noise levels between 30 to 60 dBA, the author has proposed that an effective indoor noise rating method should begin with a rating of level (either dBA or sones), then an assessment of spectral quality, tones, and fluctuations. How well would such a system work at very low levels of ambient noise, though, as found in performing arts facilities? This paper compares and discusses the performance of assorted indoor noise rating metrics, calculated from background noise level data measured in existing performing arts spaces.

The acoustical design of the Christchurch Town Hall

Harold Marshall (Marshall Day Acoustics Ltd,)

Paper #: P070

The Christchurch Town Hall (New Zealand) was opened in October 1972. Disastrous earthquakes hit Christchurch in September 2010 and February 2011. Most of the CBD and the historic buildings were destroyed or damaged by the February event, including much of the Town Hall complex. The City Council in November 2012, resolved to restore the entire building but at the time of writing there remains uncertainty. The intention of this paper is to put on record the history of the Christchurch Town Hall design in case it does not survive the political after-shocks of the earthquakes. With the building's future now in jeopardy it seems appropriate to set out the process that led to this unique design, acknowledge the many contributors, outline its research base, the innovations in predictive technology employed, the evaluation of its acoustical properties and the learning that flowed from it.

New On/Off absorption technology that includes low frequencies

Niels Adelman-Larsen (Flex Acoustics)

Paper #: P071

Previous studies have shown that what distinguishes the best from the less well liked halls for pop and rock music is a short reverberation time in the 63, 250 and most importantly the 125 Hz octave band. Since a quite long reverberation time in these bands is needed in order to obtain warmth at classical music concerts, variable acoustics must address these frequencies in order to obtain desirable acoustics in multipurpose music halls. A new, patented, variable broadband absorption technology is presented. Absorption coefficients measured are approx. 0.4 to 0.5 in the 63 to 1 kHz octave bands while decreasing at higher frequencies when in the ON position. In the OFF position the product attains

absorption values close to 0.0. Since the product, that complies with all relevant fire regulations etc., is placed on the entire ceiling area, the T30 of a hall can be lowered by 40 to 50 % in all the most relevant octave bands of musical instruments at the push of a button. The technology, which is the only one to enable for variability at low frequencies, is meant to be used anywhere where both classical as well as amplified music is being played such as in music schools and performing arts centres.

Orchestral performance practice and the perception of acoustic quality in concert halls

Pamela Clements (Clements Acoustics Design Associates)

Paper #: P073

One major challenge in perceiving - and hence making judgments about - acoustic excellence in concert hall design relates to factors outside the framework of acoustic science. In the most iconic concert halls it is possible to hear sublime performances (thus justifying the hall's reputation) just as it is possible to hear performances that are not well matched to the room acoustic conditions, and exhibiting defects such as frequency distortion, poor balance or overloading. In architecturally displeasing halls it can be difficult to perceive musical beauty or acoustic quality, while on occasion it can be possible to experience thrilling musical performances in less than ideal acoustic environments. This paper will suggest that listening 'musically' and 'acoustically' are dual and intersecting skills needed by acousticians in order judge acoustic quality more effectively. Listening musically involves knowledge of repertoire and orchestral performance practice, including how the approach of the conductor, ensemble size, the setting of the musicians onstage, characteristics of the instruments, the experience of the musicians and skill align with and respond to the acoustic character of the hall. It will be argued that acousticians can hone their musical listening skills to inform their acoustic evaluation of different halls, improve their ability to listen for the effects of architectural form, and refine aspects of their perception of acoustic parameters. The presentation is based on the author's research and listening to concerts in great contemporary and historic halls as well as listening to particular orchestras performing the same programs or similar repertoire in different acoustic environments.

Room acoustical quality of concert halls: perceptual factors and acoustic criteria - return from experience

Eckhard Kahle (Kahle Acoustics)

Paper #: P074

Several acousticians have attempted to define a complete set of factors describing room acoustic quality, based on laboratory and/or real hall listening tests. After finishing a PhD thesis on room acoustic quality, the author has worked on new constructions of performance spaces, renovations as well as optimizations of existing spaces and the question can now be asked whether the widely used set of objective criteria and perceptual factors proves sufficient to describe the problems and challenges encountered. When working on high-quality acoustic spaces, the commonly used set of acoustic criteria is insufficient to describe all aspects and problems. Further descriptors are required with respect to both acoustic measurements and perceptual factors. Proposals for additional acoustic criteria and their link to the architecture of a space will be given, aiming to better describe the signature of a room with respect to both source presence and room presence. The concept of 'stream segregation' into source presence and room presence is confirmed, but for both the source and room parts not only the magnitude (strength) needs to be considered, but equally more detailed aspects like lateralness and direction of arrival, i.e. what could be called the spatial center of gravity. For example, changing the spatial center of gravity of the reverberation has very strong perceptual consequences. Another aspect that often tends to be neglected is the question of orchestral balance (for audience members but equally for musicians on stage) that can strongly be influenced by acoustic design decisions.

Acoustic measurements and simulations for the Gki Maulana Yusuf church in Bandung, Indonesia

Joko Sarwono (Engineering Physics ITB)

Wimanda Moestopo (Engineering Physics ITB)

Soelami FX Nugroho (Engineering Physics ITB)

Paper #: P075

This paper were discussed the acoustics condition of GKI Maulana Yusuf's church in Bandung Indonesia, including its sound reinforcement system. Existing acoustics performance was examined by field measurements for the following parameters: noise level, distributions of sound pressure level, reverberation time, definition, and clarity. Moreover, simulations using the CATT Acoustic software was used to obtain the value of various parameters as well as their distributions on the entire position inside the sanctuary consist of two different floor plans. The measurement results show that the sanctuary has noise level well over the threshold for church building, with NC value of 53. The examination on sound pressure level distributions shows that the lower floor acoustical condition was worse than the upper floor, with the sound pressure level difference of 5 dB. Reverberation time is around 1.3 seconds. The lower floor also has definition and clarity distributions which were less than 50% and outside the range of -2 to 4 dB, respectively. Acoustics simulations were also carried out to increase Church performances. Modification of the sanctuary surfaces and sound reinforcement system rearrangement were done through this simulation. The result show that the sound pressure level, reverberation time, and clarity have reached the targets, while the definition was still needed further examinations.

Subjective and objective evaluations of scattered sounds in concert halls

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Hyung Suk Jang (Architectural Engineering, Hanyang University)

Yong Hee Kim (Architectural Engineering, Hanyang University)

Michael Vorländer (ITA, RWTH Aachen University)

Paper #: P077

The effects of wall diffusing elements on the perception of sound fields were investigated in a scale model and in a recital hall. Acoustical measurements were carried out in both halls with and without diffusers. The front halves of both side walls in the recital hall were covered with plastic panels and/or absorptive materials, and thus diffusive, reflective and absorptive conditions were measured in the audience area. The diffusive surfaces affected the decrease of EDT (coefficient of variation for relative standard deviation of EDT) and increase of the Number of peaks (N_p) in different frequency bands, which were calculated to evaluate the diffuseness of the halls. Then, auditory experiments were conducted using a paired comparison method. It was found that a dominant factor for the acoustical preference in the recital hall were ' N_p ' with different wall surface treatments.

Evaluation of the absorption by the orchestra in concert halls using scale models and computer simulations

Hyung Suk Jang (Architectural Engineering, Hanyang University)

Jin Yong Jeon (Architectural Engineering, Hanyang University)

Paper #: P078

The ISO 3382-1 specified to describe accurate occupancies on stage. The sound absorption of orchestra was evaluated for the audience acoustics in scale models. 1:10 scale model musicians were made with a consideration of the surface areas of orchestral instruments. The absorption of the models was

measured in a reverberation chamber. Then the effect of model orchestra on auditorium acoustics was investigated for different shapes of the concert hall and compared with empty stage conditions. Reverberation Time, Early Decay Time and Sound strength (G) decrease by increasing the number of musicians. Additionally, the proper simulation model musicians were suggested as a flat surface on covered stage with scattering coefficient. The decreases of RT by the orchestra depended on the total absorption of the hall. There was much larger decrease of RT in more reflective halls.

Preferred Acoustical Conditions for Musicians on Stage with Orchestra shell in multi-purpose halls

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Yong Hee Kim (Architectural Engineering, Hanyang University)

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Paper #: P079

Acoustical conditions in relation to stage supports have been investigated for musicians performances in concert hall stages with a proscenium arch and orchestra shell. Stage acoustical parameters, such as ST_{Early} and ST_{Late}, were measured in order to characterize stage acoustics at various measurement positions. Solo and ensemble performances were investigated in performance tests; subjective scores for hearing oneself (each other) and preference were gathered from musicians on stage. It was found that the highly preferred position for soloists was shown to be the central stage in an area with the highest ST_{Late}; the rear stage area was preferred by instrumentalists and the frontal stage area was preferred by vocalists. But the ensemble performers preferred to occupy central and rear middle stages.

Effects of stage volume on concert hall acoustics as a design element

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Paper #: P080

In this paper, stage volume is investigated as dimensional aspects for stage design in concert halls. From a survey of hall measurement data, halls with relatively small stages tend to form higher sound strength as indicated by the parameter G. The effect of this stage design element was investigated further by computer simulation. A rectangular hall was modeled with variations in stage volume. The results showed that a smaller stage volume mainly enhanced sound strength in the audience area. The effects of stage volume were thus applied to various hall types, and optimum values of stage volume were investigated for each hall.

Implementing a spherical microphone array to determine 3-D sound propagation in the 'Teatro 1763' in Bologna, Italy

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Andrea Venturi (IED, University of Parma)

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Paper #: P082

The analysis of the 3-D properties of the sound field have been strongly improved in recent years, after spatial properties of sound propagation have been acknowledged to be important during the design or correction of theatres and auditoriums. Besides, a proper assessment of spatial accuracy is requested for 3-D sound reproduction systems, initially designed for acoustical virtual reality and now also employed in the entertainment/cinema industry (Immsound, Auro-3D, NHK 22.2). Often only monaural or binaural measurements are performed by means of omni-directional microphones and dummy heads, although international standards like ISO 3382/1:2009 also define some 'truly spatial' parameters such as JLF and JLFC. The two latter parameters are derived from measurements made with a pressure velocity (p/v) microphone, but this is still a 2-channel measurement. 3-D Impulse Responses (4-channel B-format) have for many years been measured and employed for sound reproduction. Recently, higher-order 3-D Impulse Responses have been measurable thanks to the availability of compact microphone arrays employing a much larger number of transducers. In this paper, two procedures for measuring and analysing the complete spatial sound information are presented, which are aimed to create easy-to-understand images and videos showing the direction-of-arrival of the room reflections. The description of these techniques is emphasised. This new method has been applied in the Teatro Ma'acorati, Bologna, Italy, and the results are here illustrated

Interactive real-time simulation and auralization for modifiable rooms

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Michael Vorländer (ITA - RWTH Aachen University)

Paper #: P083

To study the effects of any changes to a room or setting on the room acoustics, a framework was developed that enables immediate acoustic feedback to the user. This is achieved by running interactive room acoustics simulations and auralizations in real-time. Physically based binaural room impulse responses (BRIRs) are calculated using the image source method and ray tracing and are divided into direct sound, early reflections and late reverberation. Any part of the BRIR is updated as quickly as possible depending on the user's interaction with the scene. This includes changes to sources and receivers (positions/orientations/directivities/HRTF), to surface materials and to the room geometry itself. Using streaming low-latency convolution, an immediate feedback is provided to the user. A parallelization concept features multi-threading and networked PC-clusters, so that the workload can be effectively distributed, offering a scalability to simulate small to huge scenes, depending on the available computation power. For convenient scene design and interaction, a plugin for Google SketchUp was developed that enables real-time room acoustics and room acoustics parameter visualization to this easy-to-use CAD modeling tool.

Room acoustics viewed from the stage: Solo performers' adjustments to the acoustical environment

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Stefan Weinzierl (Audio Communication Group, TU Berlin)

Paper #: P086

When evaluating the acoustical quality of performance venues, the perspectives of the musicians and the audience need to be distinguished. Not only do their positions in the concert hall entail different acoustical transfer functions, also their involvement in the performance situation is not the same. This both implies a distinct access to the acoustical situation and potentially different requirements

concerning the room acoustical conditions. While the perception of concert halls by listeners has been quite thoroughly studied and several parameters have been identified as appropriate predictors for their subjective impression, the perception of musicians turned out to be much more difficult to investigate. Most studies have used questionnaires to collect performers' responses to different stage configurations. In the study presented here, the immediate reaction of musicians to varying room acoustical conditions was investigated by analysing their performances. Solo instrumentalists were recorded while playing in a variety of acoustical environments simulated by dynamic binaural synthesis in an anechoic room. By means of a software-based analysis, performance-related audio features were extracted from the recordings. The effect of room acoustical properties on the performance properties was analysed with hierarchical linear models, revealing their relevance and their influence on the musical performances.

Comparison of strategies to model spatial fluctuations of room acoustic single number quantities

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Paper #: P087

In a number of independent empiric studies it was shown that room acoustic single number parameters vary severely with small changes of the source and microphone position. Presently there is no evidence that these spatial fluctuations can be modelled using simulated impulse responses. As a result there is limited knowledge about the origin and the contributing influence factors of this variance over space. In this contribution the results of simulations using wave based as well as ray tracing simulations are compared to each other. It will be discussed if these simulations are able to predict the fluctuations that were found in measurement series taken in a number of different auditoria.

Early and Late Support measured over various distances: the covered versus open part of the orchestra pit

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Paper #: P088

The Early and Late Support parameters (ST_{early} and ST_{late}) are used to describe acoustic conditions on stage. Recently, extended Support parameters have been introduced which can be measured at various distances: $ST_{early,d}$ and $ST_{late,d}$. This way, the amount of reflected sound energy can be studied for sound paths with distances between source and receiver larger than 1 meter. Occasionally, Early and Late Support are also used to investigate orchestra pits. Using the extended Support parameters, the mutual support from reflections between the positions in the open and covered part of the orchestra pit has been investigated. It is found that, when plotting $ST_{early,d}$ as a function of distance, three different trends are found each having a distinctive shape for different types of source and receiver positions: both positions in the open part; both positions in the covered part; and just one of both positions in the open or covered part. When comparing the different trends, a large increase is found in early reflected sound energy when either source or receiver or both are in the covered part of the pit. In the covered part, at 1 meter distance the level of reflected sound can even be in the same order of magnitude as the

direct sound. When considering the late reflected sound energy it was found that $ST_{late,d}$ was not dependent on the source to receiver distance and less difference was found between the open and covered part of the orchestra pit.

Strength measurements with in-situ reference

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Henrik Möller (Akukon Ltd)

Paper #: P089

Strength is one of the most important objective room acoustic parameters, in essentially all rooms where acoustic conditions are important. The strength parameter is a number describing the acoustic reinforcement of the space and is therefore equally important for music performance as for speech. The measurement of the strength parameter is defined in the standard ISO 3382-1. It requires the measurement to be done with a type 1 microphone chain and calibrated sound source. Using a calibrated sound source is difficult, mainly because the omnidirectional sources and amplifiers used for room acoustic measurements are not necessarily stable over long periods of time, in other words the anechoic calibration must be done often. Another issue is that the measurement of Late Lateral Strength requires a calibrated Figure of 8 microphone. Figure of 8 microphones are typically not stable measuring grade microphones but normal studio/Pro-sound microphones, not designed for absolute long-term stability. Another approach to calibration is to measure the sound level at 1 m distance from the sound source in the space and use this as reference. The advantage of this is that it also provides an easy way to calibrate the Figure of 8 microphone. In this paper we will compare the two methods for calibration for Strength and lateral measurement. Data for 3 different loudspeakers will be used for the comparison. All 3 loudspeakers are measured in an anechoic chamber and measurements are done in 3 different spaces, in accordance to ISO 3382-1.

Binaural sound exposure to the direct sound of one's own musical instrument

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Paper #: P090

The amount of sound exposure of musicians within a symphonic orchestra is dependent on a large number of aspects. Among these aspects are the many different musical instruments and the impact of room acoustics by the reflected sound. However, it is impossible to obtain separately the contribution of each different aspect from the individually measured sound exposure. Therefore a sound level prediction model was proposed based on measured directivity and sound power of musical instruments and measured $ST_{early,d}$ and $ST_{late,d}$ (Early and Late Support parameter) over various distances. As part of this model, the sound level at the ears caused by the direct sound of your own musical instrument is estimated using the directivity and sound power measured in the free field at a distance of more than 2 m combined with the distance and angle between the musician's ears and its own musical instrument. To validate this method, binaural sound levels have been measured in an anechoic room while playing the flute, trumpet, trombone and violin. Also, a reference sound level measured in front of the musician at 2 m distance was used to calibrate the model. It was found that the model can predict the binaural sound level by the direct sound of the own musical instrument within 1 dB(A) accuracy; also interaural level differences have been measured up to 7 dB(A). However, estimating the average distance and

angle between the acoustical center of the musical instrument and the separate ears is not always straight forward.

Room in room acoustics: Using convolutions to find the impact of a listening room on recording acoustics

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Paper #: P092

From experience and earlier investigations it is clear that room acoustical details in recorded music or speech can only be heard in a room having a reverberation time shorter than the one in the room in which the recording was made. The acoustical properties of listening rooms influence the perceived acoustics of the recording. In earlier investigations, the practical impact of listening room impulse responses on recording room impulse responses was shown by convolving many random combinations of measured room impulse responses. For more insight in the impact of listening room acoustics on rendered acoustics, in this new research, convolutions of synthetic impulse responses have also been used. Both the effect of the decay rate and the amount of direct sound were taken into account, where the resulting change in an acoustical property is assumed to be negligible if it does not exceed the JND (Just Noticeable Difference). Both theoretical and practical cases show that during playback, the decay curve derived from the recorded impulse response turns into a curve with a slow attack and a concave level decay line. The more both impulse responses (recording and playback room) are diffuse and equal in decay rate, the higher the impact. Even when using nearfield playback, it is very difficult to reduce the negative impact of a listening room on acoustical details in a recording.

A new software tool to facilitate NURB based geometries in acoustic design

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Paper #: P095

Non-rational uniform B-splines (NURBS) are liberating acoustic design. Geometrical acoustics is no longer limited to flat surfaces. For decades, curved surfaces in computer models had to be decimated into a series of contiguous flat surfaces; a procedure prone to inaccuracy. With NURBS this is no longer the case. A new software tool has been developed by the authors, called NRAT, intended to facilitate acoustic design in NURB based geometries. Two parameters have been developed to quantify the efficiency of reflectors as they are being designed. They are called Reflector Efficiency (RFE) and Receiver Coverage (RCC). The two are quoted together, much like a blood pressure reading might be. The two parameters are required for reasons that became apparent to the authors as the NRAT tool was being developed. A small reflector, perhaps one that might be part of an array, may have a very high percentage of its surface area effectively casting reflections to the audience (perhaps 85%) but those reflections may only cover a small proportion of the audience area (say, 12%). Conversely, a large reflector, for example the side wall of a shoe box shaped concert hall, may only have a small area casting reflections to the audience in our experience, in the range of 6%. But this small zone efficiently casts reflections across the expanse of the audience, sometimes as much as 90% or more. The quantification of the two RFE/RCC scenarios presented above would be, respectively, 85 over 12 and 6 over 90. Two case studies will be presented.

Stage Acoustics, ISO 3382 and beyond

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Paper #: P096

The ISO 3382 gives two specific parameters for stage measures which can be derived from impulse responses. Earlier investigations indeed showed no correlation between the opinion of musicians in a symphonic orchestra and the other parameters derived from impulse responses as given in the ISO. This might have to do with the fact that on stage the distances between source and receiver are short, so the influence of the direct sound on the 'usual' parameters is large compared to the influences of stage environment. Nevertheless, musicians react strongly on different stage environments, so there must be something that can be measured which is in agreement with the opinion of musicians. Our investigation on stage acoustics started with the renovation of De Doelen Rotterdam in 2008, where we were asked to investigate the re-introduction of reflectors above the stage. From a small tour with the orchestra we found that the subjective opinion for 'hearing oneself' correlated quite well with STEarly (contrary to ISO 3382) and 'hearing each other' did correlate with the G5-80, also the strength G calculated without direct sound and until 80 ms. In 2012 we followed two orchestras on tour to extend our investigation on stage acoustic. The musicians were individually asked to fill out a questionnaire, and extensive impulse response measurements were performed on all stages. A large number of musicians participated (~60% of the orchestra) and the subjective answers are statistically significant. This paper gives an overview of the results of correlation to different parameters.

Shape Optimization using NURBS Definition of Acoustic Reflectors

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Prasanth Nair (University of Toronto)

Paper #: P097

Currently available acoustic software does not allow for efficient manipulation of curved surfaces with the sophistication for accurate mathematical depiction as well as the simplification for usability. The following research uses a non-uniform rational basis spline (NURBS) based software package known as Rhinoceros and a ray tracer plugin that has been developed by the authors and their colleagues to manipulate NURBS representation of acoustic reflectors. The research focuses on developing and applying stochastic optimization algorithms, mainly simulated annealing and gradient based techniques, to determine reflector shapes that optimize performance metrics. The performance metrics of primary importance are the distribution of sound rays on a receiver plane as well as how efficiently the reflectors are being used.

Parametric control of convolution based room simulators

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Paper #: P099

For several decades, reverberation processors have been based on feedback delay networks (FDN) that provide an efficient way to control the distribution of early reflections and the statistical properties of room reverberation. Their algorithmic architecture also allows for a flexible control thru different levels of descriptors, from low-level signal processing parameters (e.g. initial delay, echo density, reverberation decay, etc.) to high-level perceptual descriptors (e.g. source presence, envelopment, reverberance, etc.). Nowadays, most reverberation units rather opt for a convolution approach using a

database of room impulse responses (RIR) measured in existing performance halls or paradigmatic venues (cathedral, antique theatre, etc.). This auralization approach guarantees the naturalness and authenticity of the listening experience. However, a strict obedience to such approach would rapidly lead to an unmanageable mass of measurements: multiplicity of measured halls as well as a multiplicity of the source or receiver positions and orientations within each room. Moreover each measurement should be repeated with various microphone setups to cover all possible rendering formats. The objective of the present work is to develop a signal-processing environment dedicated to the analysis and re-synthesis of directional room impulse response (DRIRs) measured with higher-order spherical microphone arrays. During the analysis step, various acoustical or perceptual features can be extracted from measured DRIRs. During the re-synthesis step, the DRIR can be modified along the acoustical or perceptual dimensions keeping the micro-structure of the original RIR. Moreover, the modified DRIR may be converted in different audio formats to match the rendering setup.

Design-focused acoustic analysis of curved geometries using a differential raytracing technique

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Yann Jurkiewicz (Kahle Acoustics)

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Paper #: P100

Curved surfaces have a major influence on the propagation of sound in rooms. Convex surfaces always lead to attenuated reflections spread out over a larger area, while concave surfaces create either amplification or attenuation of reflections, depending on the source and receiver positions relative to the curved surface. Contemporary architecture often involves extensive use of both convex and concave surfaces. Therefore, acoustic consultants need to be able to quickly gain a thorough understanding of a given curved geometry, and judge to what extent the arising focusing will be either benign or problematic (due to inhomogeneous sound distribution or flutter echoes). The advent of NURBS-based 3D software (e.g. Rhino) has made it possible to carry out very precise geometrical raytracing on curved surfaces, revealing their geometrical coverage. As a further refinement, a differential raytracing technique is proposed, allowing the straightforward calculation of the amplification or attenuation created by a given curved surface. This purely geometrical technique can also be applied to higher order reflections, in order to help identify flutter echo problems created by multiple reflection paths involving concave surfaces. Practical examples of halls with significant curved geometries will be given to illustrate the use of this approach, including Wigmore Hall, London and Wuxi Grand Theatre.

Subjective and objective measures of relevance for the description of acoustics conditions on orchestra stages

Anders Christian Gade (Gade & Mortensen Akustik A/S, Denmark)

Paper #: P103

Even after three decades of research, we still have quite little knowledge about how to describe and evaluate the acoustics of orchestra stages. This became clear after a comparison of results from several studies which seemed to indicate that objective parameters correlating with subjective evaluations differ depending on the stimuli (halls) applied in the study. A likely reason for this is that the number of degrees of freedom in hall design is much larger than the number of halls investigated in each study. If this is true, the only way to obtain sufficient data for a valid, statistical analysis to be carried out is to pool results from useful existing and future studies in an open data base; but this requires that the same type of subjective and objective data have been reported from these studies. Based on communication

with a number of researchers and practitioners active in this field, such a unified set of objective and subjective data will be suggested and discussed in this paper.

Influence of sound reinforcement system on acoustical performance in a Catholic Church

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Paper #: P104

Liturgical practices of Catholic Church require good room acoustic quality, due to its main activities that involves speech and music. Sound reinforcement systems (SRS) are commonly used as a support for speech intelligibility and clarity of music at these spaces. Although worship acoustics is the subject of some recent researches, it is common to see results regarding the room's sound field, without considering the sound reinforcement system. The objective of this research is to identify the influence of sound reinforcement systems in Catholic Church sound fields and its contribution to speech intelligibility and clarity of music. Acoustical parameters were measured with the impulse response technique and were compared in two situations: with and without a sound reinforcement system. Reverberation Time (RT), Early Decay Time (EDT), Clarity (C80), Definition (D50) and Speech Transmission Index (STI) were measured at a Brazilian Catholic Church, 'Igreja Nossa Senhora das Dores' in Campinas, SP in both situations: with the impulse response measured through the sound system and through an omnidirectional sound source according to ISO 3382-1. The results were then compared. Some aspects about the use of sound reinforcement systems were identified and its possible influence on the sound perception of users were indicated.

Visualization and evaluation of reflections inside an enclosed space using sound intensity measurement

Akira Omoto (Kyushu University)

Kohta Sugiura (Kyushu University)

Paper #: P105

Recently, relationship between surface scattering and the properties of sound field is becoming clear. However, the changes in the impulse response due to the changes of average scattering coefficient is quite small and the total decaying curve is not altered. To clarify such small changes, visualization technique based on the sound intensity measurement is introduced. Measurement of the impulse responses at closely located four points yield the intensity response in three orthogonal directions. Dominant peaks in the intensity response could be recognized as the dominant reflections from the certain room surface. Our method projects such information onto the spherical panoramic photo of the field. The proposed method including the animation of successively arriving reflections would be a useful tool for qualitative grasp of the nature of sound field. For example, the changes of the reflections with scattering or flat surfaces could be demonstrated. In addition to such qualitative visualization, quantitative examination is also tried. Historically, the indexes such as Directional Diffusion are well established and often used for such purpose. We have introduced here the index called uniformity of arrival directions, UAD, as one measure of sound field. The UAD is defined by the temporal changes of uniformity of arriving directions of reflections and is calculated by the intensity levels observed at equally divided solid angles on the surface of imaginary sphere around the measurement point.

Calculation of the evenness with levels would be reasonable for the examination of small changes in reflection energies due to scattering.

A study to establish benchmarks for acoustical parameters derived from impulse responses

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Atsushi Marui ()

Paper #: P107

Acoustical parameters are measured in a room for obtaining its quantitative acoustic characteristics. The calculation techniques for acoustical parameters are described in ISO3382-1. However, the values of the acoustical parameters often include some errors, which are due to a variety of measurement conditions and loosely defined calculation procedure. A Working Group on Analysis of Acoustical Parameters by the Architectural Institute of Japan (AIJ) is organized to set benchmarks for calculating and evaluating acoustic parameters derived from room impulse responses, with the ultimate aim of reducing the errors in calculation. First, for calculating parameters such as T or EDT used for evaluating the slope of decay, we discuss the SN ratio of the impulse response and the length of the impulse response. Second, for calculating the parameters used for evaluating the energy ratio, such as C80 or D50, we discuss detecting the starting point of the impulse response and the order of time-windowing and octave band filtering. Appropriate impulse responses as benchmarks are designed on the basis of these discussions. Finally, in this paper, the framework of benchmarks is described; all these details will be published on the World Wide Web.

Acoustical design through optimization

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David Rife (Arup Acoustics)

Lucas Dellatorre (Arup Acoustics)

Paper #: P108

The use of 3-D computer modeling tools has revolutionized, through the 90s, the practice of Architecture. Opening new territories, architects have incorporated new forms into their design, impossible to build beforehand, created new aesthetics and established new processes for the construction of complex shapes and materials. Coupled with recent developments in auralization, these techniques are also available to acoustic designers for the shaping of buildings. Through several performing art projects, this paper gives an overview of processes commonly used today by acousticians to optimize designs either through iterative design processes, auralizations, set constraints and geometric computation, lighting simulation, fast physical scale modeling, printing techniques and real-time computer modeling. The paper discusses how these new intuitive design tools can be applied to optimize room, walls and reflector shaping for acoustics and allow for more creative designs helping solve complex architectural situations and communicate ideas. Contextualized with design practices from different period of history, the paper also shows how modern tools help bridge design and intuition and lead towards real-time modeling and auralization technologies.

Simulation and evaluation of acoustic environments

Michael Vorländer (RWTH Aachen University)

Paper #: P110

Humans experience their environment in various work, educational and living situations and in concert halls and opera houses. Whether the environment is considered appropriate or not depends on many factors. The acoustic modality is of high relevance as soon as it comes to communication, education, or to performances of music and speech. A research unit called SEACEN is currently working on a coordinated effort to improve the complete signal chain from the numerical modeling, the data acquisition within numerical or real sound fields, the coding and transmission to the electro-acoustic reproduction by binaural technology or by sound field synthesis. A novel approach for the comparative evaluation of real and simulated environments will also enable the evaluation of the plausibility and/or the authenticity of virtual acoustic environments and a contribution to the development of better physical metrics to predict the qualities of concert halls and opera houses. These activities are relevant not only for concert hall acoustics but for acoustic spaces in general. The activities of SEACEN are summarized and some projects discussed in more detail. This includes investigations on uncertainties in room acoustic measurements, on simulation parameters in geometrical acoustic models, and new approaches to wave modeling of sound fields in for rooms with locally and non-locally reacting boundaries.

Design of diffusive surfaces for improving the sound quality of underground stations

Yong Hee Kim (National Institute of Advanced Industrial Science and Technology (AIST))

Yoshiharu Soeta (National Institute of Advanced Industrial Science and Technology (AIST))

Paper #: P111

This study investigated the effective designs of diffusive surfaces on wall and ceiling in underground station platforms for improving sound quality. For this purpose, two underground stations were constructed with island and side platforms using computer simulation. Scattering characteristics of various diffusive surfaces such as hemisphere, ribbed, box, Schroeder diffuser were surveyed in advance. Diffusers were applied to wall and ceiling surfaces of the simulation model in longitudinal and cross-sectional arrangements. Acoustic parameters such as speech intelligibility, sound pressure level, reverberation time and Interaural cross-correlation coefficient were derived. From the simulation results, contribution of diffusers on the improvement of sound field characteristics will be discussed according to diffuser location, platform style. In addition, the results of scale model tests will be discussed with the simulation results.

Integration of acoustics in parametric architectural design

Thomas Scelo (Marshall Day Acoustics)

Simon Yu (Zaha Hadid Architects)

Paper #: P112

The integration of basic geometrical acoustics into architectural design is not new. The arrival of 3D modelling packages such as Grasshopper and Maya has certainly increased the consultant's efficiency, the dialogue within the design team and propelled a new generation of architects into glamorous spheres. But it has also, thankfully, forced the consulting profession to go back to the basic. Efficient algorithms are complex and their development time consuming. At first, Grasshopper's apparent limitation in complex calculus seems to confine its use to basic trigonometry. In many ways, our parametric contribution was not more evolved than that of our predecessors, it simply is virtual, tri-dimensional and in real time. Much has been said about geometry analysis including 1st and 2nd order reflections, reflector coverage, delays and energy density. However, little is discussed about actual parametric design. Recent collaborations with architects well versed in parametric design have offered us the opportunity to translate conceptual acoustic considerations into real input parameters for the

automated generation of rooms. In more technical terms, Grasshopper and Maya are used to resolve inverse problems for which the output is assumed. The unknown to the problem is the transfer function, for which one geometry is built for a given source and receiver locations. This paper describes the collaborative approach to develop a single algorithm for both acoustic and architectural form generation.

Desired room acoustical response for amplified music

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Paper #: P113

Room acoustics for amplified music has traditionally been focused on reducing reverberation and damping strong reflections back towards the stage, which in many cases have led to very dead-sounding spaces. Adelman-Larsen has through several publications emphasized the importance of low-frequency control, but still allowing for a higher reverberation time at mid and high frequencies. In a recent paper he has even suggested that a significant rise in reverberation time for higher frequencies might be acceptable, or even desired. In this paper, the desired amount of room acoustical feedback for amplified concerts, both within the audience area and on stage, is discussed. The properties of line array systems, which are typically used for sound reproduction in medium and large halls, will be related to the room acoustical treatment, and it is discussed whether a high degree of lateral early energy through the use of diffusing sidewalls might be beneficial. Other key issues are stage support, performer-audience interaction and desired feedback from the hall on stage. Perhaps the desired conditions for amplified concerts with regard to stage support and feedback from the hall are very different to those required for purely acoustical performances, as long as the room acoustical design is adapted to the way the soundstage is created for amplified concerts, including directivity properties, source localization, frequency balance and sound levels?

Acoustical design of concert halls with small seating capacities

David Kahn (ACOUSTIC DIMENSIONS)

Paper #: P114

Concert Halls for educational facilities often do not require even 1,000 seats, yet the ensembles and repertoire are typically similar to ensembles and repertoire performed in large (2,000 seats and higher) concert halls. Many of these institutions include large wind ensembles that produce sound levels that exceed a full symphony orchestra. The result is often either excessive loudness or excessive sound absorption to control excessive loudness which results in room acoustics considered to be 'too dead' or lacking in reverberation. The design of these halls often includes an over-sized platform to accommodate the large and powerful ensembles, but volumetrically, these halls are recital hall sized, and the size and volume of these halls is often similar to that of a mid-size to large recital hall, and well below the size and volume of a typical concert hall. The acoustical scale of a typical Concert Hall with seating for 1,000 seats or less is often well below optimum for most symphonic music, and for large wind ensembles. We present several built examples of some low cost options to provide additional volume in order to provide for a more appropriate acoustical scale for the large ensembles, and to have enough volume to control loudness of these larger and powerful ensembles without having to sacrifice reverberation.

Anticipating the challenges of modern mechanical system approaches in low-noise design

Scott Pfeiffer (Threshold Acoustics LLC)

Paper #: P115

Setting the right ambient noise requirements and achieving them in modern systems requires an adjustment of our approach to align with today's low energy systems. Constant volume, low velocity systems are at odds with low energy design. Solving the new issues that surround radiant systems, natural ventilation, and higher velocity (yet quiet) delivery using aerodynamic nozzles and other innovations must be part of the solutions rather than rote application of the standards of our last few decades. Exploration of both the background noise criteria and techniques for achieving the desired outcome are presented through built examples and design principles.

Theoretical modeling of room shape for ray tracing simulation

Kazuma Hoshi (Nihon University)

Toshiki Hanyu (Nihon University)

Paper #: P116

With the recent developments in CAD technology, the detailed modeling of shapes has become easy. It is well known that the result of geometrical acoustic simulation with a details modeled room do not agree with the actual sound propagation for low frequencies. Therefore, roughly modeled room shapes are commonly used and scattering coefficients are set for each material in this kind of simulations. However, scattering coefficients are hard to use for creative room shape design, because scattering coefficients need to be measured in advance. Thus, I propose a new method for ray tracing simulation instead of the using scattering coefficient method. This paper presents a discussion on how to make the appropriate room shape for the analyzed frequency from a detailed modeled room. The proposed method was validated using evidence obtained from an FDTD method simulation based on the wave equation. The results indicated that the proposed method is able to simulate sound propagation according to variations in the analysis frequency.

Using Ambisonics for stage acoustics research

Anne Guthrie (Rensselaer Polytechnic Institute, Arup)

Terence Caulkins (Arup)

Sam Clapp (Rensselaer Polytechnic Institute)

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Paper #: P117

Impulse response measurements of 10 different concert halls in New York were captured in 3-D with a 2nd-order ambisonic microphone built based on techniques developed by J. Daniel, S. Moreau and others. A real-time auralization system was developed in the Arup New York Soundlab that captures the signal from a musician using close-microphone technique and reproduces the acoustic response of each hall over a sphere of 22 loudspeakers. 20 musicians visited the Soundlab and performed virtually onstage in each hall, ranking their preferences both when performing as a soloist and along with a pre-recorded orchestra. Using multi-dimensional scaling, the preferences for each musician have been analyzed and compared to known acoustic parameters. Strong trends are visible in preferences for both solo and ensemble conditions, trends that can only partially be explained by known parameters. Additional spatial parameters have been explored and analyzed using beamforming techniques developed by R. Duraiswami and others in order to understand the influence of spatial information on musician preference. Results suggest that spatial distribution of energy is influential in musician comfort

and ease when performing both as a soloist and with an orchestra. Additionally, these parameters have been correlated to architectural criteria in order to inform future stage enclosure designs.

Why silence?

Robert Essert (Sound Space Design)

Paper #: P119

In designing performing arts buildings we design HVAC systems to be silent, or at least appropriately quiet, and we isolate performance spaces from environmental noise and vibration. Different performing arts have developed in different cultural contexts and noise environments, and background noise criteria can, and should be derived from an understanding of the acoustics of the specific performance practice. For example, how important is information transfer? Or emotional connection? This paper investigates what is 'appropriately quiet' for different performance types, based on the salient aspects of the performance and audience appreciation and experience over 30 years of consulting practice.

Perception of reverberation in coupled volumes: discrimination and suitability

Paul Luizard (LIMSI-CNRS, Orsay, France & LAM team, D'Alembert Institute, UPMC, Paris, France)

Catherine Guastavino (SIS & CIRMMT, McGill University, Montreal, Canada)

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Paper #: P120

Reverberation in coupled volume concert halls can be modified by changing the coupling surface connecting the main hall and the control chamber(s). This study aims at investigating how sensitive trained listeners are to subtle changes in reverberation in coupled spaces. Previous research have focused on acoustical parameters in coupled volumes. The present study relies on an architectural parameter describing the sound field behavior before relating it to acoustical parameters. In a first listening test, we measured perceptual threshold (Just Noticeable Difference) for the size of coupling surface using an ABX discrimination task with 21 participants. The stimuli were generated by convolving anechoic recordings of bongos, soprano and symphony orchestra with impulse responses based on the statistical model of energy decay by Cremer-Müller, the only variable element being the coupling surface. The thresholds are expressed in terms of coupling surface (around 10% for all musical samples) and relevant acoustical parameters, namely the decay time of each slope and the coordinates of each bending point within the temporal energy decay curve. In a second listening tests, 20 participants were asked to rate the suitability of different reverberation decays for various musical samples (solo cello and timpani, choir and symphonic orchestra). Linear reverberation (exponential decays) was rated as more suitable for the symphony orchestra while coupled reverberation (double-slope decays) was rated as more suitable for solo instruments and for the choir.

Nuovo Teatro dell'Opera, Florence, Italy: Innovative solutions for a seemingly traditional auditorium

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Paper #: P121

Nuovo Teatro dell'Opera, Florence, Italy: Innovative solutions for a seemingly traditional auditorium The traditional Italian gallery theater design interpreted by avant-garde architecture -that is a possible description of the new building inaugurated in December 2011 in Florence, Italy. The new opera house,

seating 1,800, is completed by a concert hall for an audience of 1,000 plus an open-air theater seating 2,200. The presentation focuses on the entire building and in greater detail on the opera hall where the perceived architecture does no longer correspond to the acoustically effective space. Acoustically transparent linings in the auditorium create a very broad leeway for acoustical measures concealed behind them. The presentation illustrates the acoustics of a quite unique project.

Bolshoi Theatre, Moscow, Russian Federation: The secrets of the acoustical reconstruction

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Paper #: P122

Bolshoi Theater, Moscow, Russian Federation: The secrets of the acoustical reconstruction The Bolshoi Theater is lovingly referred to as 'the soul of Russia' and is a landmark of Russia. Extensive renovation works performed to stabilize the building's unstable structure included major underground extensions such as a new chamber music hall. Various renovation projects carried out during the past 100 years had considerably affected the originally perfect acoustics. Therefore, the reconstruction of the auditorium's acoustics aimed at restoring the original state as created by the architect Alberto Cavos in the middle of the 19th century. Thus, in close cooperation with the restorers, we succeeded in restoring the Bolshoi's unique acoustics.

Refinements in raytracing technique for room shaping

Matthew Lella (Diamond Schmitt Architects Ltd)

Andrea Tocchini (Diamond Schmitt Architects Ltd)

Paper #: P123

Ray tracing is a common and helpful device for acoustic modeling, despite its shortcomings as a model for wave behaviour in the architectural environment. This paper puts forth an approach to the parametric modeling of architectural elements to gain insight into the different behaviour of sound at different frequencies. Scale sensitive parameters are introduced and studied as a device to refine or coarsen the texture and sculpting of room components. This parameterization makes possible a 'frequency sensitive' model of the reflecting surfaces in a room allowing the ray-tracing to mimic more closely the behaviour of those octave bands under study. The frequency sensitivity of reflections becomes apparent and the full range spectrum can be visualised by overlaying the results of several analyses. With this in place, the idea can be used in the other direction: by using the powerful tools in rhino and grasshopper to define a source and receiving surfaces, sets of surfaces that have texture, depth, faceting and placement in space, can be found that solve for desired reflection at different frequencies.

Audio-visual interaction of size and distance perception in concert halls: a preliminary study

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Jentsch Matthias ()

Paper #: P124

The perception of rooms, particularly of concert halls, comprises various unimodal and multimodal aspects on different perceptual levels. Rather abstract however self-evident aspects are the source distance and the room size. We experimentally investigated to what extent the perceived size and

distance as supramodal aspects are based on the auditory and the visual modality, i.e. influenced by the acoustic and optical stimulus. The statistical determination of the audio-visual interaction effect demands the mutually independent variation of optical and acoustical room properties, referred to as conflicting stimulus paradigm. In addition, its generalizable quantification demands the commensurability of the independent variables, i.e. an optimum opto-acoustic equivalence regarding the origin and the range of their values. This is only feasible by means of data-based room simulations. Simulation data of six concert halls were collected acoustically by acquiring binaural room impulse responses for different head orientations and optically by acquiring stereoscopic images of the halls including the electroacoustic sound source. In the laboratory, the acoustic scene was played back applying dynamic binaural synthesis and electrostatic headphones, whereas the optical scene was displayed by the use of a full HD stereoscopic DLP display. Test participants were asked to assess the source distance and the room size. The latter item was operationalized using both one volume scale and three length scales. results indicate that hearing and seeing contribute to distance and room size perception roughly in equal shares, that physical volume is predominantly underestimated, and that the intervals of the two scales were used differently.

Experiment on adjustment of piano performance to room acoustics: Analysis of performance coded into MIDI data

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Kanako Ueno (Meiji University)

Tetsuya Sakuma (University of Tokyo)

Paper #: P125

An experiment was carried out in which 12 professional piano performers played test phrases in five types of acoustic conditions and the performance actions were recorded as MIDI data simultaneously. After the performance, they were interviewed about their adjustment of musical expression to the acoustic characteristics. For each of the five acoustic conditions, reverberation time (T30), C80, and stage parameter (STEarly) were measured. The test phrases are three extracts from classical music pieces. In the analysis, three measures of performance of duration, note-on velocity and sound segmentation were derived from the MIDI data. Since the trend of the change in their performance in the different conditions varied among the performers, a cluster analysis was conducted to divide them into groups based on the similarity of their performance pattern. Thus four groups, which were affected differently by the acoustic conditions, were obtained and the changes in performance were discussed in relation with the interview answers for each of the groups.

Sound strength driven parametric design of an acoustic shell in a free field environment

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Mario Sassone (Politecnico di Torino)

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Paper #: P126

Focusing on the issues of sound propagation in a free field condition and on the concept of uniform sound energy in an outdoor performance environment, our research aimed to develop a computer aided process for the generation of reflective acoustic surfaces to be used as concert-shells, a computational design tool for acoustic form finding. The project is ultimately aimed to investigate the acoustic potential of complex and doubly-curved surfaces through the analysis of the Total Relative Sound Level / Strength parameter (G), with reference to the proposed values set by M. Barron, based upon the source-receiver distance and the subsequent subjective judgements on loudness. A simplified and fast raytracing acoustic simulation algorithm was developed in combination with parametrically controlled shape variations of the reflective surfaces. Sound energy uniformity evaluation function considering the direct and reflected sound components was written in order to define and evaluate the rate of distribution uniformity of sonic energy over the audience. This evaluation function was used in a genetic algorithm, that enabled us to explore a wide set of surface morphologies and to finally isolate the fittest one to our specific uniformity requirements. At the end of the genetic search, an acoustic simulation plugin called Pachyderm was employed with both NURBS and mesh-based acoustic simulations, in order to validate the genetically selected surfaces with specific reference to G values. A further step of result data visualization and human selection was necessary to compare the output data and to evaluate the final surfaces from an architectural perspective.

Effect of Acoustic and Visual Stimuli on Preference for Different Seating Positions in a Concert Hall and an Opera Theater

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Paper #: P127

The sound fields and the views of several positions in a concert hall and an opera theater were simulated and the subjective preference for different seating positions was investigated. First the experiments used presentations of 1) visual stimuli only, 2) acoustic stimuli only, and 3) both acoustic and visual stimuli were constructed. In the tests the original sound level (the sound pressure level at each position was maintained as the impulse response measurements in the auditoria) and the equalized sound level conditions were compared since the previous study investigating the opera theater showed that the subjective scale of seat preference showed the highest correlation with sound level. The results of the experiments showed that the sound level, the balance between the soprano and the keyboard, and C80 were the dominant factors in seat preference. Since some positions were judged acoustically preferred but visually less preferred or vice versa, another preference test was conducted by using the combinations of the acoustic and the visual stimuli of different positions to further investigate the audio-visual interaction. The results of the preference tests showed that the preferred acoustic and the visual stimuli did not simply increase the subjective scale of the seat preference. Under the condition investigated, better acoustic stimuli increase the subjective scale while the worse acoustic stimuli decrease the subjective scale only in the case of the less preferred visual condition for both the concert hall and the opera theater tests.

When source is also receiver

Tor Halmrast (Statsbygg, Oslo)

Paper #: P128

Musicians (and low budget acousticians) often judge the acoustics of a venue for music by clapping, shouting or making other kinds of more or less impulse-like sounds. In such situations, the source and the receiver are (almost) at the same position. This is a different situation than for standard measurements of room acoustics, where there is a (long) distance between the sound source (loudspeakers, pistols, balloons and musical instruments) and the receiver (microphone, ear). The sonic experience must be totally different, but still we trust our clapping and our ears. We probably 'recalculate' so that reverberation times etc. judged in such a way 'by ear', are often quite correct. How can this be? And: Can we learn from how a blind person uses click sounds made with the mouth in order to 'see'/echolocate surfaces and objects by the ears? In both situations the position of the source and the receiver are (almost) the same.

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